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TP11206E
Aircraft Ground De/Anti-Icing Fluid Holdover Time Field Test Program for the 1990 - 1991 Winter

Prepared for:

Transportation Development Centre
Policy and Coordination
Transport Canada
December 1991

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by

Aviation Planning Services Ltd.

December 1991

The contents of this report reflect the views of Aviation Planning Services Ltd. and not necessarily the official view or opinions of the Transportation Development Centre of Transport Canada.

Un sommaire en français de ce rapport est inclus.

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16. Abstract

The objective of this study was to manage, conduct and analyze holdover time tests used to assess the time effectiveness of commercially produced de/anti-icing fluids. These tests were carried out in order to accept or reject holdover time tables produced by AEA/ISO and presently being used by European aircraft operators. Through the participation of air carriers, fluid manufacturers, universities and government organizations, testing was carried out at six Canadian sites and seven other sites around the world. Standard test procedures were developed which consisted of pouring anti-icing fluids onto clean plates, exposing the plates to precipitation and recording the elapsed time to one of three possible end conditions. Seven commercially available fluids were tested. Failure time was affected by variables including precipitation, type of fluid, temperature, humidity, wind and type of precipitation.

Of the 907 tests which were carried out, 502 were with Type II fluids, 110 were with Type I.5 fluids, while the remaining 295 tests were unusable. Analysis of failure time against each of the independent variables failed to reveal any direct relationships, however a lower boundary relating failure time to rate of precipitation was found. This lower boundary disagrees with the 1990 ISO/AEA table values which do not appear to account for the extreme weather conditions frequently encountered, and thus do not provide realistic safety guidelines.

For future testing purposes, necessary procedural and equipment enhancements were recommended, including improved precipitation measuring equipment; outdoor and laboratory tests were suggested, including the use of ice sensors to remove the subjectivity in determining the end condition, as well as confining the tests to one or two sites with one type of fluid.

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16. Résumé

Le but de cette étude était d'organiser et de mener des essais visant à mesurer la durée d'efficacité de certains agents dégivrants et anti-givre sur le marché. Il s'agissait de vérifier dans quelle mesure les tables de durée publiées par l'AEA et couramment utilisées par les transporteurs aériens d'Europe peuvent être acceptées ou rejetées. Les chercheurs ont fait appel à des transporteurs aériens, aux fabricants des agents essayés, à des universités et à des organismes publics pour mener à bien ces essais sur 13 sites différents un peu partout dans le monde, dont six au Canada. Le mode opératoire, standardisé, a consisté à verser un agent anti-givre sur des plaques d'aluminium propres, à exposer ces plaques à diverses formes de précipitation et à mesurer le temps écoulé jusqu'à l'apparition d'un de trois états finals possibles. Sept agents ont ainsi été testés. La durée de l'effet produit par les agents anti-givre est influencée par plusieurs variables, notamment la quantité totale de précipitation, sa nature et celle de l'agent utilisé, la température, l'humidité relative et la vitesse du vent.

Des 907 mesures obtenues, 502 concernaient des agents de type II et 110 de type I.5, les 295 restantes étant inutilisables. Aucune des courbes montrant la durée de l'effet en fonction de chacun des paramètres pris en compte n'a mis en évidence une quelconque corrélation directe et convaincante, à part la découverte d'une limite inférieure bornant la courbe de la durée en fonction du taux de précipitation. Cette limite ne s'accord pas avec les valeurs dans les tables publiées par les agences ISO et AEA, indiquant que ces tables ne reflètent pas des réalités météorologiques, at ainsi que les valeurs ne pourraient pas representer des lignes directrices pour la sécurité.

Pour les recherches à venir, il est proposé d'améliorer le mode opératoire des essais et de mettre en oeuvre un matériel de meilleure qualité, notamment des pluviomètres améliorés. Il est proposé en outre de procéder à une batterie d'essais tant extérieurs qu'en laboratoire, utilisant pour cela des capteurs permettant de détecter la présence de givre ou de glace et éliminant du même coup le facteur de subjectivité dans la détermination de l'état final. Il est proposé enfin de limiter les essais futurs à un ou deux sites et de n'utiliser qu'un seul type d'agent.

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0. EXECUTIVE SUMMARY

At the request of the Transportation Development Centre (TDC) of Transport Canada, Aviation Planning Services (APS) undertook a study to manage, conduct and analyze holdover time tests used to assess the time effectiveness of commercially produced de/anti-icing fluids.

The project involved the participation of a number of Canadian, US and overseas carriers, de-icing fluid manufacturers, the Université du Québec à Chicoutimi (UQAC), the National Research Council (NRC), and the Federal Aviation Administration (FAA). Testing was carried out at 13 sites around the world. Six of these were Canadian and testing at these sites was under the overall responsibility of APS. These sites were located at Dorval, Toronto, Ottawa, St. John's, Halifax and Chicoutimi. The non-Canadian sites were all managed locally, however, the data collected was included in this analysis.

Generally, the testing consisted of pouring anti-icing fluids onto clean, inclined (by 10°) aluminium plates, exposing the plates to various winter precipitation conditions and recording the time elapsed before the plates reached one of three possible end conditions.

A test would be considered terminated if a front of ice formed on the upper end of the plate, if one third of the plate crosshairs were snow covered, or if the fluid lost its gloss. These end conditions were certainly subjective in nature, as it was possible for different individuals to make different determinations as to the time the end condition was reached.

The SAE Adhoc committee meeting, held in Montreal during June 1990, resolved to test only 100% concentration Type II fluids. The Type II fluids tested were: Kilfrost ABC-3, Dow Flightguard 2000, Union Carbide 5.1, SPCA AD104, Hoechst 1704, and Octagon 40-below. Note that Hoechst 1704 is the European equivalent to Flightguard 2000. The Canadian sites were also interested in testing Union Carbide's 250-3 Type I.5 fluid.

