ASTM E-84 and the flammability of foamed thermosetting plastics

D'Souza, M. V.; McGuire, J. H.

Publisher’s version / Version de l'éditeur:
https://doi.org/10.4224/40001764
Paper (National Research Council of Canada. Division of Building Research); no. DBR-P-724, 1977-05

ASTM E-84 and the flammability of foamed thermosetting plastics

D'Souza, M.V.; McGuire, J.H.

NRCC-16091

A version of this document is published in / Une version de ce document se trouve dans:
Fire Technology, v. 13, no. 2, May 1977, pp. 85-94

NATIONAL RESEARCH COUNCIL OF CANADA
CONSEIL NATIONAL DE RECHERCHES DU CANADA

ASTM E-84 and the Flammability of Foamed Thermosetting Plastics

by

M. V. D'Souza and J. H. McGuire

Reprinted from
FIRE TECHNOLOGY
Vol. 13, No. 2, May 1977
p. 85 – 94

DBR Paper No. 724
Division of Building Research

Price 25 cents OTTAWA NRCC 16091

SOMMAIRE

La mise à l'essai des mousses plastiques thermodurcissables dans un angle mural et dans un tunnel a suggéré que l'anomalie E-84 peut être résolue en utilisant une classification par indice d'une gamme de 0 à 77.5, où un critère de distance domine actuellement. Des imprécisions inhérentes, cependant, peuvent continuer à demander occasionnellement des essais d'angle mural.

REPRINTED FROM
FIRE TECHNOLOGY
Vol. 13 No. 2 May 1977

ASTM E-84 and the Flammability of Foamed Thermosetting Plastics

M. V. D'SOUZA and J. H. McGUIRE
Fire Research Section, Division of Building Research
National Research Council of Canada

Corner wall and tunnel testing of foamed thermosetting plastics has suggested that the E-84 anomaly can be resolved by the use of a rate index in the range of 0 to 77.5, where a distance criterion currently prevails. Inherent inaccuracies, however, might continue to require occasional corner wall testing.

FOR SOME years the assessment of the flammability (flame spread potential) of foamed plastics has proved to be a problem. The most commonly accepted flame spread test apparatus in North America is the E-84 tunnel apparatus from which can be derived flame spread classifications (FSC), a material with a low FSC (or rating) being considered less flammable than one with a higher value. Unfortunately foamed plastics have not fitted the established flammability merit sequence and, in particular, foams with a rating of the order of 50 to 75 have been found to promote fire as readily as more conventional materials with ratings of several hundreds.

One school of thought regards thermal inertia (the product of thermal conductivity, density, and specific heat of the material) as the most significant factor responsible for the anomalous behavior of foamed plastics in the E-84 test. The fire brick lining of the apparatus might be quite satisfactory for the testing of most materials but perhaps not for foamed plastics if it is desired to show their performance under unfavorable conditions, as is the practice with conventional materials. The thermal inertia of foamed plastics is so low compared to conventional materials that it might be of great importance, when discussing the extent of the hazard they present, to specify whether the environment is of a generally low or a generally high thermal inertia.

A second school of thought concerning the E-84 anomaly discusses chemical aspects and the feature that the effective surface area of a foam is much greater than that of a conventional material.

NOTE: The test method designated E-84 by the American Society for Testing and Materials is also known as NFPA 255 and UL 723.

The feasibility of including both foamed plastics and more conventional materials together in a single flammability merit sequence has been questioned, and an investigation of the validity of this concept constituted an important aspect of the work to be described.

APPROACH TO THE PROBLEM

Test methods intended to assess the flammability of foamed plastics are being developed elsewhere in North America. Their application is not clear, however, and their results are not expressed in continuous scales that permit direct comparison with conventional materials. It was decided therefore to carry out some work at the National Research Council of Canada aimed at developing a test which included the above requirement in addition to those implicit in all such work.

An environment of uniform thermal inertia materials was considered to be an appropriately stringent condition, likely to be encountered in practice. The work most clearly showing that foams of low flammability, according to E-84, could in fact behave much more poorly than fairly flammable conventional materials utilized a simple corner wall.[1] Preliminary NRC work showed that a particularly favored corner wall arrangement simulated a room, which is more representative of many practical circumstances than a simple corner arrangement. It thus seemed reasonable to regard this corner wall configuration as a useful base on which to develop a test method.