Plate failure time could be affected by any or all the following independent variables: total precipitation, test location, type of fluid, type of precipitation, temperature of the plate, ambient temperature, relative humidity, wind velocity, fluid thickness, as well as the tester's subjectivity. Equipment was used to record a number of these parameters including precipitation, temperature, wind speed, humidity and fluid thickness.

0.1 Data Collection

During the 1990-1991 test season, APS received 171 test data forms from the 13 sites around the world. Each form contained data for up to six test plates. These data forms contained a total of 907 test points of which 295 points were not used either because the tests were aborted, the fluids were diluted, or Type I fluids were tested. Of the remaining 612 points, 502 were of Type II and 110 were of Type I.5 fluids.

The following conclusions can be made regarding the classification of the Type II fluid data: Kilfrost was the most tested fluid; almost half of the tests were carried out at Dorval; a large proportion of the tests had rates of precipitation below 12.5 g/dm^2/hr; the average temperature and wind speed values were -4.1°C and 10 mph (16 kph), respectively; snow accumulation was the predominant failure mode; the average failure time for those tests terminated within one hour was 34 minutes and the relative humidity was most often between 85% and 95%.

After the testing season, with the assistance of Atmospheric Environment Services Canada, the Consultants were able to obtain relatively detailed meteorological information for all of the Canadian sites except Chicoutimi. This data was used to determine days on which testing could have taken place. The actual days when testing was done were compared to these days.

It was found that the success rates for sites other than Dorval were relatively low. The Dorval site had thirteen testable days and performed tests on ten of those days. Montreal also had the most available people to staff the site. Up to eleven APS professionals and students tested at various times throughout the winter. The other Canadian sites were staffed by pairs of university students who were required to balance working on the test program with other commitments.

0.2 Data Analysis

The analysis of the collected data was multi-faceted. Plots of failure time against each of the other variables failed to unearth any strong direct relationships. This analysis did discover a lower boundary when comparing failure time to rate of precipitation. This boundary had the form $Y = aX^{-b}$.

The effects of temperature, relative humidity, wind speed, failure mode and fluid type were further assessed by combining each, in turn, with rate of precipitation and total precipitation and plotting against failure time. The extreme variability of Type II data statistically masked any potential clear relationships or dependencies between failure time and the other recorded variables.

The European AEA/ISO holdover Type II tables were discussed with comparisons made to the data collected at Dorval. It was concluded that the AEA/ISO tables are more representative of ideal conditions than of realistic safety guidelines, and that they should provide more information with respect to snowfall, humidity, wind, etc.

A multi-variate statistical analysis was performed on the Type 1.5 fluid data collected at Dorval. This analysis found that relative humidity and wind played a significant role in failure time. The analysis, however was only able to account for about 50% of the variation in the data.

Were the variability in the data collection reduced, it may be possible to explain the greater amount of the variation. It is also a possibility that some parameters which affect fluid performance may not be measured.

0.3 Necessary Enhancements

There were several procedural and equipment difficulties encountered during testing phases of the project. Some of the more important ones are described below:

- The resolution of the tipping bucket is only 1 g/dm^2 which, under light precipitation, resulted in long time durations between tips. As a result, the magnitude of the error on the precipitation measurements can reach up to 50%.

- Sites employing the cake pan precipitation measurement method were only able to compute an average precipitation over the duration of the test.

- There is an incongruity between the procedural assumption that the fluids reach a constant thickness after about five minutes and the results of the fluid thickness analysis which indicates that this time may in reality be between 10 and 15 minutes.

- Placing a tarp over the test stand, to protect the plates from precipitation, under moderate to heavy winds became a difficult or impossible task. Sites at Montreal and St. John's tested with a tent-like covering. While this was a substantial improvement, it was still very difficult to deal with under very high winds such as those experienced at St. John's.

- Sites set up by the airlines were staffed by airline personnel. These employees had other tasks to perform throughout their work day and, as a result, few data points were received.

0.4 Future Testing

It is precisely because one eventually wants to understand holdover that future testing should be continued outdoors. It is not possible to generate ''natural conditions'' in a cold chamber. Unfortunately it is also not possible to control the outdoor conditions themselves.

The type of outdoor testing is open for discussion. Perhaps using a curved plate or representative wing section could give a little more insight into the whole phenomenon than the flat plate. Testing with tighter controls on the meteorological variables, specifically precipitation and relative humidity, combined with an objective method for determining plate failure could facilitate the analysis.

Indoor laboratory testing could provide insight into fluid behaviour under pre-determined combinations of temperature and relative humidity.

The investigation of ice sensors could also play a major role in the process of understanding the behaviour of de-icing fluids under actual conditions. The sensor currently being developed by Instrumar, at St. John's, Newfoundland, is said to have the potential of determining not only whether its sensor is contaminated, but also the type and extent of the contamination. Incorporating the ice sensor into an outdoor test program could not only provide useful insight into fluid behaviour, but could also be an excellent development tool for the sensor's manufacturer.

0. Sommaire

Mandatés par le Centre de développement des transports (CDT), Transports Canada, les Services de planification en aviation (SPA) ont entrepris d'organiser et de mener des essais visant à mesurer la durée de l'effet de certains agents dégivrants et anti-givre sur le marché.

Les chercheurs ont fait appel à des transporteurs aériens canadiens, américains et d'ailleurs, aux fabricants des agents essayés, à l'Université du Québec à Chicoutimi (UQAC), au Conseil national de recherches (CNR) et à la Federal Aviation Administration (FAA) des États-Unis pour mener à bien ces essais sur 13 sites un peu partout dans le monde. Six se trouvaient au Canada : Dorval, Toronto, Ottawa, St.John's, Halifax et Chicoutimi, la SPA ayant pris en charge la direction des essais qui y ont été faits. Quant aux essais menés dans les sites à l'étranger, ils ont été menés par les partenaires concernés. Les résultats correspondants font, cependant, partie de l'analyse présentée dans le présent rapport.

Règle générale, les essais ont consisté à verser un agent anti-givre sur des plaques d'aluminium propres inclinées à 10°, à exposer ces plaques à diverses formes de précipitation hivernale et à mesurer le temps écoulé jusqu'à l'apparition d'un de trois états finals possibles.

Un essai était considéré comme terminé lorsque de la glace recouvrait la partie supérieure d'une plaque, lorsqu'un tiers des 15 fils en croix marqués sur une plaque devenait invisible sous la neige ou lorsque l'agent anti-givre perdait son éclat. Ces observations étaient subjectives dans la mesure où la détermination du temps écoulé jusqu'à l'apparition de l'un de ces trois états pouvait varier selon les individus.

Lors de sa réunion tenue à Montréal en juin 1990, le comité mis sur pied exprès par la SAE a décidé de ne prendre en considération que les agents de type II et à condition qu'ils soient non dilués. Les agents mis en oeuvre étaient les suivants : Kilfrost ABC-3, Dow Flightguard 2000, Union Carbide 5.1, SPCA AD104, Hoechst 1704 et Octagon 40-below. Il faut noter que l'agent Hoechst 1704 est l'équivalent européen du Flightguard 2000. Au Canada, on était intéressé à essayer aussi l'agent 250-3 type I.5 d'Union Carbide.

Les variables indépendantes qui peuvent agir séparément ou simultanément sur la durée de l'effet produit par les agents essayés sont multiples : la quantité totale de précipitation, sa nature, le lieu de l'essai, la nature de l'agent, la température de la plaque, la température ambiante, l'humidité relative, la vitesse du vent, l'épaisseur de l'agent et la subjectivité du chercheur. Certains de ces paramètres ont cependant pu être mesurés à l'aide d'un instrument, à savoir la précipitation, la température, la vitesse du vent, l'humidité relative et l'épaisseur de l'agent.

0.1 Collecte de données

Au cours de la saison 1990-1991, APS a reçu 171 procès-verbaux provenant de l'ensemble des 13 sites, chacun consignant les mesures relatives à un maximum de six plaques. En tout, ces procès-verbaux contenaient 907 mesures, dont 205 étaient inutilisables soit parce que l'essai avait été interrompu, soit parce que l'agent avait été utilisé dans une forme diluée, soit enfin parce qu'il s'agissait d'un agent de type I. Des 612 mesures restantes, 502 concernaient des agents de type II et 110 de type I.5.

Les observations suivantes peuvent être tirées des résultats ainsi obtenus : agent le plus souvent utilisé : Kilfrost; lieu où près de la moitié des essais ont été effectués : Dorval; taux de précipitation observés dans une grande proportion des essais : inférieurs à 12,5g/dm²/h; valeurs moyennes de vitesse du vent et de température : 16km/h (10 mi/h) et -4,1°C, respectivement; facteur prédominant entraînant la cessation de l'effet : enneigement; durée moyenne de l'effet observé : 34 mn pour tous les essais ayant duré un maximum de 1 h; humidité relative le plus souvent observée : entre 85 et 95 p. 100.

À l'issue de la période d'essais, les chercheurs ont pu obtenir, avec la collaboration du Service de l'environnement atmosphérique d'Environnement Canada, des données météorologiques assez détaillées concernant tous les sites d'essai au Canada, à part Chicoutimi. Les chercheurs s'en sont servi pour compter le nombre de jours durant lesquels des essais auraient pu être faits, qu'ils ensuite comparé au nombre de jours durant lesquels ces derniers avaient effectivement eu lieu.

Les chercheurs ont constaté que, sauf dans le cas de Dorval, cette comparaison n'a pas été favorable. À Dorval, ils ont calculé que, sur les 13 jours propices aux essais, 10 seulement ont été mis à profit pour effectuer des essais. Montréal est pourtant le site où l'on a pu compter sur le plus grand nombre d'observateurs, soit onze personnes, spécialistes de SPA ou étudiants. Ailleurs, au Canada, le nombre d'observateurs n'a jamais été supérieur à deux à la fois, des étudiants qui devaient se partager entre cette tâche et d'autres engagements.

0.2 <u>Analyse des données</u>

Cette analyse a été de type multicritères. Aucune des courbes montrant la durée de l'effet en fonction de chacun des paramètres pris en compte n'a mis en évidence une quelconque corrélation directe et convaincante. Les chercheurs ont tout au plus découvert, sur la courbe de la durée de l'effet en fonction du taux de précipitation, une limite inférieure répondant à l'équation $Y = aX^{-b}$.

De plus, l'influence de la température, de l'humidité relative, de la vitesse du vent, de la forme de précipitation qui a fait perdre à l'agent son effet et de la nature de l'agent visé, a pu être évaluée en associant, à tour de rôle, tous ces paramètres au taux de précipitation et à la quantité totale de précipitation et en les mettant en rapport avec la durée de l'effet. Il s'est avéré que les données relatives aux agents de type II présentent des variations au point d'interdire la mise en évidence d'une corrélation quelconque entre les paramètres en jeu.

Un débat a eu lieu concernant les tables publiées par l'agence européenne AEA/ISO sur la durée de l'effet des agents de type II. Il a débouché sur le consensus que

ces tables reflètent des valeurs d'enneigement, d'humidité, de vent, etc., plus théoriques que proches des réalités météorologiques.

Les données recueillies à Dorval sur l'agent de type I.5 ont été soumises à une analyse statistique multivariée. Celle-ci a montré que l'influence des paramètres d'humidité relative et de vitesse du vent sur la durée de l'effet des agents anti-givre est prépondérante. Sauf qu'elle n'a pas réussi à expliquer près de la moitié des variations présentées par les données analysées.

Si les données mesurées avaient présenté moins de variations, il aurait été possible d'expliquer les variations constatées dans une plus grande proportion. L'autre possibilité est que les chercheurs n'ont pas pris en compte certains paramètres déterminants.