The time required to reach a particular event is generally considered a suitable variable on which a rating scale might be based. In previous work, however, the use of a variety of ignition sources and of lining configurations created several scales, not quantitatively related, making direct comparison of results extremely difficult. In the present work, a single, intense source and the same test conditions were adopted for all specimens. With highly flammable specimens, time scales then became remarkably short, but good reproducibility of the source chosen still permitted accurate measurement.

SCALE AND DESIGN CONSIDERATIONS

Most corner wall configurations currently in use in North America have dimensions of 8 ft (2.4 m) or more, cubed, and it was decided that some work on this scale was essential. Dimensions of 8 ft by 8 ft by 8 ft were in fact chosen and, on the sides not occupied by specimens, a canopy approximately 3 ft (0.9 m) deep was installed.

With a view to establishing a more economical test method, consideration was also given to a geometrically scaled model of the 8-ft corner. Previous experience with a 2-ft by 2-ft (0.6-m by 0.6-m) corridor had shown that its behavior was markedly different from that of an 8-ft (2.4-m) high by 6-ft (1.8-m) wide corridor under similar boundary conditions,[2] and it was thought that this finding might have some relevance to the present question. Despite the desirability of miniaturization, it was therefore decided not to attempt too great a reduction, but to experiment with a half-scale model (4 ft by 4 ft by 4 ft). Thus, two sizes of corner wall, of the configuration illustrated in Figure 1, were constructed.

The choice of an ignition source was seen to be critical. A novel design of gas burner, originated by Parker[3] and drawn to the authors' attention by one of our colleagues, A. Rose, was used. It consisted of a horizontal sand bed through which natural gas flowed to produce a diffusion flame. The design was especially meritorious in that its reproducibility and repeatability were excellent, permitting accurate definition of the exposure and of the time of origin of a test.

For the model, time was chosen to be independent of scale. It was thought desirable that fuel input should scale as L^2 (where L is any linear dimension of the corner), for, with the time-scale invariant, total specimen fuel and specimen fuel consumption per unit time would also scale as L^2.

Flame-height similarity was also thought desirable; and to achieve it, the variable D, diameter of the sand bed, was available. The requirement could have been attained by a plot of flame height (l) against diameter D, but each point would have necessitated an individual sand tray and the graph would not have been linear. Because of the difficulty of measuring flame height, a linear relationship and a substantial number of results were desired to reduce error. To accomplish this, recourse was made to flame-height theory and dimensional analysis.

Thomas[4] gives the following expression for flame height.

$$\frac{l}{D} = f\left[\frac{\dot{Q}^2}{gD^5B\,\Delta T}\right]$$

where l = flame height, D = characteristic burner dimension, $\dot{Q}$ = fuel flow rate, B = expansion coefficient of gases, ΔT = flame temperature (above ambient), and g = gravitational constant.

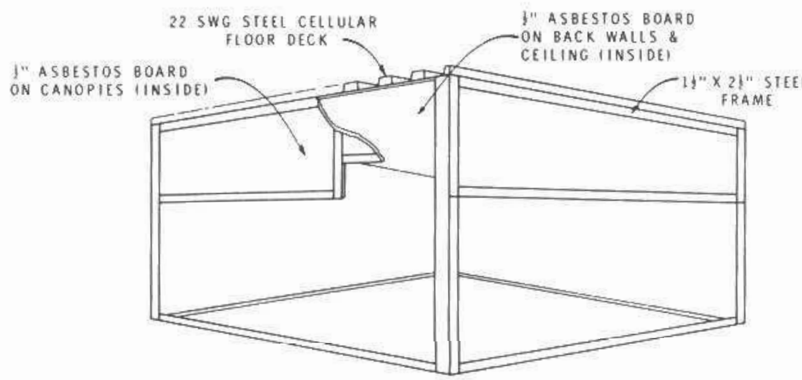

Figure 1. Corner wall test arrangement.