0.3 Améliorations nécessaires

Le mode opératoire des essais et le matériel mis en oeuvre ont posé des difficultés qui ont entravé la bonne marche des essais. Certains parmi les plus importants sont décrits ci-dessous :

- La résolution du pluviomètre à augets basculeurs n'est que de 1 g/dm^2, ce qui allonge indûment les temps de mesure lorsque la précipitation est faible. Il en résulte des erreurs dans les quantités mesurées dont l'ordre de grandeur peut atteindre les 50 p. 100.

- Dans les sites équipés d'un pluviomètre à collerette, seule la valeur moyenne de précipitation a pu être obtenue pour la durée des essais.

- Il existe un désaccord entre la valeur théorique de cinq minutes admise selon l'hypothèse que l'épaisseur de l'agent devient uniforme quelque cinq minutes après qu'il ait été versé et celle de 10 à 15 minutes qui se rapproche davantage des résultats analytiques.

- Vouloir placer une bâche destinée à empêcher la précipitation de tomber sur les plaques en dehors des périodes d'observation s'est avéré une tâche difficile, voire impossible, dans des conditions de vent allant de modéré à fort. À Montréal et à St.John's, une protection formant tente a été essayée. Il a quand même été très difficile de la mettre en place à St.John's à cause des vents violents qui y soufflent parfois.

- Les sites placées sous la responsabilité d'un transporteur aérien n'ont permis de récolter que peu de données, les observateurs dépêchés sur place n'ayant que peu de temps à consacrer à cette tâche.

0.4 Essais futurs

C'est précisément parce qu'on veut approfondir les paramètres déterminant la durée de l'effet produit par les agents anti-givre que les essais à venir doivent se tenir à l'extérieur. Une chambre froide ne peut pas reproduire les «conditions naturelles», alors que malheureusement, à l'extérieur, la maîtrise de celles-ci nous échappe.

La nature des essais extérieurs à entreprendre reste encore à déterminer. Il est possible qu'avec une plaque incurvée ou avec profil d'aile type on puisse obtenir des résultats plus probants qu'avec une plaque plane. Il faut pouvoir maîtriser davantage les variables en jeu, notamment la précipitation et l'humidité relative tout, en mettant au point une méthode permettant de déterminer objectivement la durée de l'effet.

En laboratoire, il sera possible d'approfondir le comportement d'un agent dégivrant ou anti-givre dans des conditions précises de température et d'humidité relative.

La recherche sur les capteurs permettant de détecter la présence de givre ou de glace aidera beaucoup à approfondir le comportement de ces agents dans des conditions réelles de service. Aux dires de Instrumar qui développe un tel capteur à St.John's (Terre-Neuve), ce dernier promet non seulement de détecter la présence d'une précipitation, mais également d'en indiquer la nature ainsi que la quantité. L'adjonction d'un tel capteur au programme d'essais extérieurs facilitera l'obtention des données voulues sur le comportement des agents, fournissant à son fabricant l'occasion de le développer au maximum de ses possibilités.

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1. INTRODUCTION

At the request of the Transportation Development Centre (TDC) of Transport Canada, Aviation Planning Services (APS) undertook a study to manage, conduct and analyze holdover time tests used to assess the time effectiveness of commercially produced de/anti-icing fluids.

In the last decade, a number of fatal aircraft accidents occurred at take-off during periods of freezing precipitation or precipitation which could contaminate aerodynamic surfaces; in several of these accidents the effectiveness of ground anti-icing has been suspect. Two of these accidents occurred in Canada. The anti-icing fluids generally used on aircraft until recently were only expected to provide protection for the surfaces during brief taxi and take-off periods, but this was based on the operating environment of the 1950s and 1960s. As traffic demand grew and navaids were improved, operations under more extreme weather conditions increased. Traffic congestion on the airports introduced lengthy queues for take-off with the accompanying longer anti-icing protection requirement. This led to the development of the Type II anti-icing fluid and the need for a standard means of measuring the protection time of these fluids.

Currently in Canada, aircraft are de-iced using Type I de-icing fluids, which are sometimes diluted. While excellent for removing ice and snow which has already accumulated on the wings of aircraft, Type I fluids do not offer extended duration protection against further ice build up. The Type II fluids, being significantly more viscous, are said to offer this kind of protection. However, these fluids are not always suitable for small aircraft as residual fluid on the wings or fuselage may not flow off with the lower aircraft take-off speeds. In between these two fluids, in terms of effectiveness, are Type I.5 fluids. While providing longer holdover capability than the Type I fluids, Type I.5 fluids are less viscous than the Type IIs which allows them to be used on smaller aircraft.

The need for this project was identified over two years ago. Following a series of meetings in 1988-1989 on holdover time, held under SAE auspices, with many major airlines and anti-icing fluid manufacturers, Air Canada and the Transportation Development Centre (TDC) took the initiative to develop a small field test program for the 1989-1990 winter season to determine the fluid time effectiveness under real precipitation conditions. This small scale program involved four Canadian sites, each staffed with one university student. The results were unsatisfactory for a number of reasons that were subsequently addressed at a TDC sponsored meeting of the SAE Ad Hoc Committee Working Group (Aircraft Ground De-icing Tests), June 6^{th}, 1990, in Montreal. Agreement was reached on standardized test equipment, procedures and the scope of the data to be collected during the 1990-1991 winter. Despite the experience and the agreement, additional procedural changes were enacted throughout the testing year.

This project formed the focus for the 1990-1991 series of tests in Canada, USA, Europe and Japan; it involved the participation of a number of Canadian, US and overseas carriers, de-icing fluid manufacturers, the Université du Québec à Chicoutimi (UQAC), the National Research Council (NRC), and the Federal Aviation Administration (FAA).

The test activities included qualification of the anti-icing fluids in the new UQAC wind tunnel (written up as part of a separate report published as TP 11078 E), and the field testing of these fluids at six Canadian sites as well as at sites throughout the world according to the procedures developed. The data collected at all sites was assembled and analyzed, and is presented in this report.