Assuming that B and ΔT are substantially constant reduces the relationship to

$$\frac{l}{D} = f\left[\frac{\dot{Q}^2}{D^5}\right]$$

A number of flame height measurements were made, with three sand bed diameters (11, 7, and 4 in. or 27.9, 17.8, and 10.2 cm) using $\dot{Q}$ as the principal variable. Different environments (4 and 8 ft corners and unconfined) were also tried. The results, shown in Figure 2, give the relationship

$$\frac{l}{D} \propto \left[\frac{\dot{Q}^2}{D^5}\right]^{0.285}$$

Using the fuel and flame height requirements already specified (l/L = constant and $\dot{Q} \propto L^2$), permits elimination of $\dot{Q}$ and l to give the scale relationship between D and L as

$$\frac{D_1}{D_2} = \left[\frac{L_1}{L_2}\right]^{0.829}$$

For the large-scale (8 ft) corner, a cylindrical sand bed of 11 in. (27.9 cm) diameter and a natural gas input of 7500 Btu min^{-1} were chosen, giving a flame height of roughly 85 in. (216 cm). The corresponding values for the small-scale (4 ft) corner were a sand bed diameter of 8.75 in. (22.2 cm) and a gas input of 1875 Btu min^{-1}, resulting in a flame height of 42 in. (107 cm). These choices created an exposure sufficient to give continued fire development with all foams excepting those known to be of remarkably low flammability.

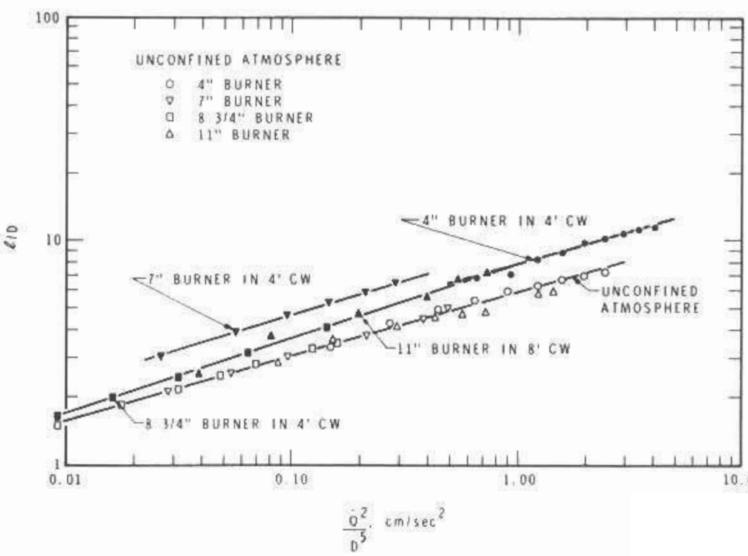

Figure 2. Burner flame-height relationships.

PRELIMINARY EXPERIMENTS

Possible users of the test method asked that it represent conditions in a room during the initial stages of a fire. Preliminary experiments were conducted to determine the extent to which a canopy would achieve this. Three arrangements were investigated on the smaller scale: an open corner (with no canopy), a corner with a canopy as shown in Figure 1, and one with the canopy extended to floor level to establish a small room with an open door. It was seen that propagation of the fire across the ceiling of the open corner followed a different pattern and took appreciably longer than with the other two configurations (see Table 1). The behavior of the corner with the canopy and of the room were regarded as sufficiently similar to consider the former as substantially representing the latter.

The small cutout in the canopy was made at the request of prospective users of the apparatus to represent a doorway. Smoke flow patterns during tests indicated that the cutout was not of great significance. As the smoke layer built downwards from the ceiling to the bottom of the canopy, losses from the cutout did not seem to have much influence on downward velocity of the smoke boundary. Correspondingly, when the boundary reached the bottom of the canopy the underspill of gases greatly exceeded the flow through the cutout.

During the course of the preliminary investigation to determine exposure conditions, attention was paid to the repeatability of the test arrangement. The 4 ft corner was used with a fuel input of 625 Btu min^{-1} and test specimens of fiberboard. The time for flames to issue from beneath the canopy (generally at the corners adjacent to the lined walls) was taken to be the end result of the test, and three repeat experiments gave a mean time of 2.05 min and a standard deviation of 0.04 min.