The success of the project depended heavily on the collaboration of the de-icing fluid suppliers, the NRC, UQAC, the FAA and Air Canada. The cooperation of the international airlines was also essential in supplying the study with some international impact. The influence and assistance of TDC was instrumental in achieving this cooperation.

The current standards in Europe are based on a series of tables constructed with data obtained during indoor, cold chamber testing under highly specific conditions. These tables provide a "holdover" time which is supposed to be applicable to actual aircraft under all varieties of precipitation conditions. It is being proposed that these European tables be adopted in North America, even though the temperature and precipitation conditions vary greatly from those found in Europe. The analysis of the data in this report will be used to ascertain whether adoption of these tables is advisable.

The next section of the report outlines the testing procedures and equipment requirements with special emphasis on the problems experienced with both. Subsequent sections describe the data received, in terms of where it was collected, under what sort of conditions, note deficiencies and subjectivities in the data, and deal with the analysis of the data, through failure curves, fluid thickness analyses and a purely statistical factor analysis. The final sections provide a discussion of the necessary procedural and equipment enhancements for future testing, the conclusions, based on both the testing experience and the data analysis, and recommendations as to the adoption of the European tables and additional testing.

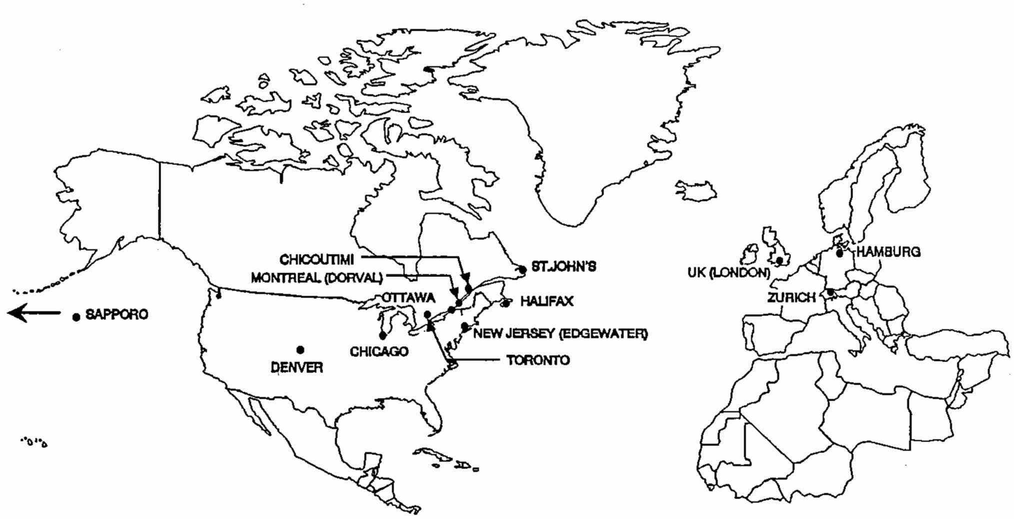
2. METHODOLOGY

The methodology description is sub-divided into six sections dealing with: worldwide sites; test procedures and data forms; equipment; fluids; personnel and participants; and analysis methodology.

2.1 Worldwide Sites

This testing was truly an international effort, with sites as close as Dorval, Québec to sites as far away as Sapporo, Japan. Figure 2.1 indicates the 13 sites involved in the project. The amount of data submitted to APS for analysis varied widely from country to country, and site to site. The breakdown of data submitted, by site, is left for Section 3.1.2.

FIGURE 2.1
TEST SITES FOR DEICING PROGRAM

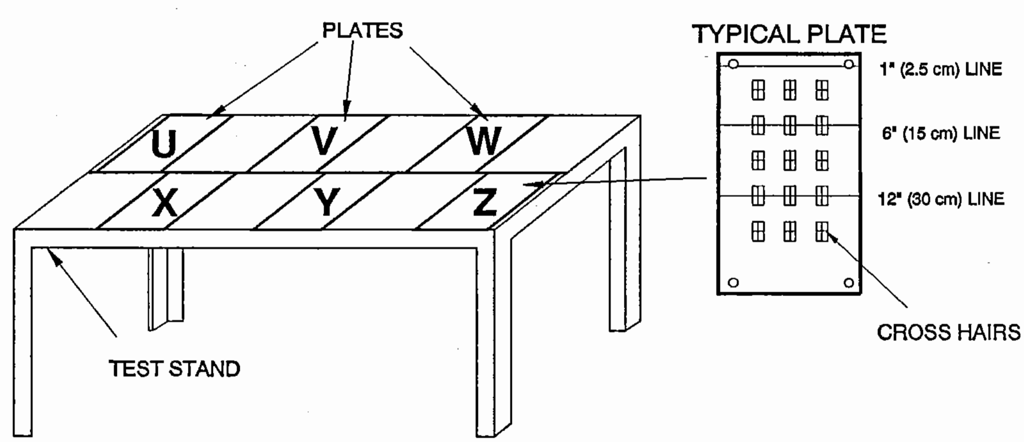


2.2 Test Procedures and Data Forms

Generally, the testing consisted of pouring de-icing fluids onto clean, inclined (10°) aluminium plates, exposing the plates to various winter precipitation conditions and recording the time elapsed before the plates reached one of three possible end conditions. Although complete details are provided in Appendix A, which documents the actual test procedures and equipment requirements supplied to the program participants, a brief list of the required steps is given here:

- Orient test stand (test stand and panels are displayed in Figure 2.2 and Photo 2.1) to face into the wind;
- Clean the plates with an alkali detergent and install onto stand;
- Cover stand with a plastic tarp and allow panels to cool to outside temperature;
- Pour fluids slowly and evenly over entire panel surface;
- Allow fluid to settle on panels for a minimum of five minutes, measure fluid thickness at 2.5 cm (1 inch), 15 cm (6 inch), and 30 cm (12 inch) lines using a wet film thickness gauge;
- Record air and panel temperatures, wind speed and relative humidity;
- Expose plates to precipitation, start timer and precipitation recording device and continue monitoring precipitation every five minutes until end condition is reached (described below);
- After all plates have failed, record wind speed, air temperature and relative humidity;