So far, testing had been confined to thermosetting foamed plastics. When the corner wall was used to examine foamed polystyrene, melting of the specimen proved to be of considerable importance. Flame propagated steadily and slowly at the melting boundary, and there was burning of melted material on the floor. No rapidly developing phenomenon of the nature of flashover occurred however. To assess whether such a hazard existed, line burners were substituted for the cylindrical sand bed, and a

TABLE 1. *Effect of Canopy (Apparatus size = 4 ft; burner diameter = 8.75 in.; heat input = 625 Btu* min^{-1}*; and lining material = fiberboard.)*

Configuration	*Time to full ceiling involvement (min)*	*Time for flames to issue from apparatus (min)*
Open corner	2.60	1.34
Corner with canopy	1.70	2.04
Corner with canopy	1.80	2.10
Room	1.58	2.00

further test was conducted, leaving the ignition source gas flow rate unchanged. Before melting was able to exert great influence, there was more rapid development and full involvement of the vertical walls. It is thus apparent that some hazard does exist, and a means of assessing it is called for. The concept of correlation with E-84 is, however, not valid in the context of thermoplastic foamed plastics, as E-84 does not constitute a satisfactory test for these materials because of anomalous behavior associated with melting of the specimen. Further investigation of thermoplastic foamed plastics was deferred to permit emphasis on the resolution of the lesser problems associated with foamed plastics that did not melt.

RESULTS AND DISCUSSION

Most of the test results are presented in Table 2. Ceiling gas temperatures were measured at several locations, 1 in. (25.4 mm) below the surface of the specimen. The values recorded at the geometrical center of the ceiling, at the time at which flames issued beneath the canopy (T_{C2}), revealed surprisingly little variation (less than 9 percent) with a mean for all tests of 750° C. This figure compares favorably with the average upper air layer temperature value of 730° C suggested by Parker[3] as an indication of flashover.

The first consideration was to compare the corner test results, expressed in terms of time for flames to issue beneath the canopy, with

TABLE 2. *Test Results*

No.	Material Type and Form	Sample Condition	Corner Size (ft)	Time (min) (1)	Time (min) (2)	Tunnel Flame Spread Indices E-84	Tunnel Flame Spread Indices 28.2 d t
1	Natural fiberboard	—	4	—	0.890	71.2	72.3
2	Natural fiberboard	—	8	—	0.600	129.4	129.4
3	Natural fiberboard	—	4	0.450	0.790	90.7	81.5
4	Polyurethane board	Bare	4	—	0.170	51.3	564.2
5	Polyurethane board	Bare	4	—	0.260	56.4	310.3
6	Polyurethane board	With foil	4	—	0.920	314.3	314.8
7	Polyurethane board	With foil	4	—	0.870	35.9	124.5
		With foil	8	—	0.750	35.9	124.5
		With foil	8	0.740	0.800	35.9	124.5
8	Polyurethane board	Without foil	4	—	0.400	46.2	182.7
		With foil	4	—	1.160	46.2	92.3
9	Polyurethane board	Without foil	4	—	0.230	550.0	550.0
		With foil	4	—	0.830	275.0	275.0
10	Polyurethane board	Without foil	4	0.165	0.165	785.9	785.9
		With foil	4	0.540	0.620	733.5	733.5
11	Polyurethane board	Without foil	8	—	0.370	18.0	116.0
12	Polyisocyanurate board	Bare	4	0.345	—	23.1	79.3
		Bare	4	0.360	—	23.1	79.3
		Bare	8	0.420	—	23.1	79.3
13	Polyisocyanurate board	Bare	4	—	—	23.1	76.9

Fuel Input 1875 and 7500 Btu min^{-1} for 4 and 8 ft corners respectively.

(1) Time for cotton thread to break.

(2) Time for flames to issue beneath canopy.

the FSC of the test material as determined by the E-84 method. As shown in Figure 3, no relationship between the two quantities is evident. The points in the lower lefthand quadrant of Figure 3 are particularly anomalous, because they represent foams rated as highly flammable by the corner test but not by the tunnel. In this regime (FSC < 77.5), E-84 ratings are based on a flame spread distance criterion not involving rate. Although this approach has hitherto appeared reasonable and satisfactory, it is noticeable with foamed plastics that flame fronts proceed down the tunnel more rapidly than those of conventional materials in the same E-84 rating categories.

To take account of this rapid propagation in arriving at indices, a formula based on rate of propagation suggested by Williams-Leir was utilized. It is derived from the E-84 formula FSC $= 550/t$, which, instead of having its application restricted to the value $d = 19.5$ ft, is used for any value of d by writing FSC $= 28.2\, d/t$.

The application of the concept is not without problems for, with very low values of d, measurement accuracy is poor. Permitting the choice of any value of d would have made the presentation subjective because, by judicious selection, an extremely close correlation between tunnel and corner wall results could have been derived. During this study, the formula was always applied for the value of d at which rate reduced rapidly. For many materials, d referred to the end point, and for others, to a point where a definite recession occurred prior to further progression.

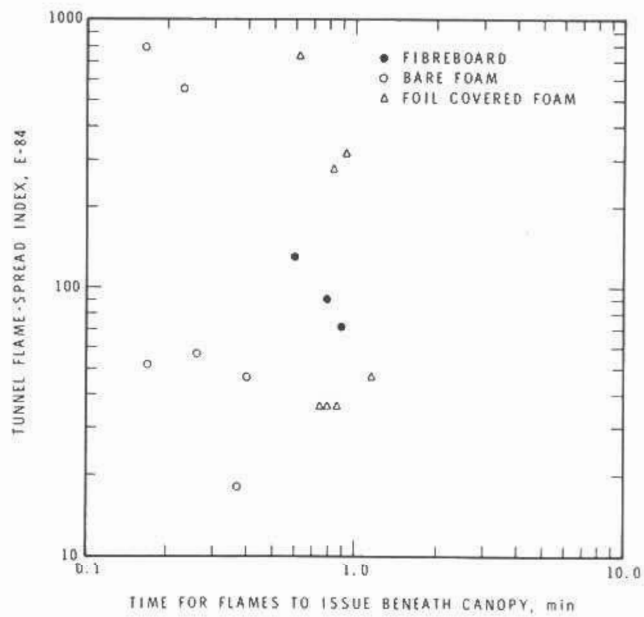

Figure 3. Standard (NFPA 255) flame spread index correlation.

In some instances, however, the flame front merely slowed down and the choice of the value of d to be utilized tended to be subjective in the light of the desire for a particular value of tunnel rating.

All the relevant results are presented in Table 2, and the correlation involving the formula FSC $= 28.2\ d/t$ is shown in Figure 4. Several features of these results call for comment, as follows:

- Application of the rate formula to foams nominally below 77.5 produced flammability rating increases as much as ten times; whereas in the case of three cellulosic materials, influence was minimal.

- The results of the cellulosic materials and of the bare foams fit together to give a single flammability scale. Aluminum-foil-covered foams, on the other hand, depart sharply from the correlation and form a separate one. It is of considerable importance to note that, from the point of view of a merit sequence, the tunnel rates aluminum-foil-covered foams as much more hazardous than does the corner wall test.

- The existence of the correlations indicates that results from the 4 and 8 ft corners follow the same scale.

- With materials Nos. 12 and 13 (polyisocyanurate board), the fire developed rapidly and momentarily involved the entire ceiling, but flames did not issue beneath the canopy. Accordingly, the results of tests involving these materials are excluded from Figure 4. This subject is discussed in the following section.

SUBSEQUENT SUPPLEMENTARY CORNER WALL INVESTIGATION

The polyisocyanurate boards (material Nos. 12 and 13) that did not give flames issuing from beneath the canopy had tunnel ratings of 79.3 and 76.9; whereas, a fiberboard with the nominally lower rating of 72.3 behaved normally. It was thought possible that the mechanism responsible for this arrested fire development might be the same as that associated with the similarly anomalous tunnel behavior. Unfortunately, no further samples of material No. 13 were available, but a test on material No. 12, with the test specimen lining the interior of the canopy as well as all other interior surfaces, eliminated the anomalous behavior, and flames issued beneath the canopy in approximately 0.5 min.

A cellulosic material was also tested with the specimen lining extending over the interior of the canopy. In this case, the only obvious effect of the additional linings was a slight reduction in the time at which flames issued beneath the canopy. It is suggested that in subsequent work the canopy should always be lined.