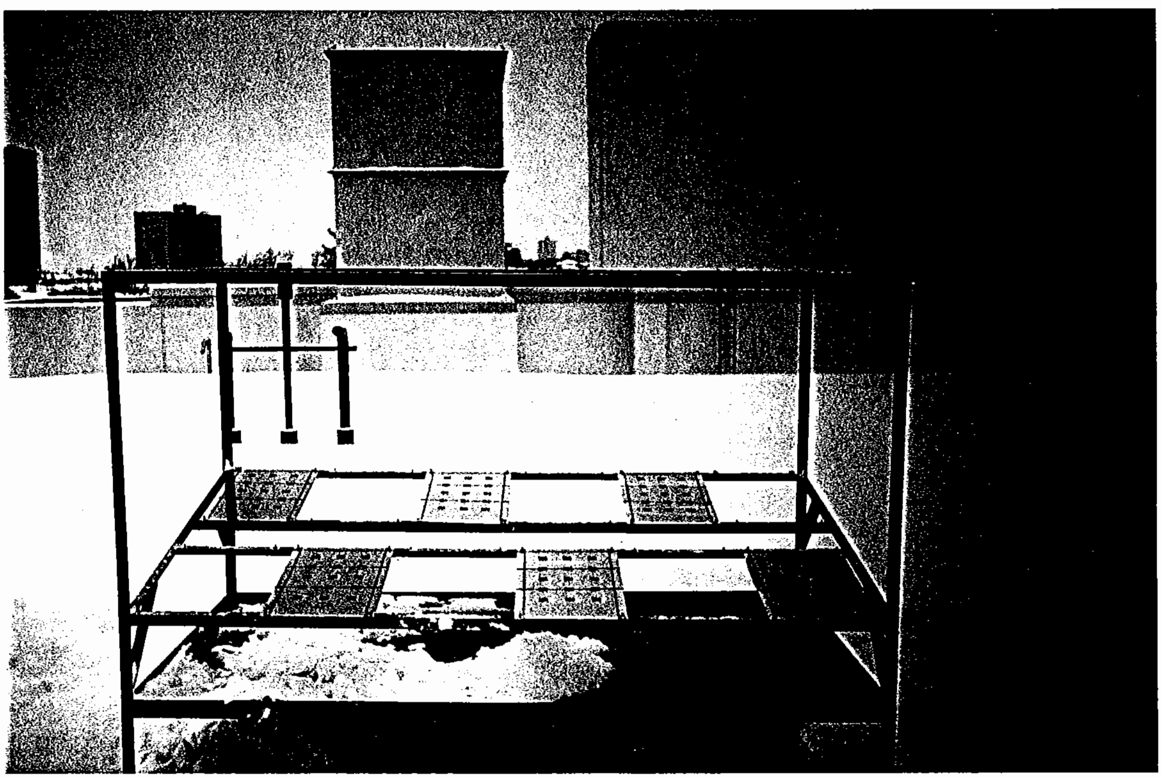
FIGURE 2.2
TEST STAND AND PLATES



- Clean plates with isopropyl alcohol or pure glycol and begin entire procedure again.

As shown in Figure 2.2, the plates were marked with three lines, at the 2.5 cm, 15 cm and 30 cm point of the plate. The plates were also marked with 15 crosshairs. These crosshairs were used to assist the test personnel in determining whether end conditions were achieved.

Photo 2.1 - Test stand and plates



As mentioned in the Introduction, the procedure evolved from the experiences of various test programs for the 1989/90 winter season. The combined experience of the testing organizations was employed during the SAE Ad Hoc committee meeting on the 6th of June, 1990 to develop a consistent testing procedure for this program. One key element of discussion was the determination of the test end conditions. It was decided that the test would be considered terminated if:

- A front of ice descended from the top of the plate to the 1 inch line; or

- Snow built up on the plate so that five or more of the 15 crosshairs were obscured; or

- The absorption of snow or freezing rain was such that it resulted in a loss of gloss for the fluid, again over five or more of the 15 crosshairs.

Along with the written procedure, the participants were supplied with a training video. This training video was produced by APS during the fall of 1990. A copy of this video, in VHS format, is included with the report. While the meteorological conditions at the time of filming did not match those expected during actual testing (i.e. filming occurred on a warm sunny day) the general ideas and practices were all included. Examples of the test end conditions were given by using excerpts from a video of previous testing provided by Air Canada.

The end conditions are certainly subjective in nature. While examples of the latter two end conditions were shown on the supplied training video, it was still possible for different individuals to make different determinations as to the time the end condition was reached. To mitigate this concern, it was suggested that a single individual at each site be responsible for making the "end condition" determination. While this still left room for variation between sites, it was hoped that such variation may be visible in the overall data analysis. All data recorded during testing was to be recorded on supplied data forms, which are also included in Appendix A. The original form was cumbersome to work with and did not record sufficient information. Therefore, a second, single-sided form was produced and sent out to all the participants. Because of the inadequacies of the first form, several sites developed their own forms before the updated form was available. This led to the existence of several versions of forms in use, not all of which recorded sufficient information.

2.3 Equipment

The equipment list and specifications are also included in Appendix A. Equipment was required to record precipitation, temperature, wind speed, relative humidity and fluid thickness. The most important parameter of this list was thought to be precipitation.