During the course of the experimentation, it was found that assessment of the time at which flames issued beneath the canopy was not merely subjective but was also very difficult in cases where dense smoke was generated. As an alternative, cotton thread was extended about an inch beneath the canopy along the whole length of the lower edge, its time of

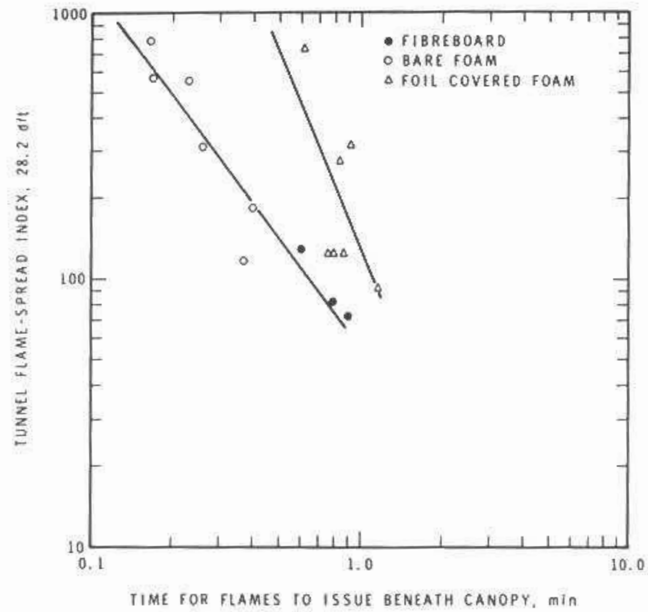

Figure 4. Modified (28.2d/t) flame spread index correlation.

breakage being the feature of interest. Preliminary experiments indicated that the gage and tensioning of the thread were not critical. Where short times were involved (less than 0.2 min) the time of breakage substantially coincided with the time at which flames issued beneath the canopy. With a material that made little contribution to the source fire, however, the cotton fractured at between 2 and 4 min in the region of the canopy cutout. Merely ensuring that the cotton remained at the same level and did not follow the contour of the cutout was sufficient action to ensure that the cotton would not fracture from temperatures associated with the ignition source only.

CONCLUSIONS

The principal conclusion to be drawn from the work described is that the tunnel should be regarded as the base on which the flammability of foamed plastics can be assessed (provided that flame spread ratings are suitably calculated). If, during a tunnel test on a bare, thermosetting foamed plastic, the distance of propagation is small, it might be very difficult to arrive at an accurate rate index. In these cases, corner wall testing, as described, is desirable, the result being expressed in terms of a tunnel rating using a correlation previously derived. Unfortunately the correlation given by Figure 4 is not entirely appropriate, as it relates to a corner wall in which the canopy is not lined with specimen material. As stated in the preceding section, it has subsequently been shown that lining of the canopy is essential. This change of configuration will have some influence on corner wall times. Preparation of a revised correlation awaits further corner wall testing and the completion of some maintenance and construction work on the tunnel facility (including the provision of pollution control equipment).

For foil-covered thermosetting foamed plastics, it should be noted that a different correlation relates tunnel and corner wall results. In terms of a merit sequence, the tunnel attributes greater hazard to foil-covered foamed plastics than does the corner wall. If a conservative approach is to be adopted, assuming the most undesirable environment, the results given by the tunnel are then preferable.

A detailed study of thermoplastic foamed plastics has not yet been carried out, but it is clear that the tunnel with the specimen in the E-84 orientation (i.e., on the ceiling) and the corner wall, set up as here described, will not constitute satisfactory test methods because of specimen melting. It is hoped, following the necessary study, that the tunnel with the specimen mounted on the floor will prove to be a valid test with a scale of results substantially the same as the E-84 scale. This hope is predicated on previous experience with the tunnel and on the present work indicating that problems resulting from the fact that a material is in the form of a foam can be resolved by amendment of the E-84 index calculation.

REFERENCES

[1] Williamson, R. B. and Baron, F. M., "A Corner Fire Test to Simulate Residential Fires," *Journal of Fire and Flammability*, Vol. 4 (April 1973), p. 99.

[2] McGuire, J. H., "The Spread of Fire in Corridors," *Fire Technology*, Vol. 4, No. 2 (May 1968), p. 103.

[3] Parker, W. J. and Lee, B. T., "Fire Buildup in Reduced Size Enclosures," National Bureau of Standards Special Publication 411 (November 1974), p. 139.

[4] Thomas, P. H., Webster, C. T., and Raftery, M. M., "Some Experiments on Buoyant Diffusion Flames," *Combustion and Flame*, Vol. 5, No. 4 (December 1961), p. 359.

ACKNOWLEDGMENT: Acknowledgment is due to A. Rose for providing records of tunnel tests.