There were two methods employed to measure precipitation. The first used a heated rain/snow gauge tipping bucket. The model used in North America registered a "tip" for every gram per square decimetre of snow that fell (which equated to 0.1 mm of liquid precipitation). This proved to be too coarse for most of the precipitation conditions measured. A light to medium snow fall would register only 4 or 5 tips over a one hour period. The model used at one European site was 20 times more accurate than the North American model. This model counted "drops" and not "tips". The existence of such an accurate device was not known to the North American sites at the beginning of testing. In reality, the German company, Thies, which manufactures the unit, has a Canadian distributer in Toronto. The cost is approximately 4 times the cost of the Qualimetrics unit used by the sites in North America ($4,000 vs $1,000).

The second method for calculating precipitation involved using one or two cake pans. Pre-wetted and pre-weighed pans were used to collect snow and/or freezing rain. At the end of the test, the pans were re-weighed. The difference in the two weights was the total precipitation while the difference divided by the time span provided the average rate of precipitation. Difficulties encountered with this method were that wind blown snow often did not settle in the pan, even with pre-wetting. This snow may have adhered to the test plates. Also, if the precipitation was changing in terms of intensity, the cake pans only provided average values.

A problem with the equipment related to the method with which the test stand was covered in between tests. The testers were required to apply fluids without uncovering the stand, so as not to prematurely allow contact between the plates and the precipitation. The equipment list suggested a plastic tarp be used to cover the stand. A picture of one site with the tarp covering is included in Photo 2.2. This was adequate for very low wind conditions but not during tests which had any appreciable wind. The tarp would disturb the fluid as it was lifted off and could sustain damage by the wind. The students at the Chicoutimi site constructed extension bars to the test stand to allow them sufficient room to move under the tarp while working with the plates and also to eliminate the inadvertent contact between the tarp and the plates. Another solution,

PHOTO 2.2 - Test stand with plastic tarp covering

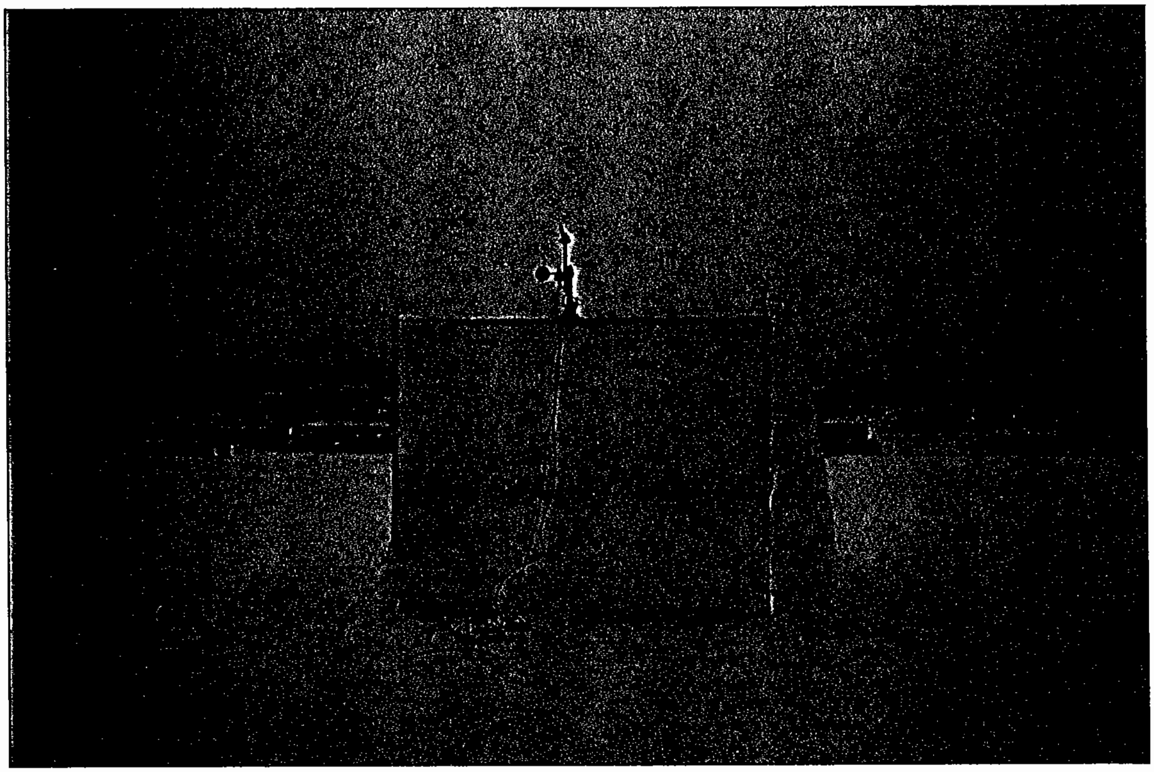
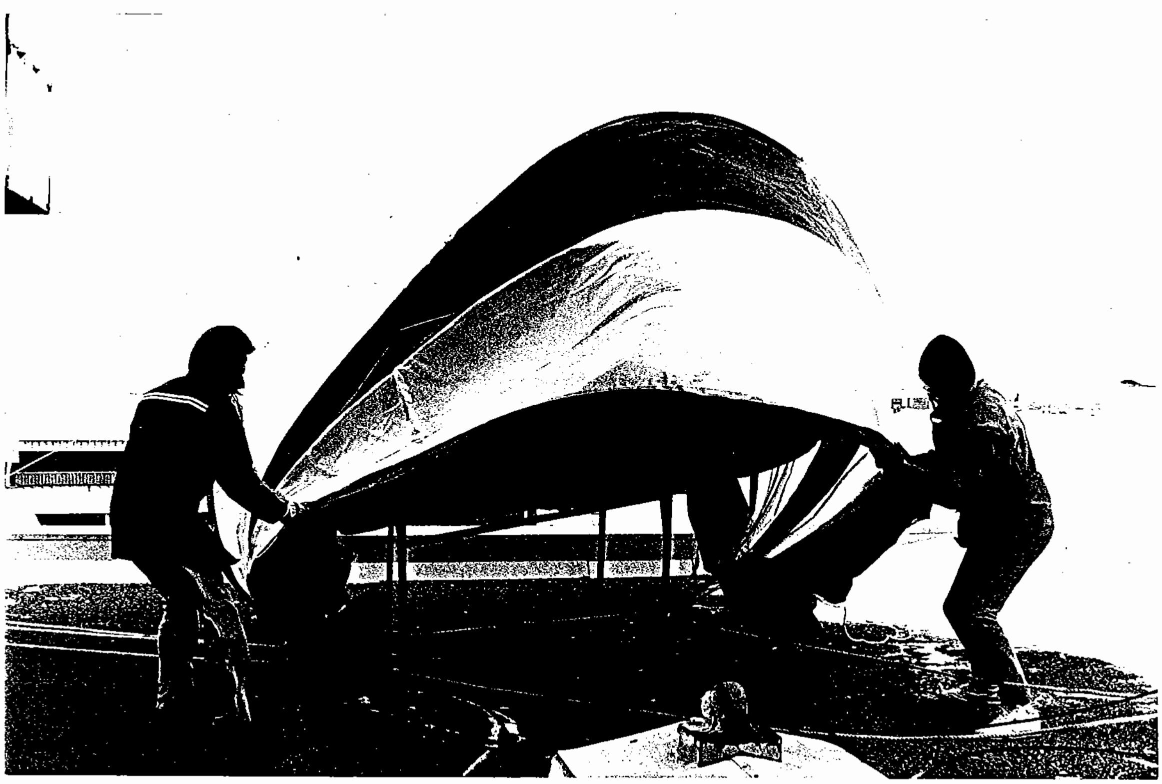


PHOTO 2.3 - Collapsable tent



which worked well in Dorval, but was only partially successful in St. John's due to the high wind, was a "slinky type" enclosure depicted in Photo 2.3. This tent folded over the stand and allowed workers inside the tent to work with the plates. When it was time to begin testing, the tent was just folded together like a slinky. As can be seen in Photo 2.3, even this folding tent was susceptible to problems during strong winds.

2.4 Fluids

The SAE Adhoc committee meeting resolved to test only 100% concentrated Type II fluids. The Canadian sites were also interested in testing Type I.5 fluids. The Type II fluids tested were: Kilfrost ABC-3, Dow Flightguard 2000, Union Carbide 5.1, SPCA AD104, Hoechst 1704, and Octagon 40-below. Note that Hoechst 1704 is the European equivalent to Flightguard 2000. The Type I.5 fluid was Union Carbide 250-3. In addition some minor testing was done, at some American and European sites, using Type I fluids, although no analysis of Type I fluids is included in this report.

Some problems occurred with the fluid deliveries. While Kilfrost responded very rapidly to the requested deliveries, some of the other manufacturers responded more slowly resulting in Kilfrost being the most tested of all fluids, as will be shown in Section 3. In addition, some sites received insufficient fluids for testing. The Rutger's, New Jersey testing was to encompass a total of six sites while the Dorval site was to act as distributer for three other Canadian sites. The need for multiple amounts of fluids for these sites was indicated to the manufacturers on more than one occasion but some were still slow in responding to this request. Lastly, some sites received incorrect fluids. The Rutger's sites were supposed to receive Type II fluids but were sent Union Carbide's Type I.5 fluid, 250-3, instead of the Type II fluid, Union Carbide 5.1. Also, the lack of a clear indication of the fluid name on the Union Carbide drums led to some mix-ups with data for sites testing both. The error was discovered during the analysis and some changes were made after discussions with the affected participants.

2.5 Personnel and Participants

The Canadian sites were staffed mainly by university students. The local site at Dorval, was staffed both by students and by APS professionals. This APS involvement was critical in giving the analysts a thorough understanding of the intricacies and potential problems with the data collection process. Aside from the Rutger's site, which was staffed by university personnel and students, the other worldwide sites were staffed by airline personnel.

The main difficulty with respect to staffing was in having someone on-site when the precipitation fell, whether it be 3:00 in the afternoon or 4:30 in the morning. For the sites staffed by airline personnel, it was very difficult to perform this testing regardless of the time of day. Employees have other tasks to do and are unlikely to work substantially outside of their scheduled hours. Sites staffed by students suffer from a similar problem. The students attend classes and cannot simply leave any time it starts to snow. In addition, homework, studying and exams can also interfere with testing time. In all cases, even if the testers are at the site, they may not be able to physically perform testing throughout a major snowfall. More than three or four hours of exposure to the cold and wet conditions, which are constituent elements of the testing process, is very unpleasant.

The most proficient site, the Dorval site run by APS, had the advantage of seven fully trained APS staff members and four students all on call. Shifts worked during major snowfalls, and students and/or staff were on call for nights when precipitation was expected. This resulted in few precipitation events being missed.

2.6 Analysis Methodology

Before all the collected data was analyzed (Sections 3 and 4), the raw data underwent some manipulation and verification. As data was received from sites in Europe and Japan, as well as North America, the first phase of the process involved bringing all data to a common set of units. The individual data parameters and the units used in the final analysis are presented below.

- Precipitation rate - ($g/dm^2/hr$)
- Total precipitation - (g/dm^2)
- Air temperature - (°C)
- Panel Temperature - (°C)

- Wind speed - (kph)
- Relative humidity - (%)
- Film thickness at 2.5 cm line - (mils; 1 mil = .001 inches)
- Film thickness at 15 cm line - (mils)
- Film thickness at 30 cm line - (mils)
- Time to failure - (min.)

All these parameters were used in the analysis except for panel temperature. Many sites did not record panel temperature and those that did experienced some difficulty with the measuring instrument. As most of the acceptable panel temperature measurements hovered around ambient air temperature, the assumption was therefore made that all panel temperatures would be equivalent to the ambient air temperature for that particular test. In the case where temperature and relative humidity could not be obtained, the local weather bureau was contacted for this information.

As the project progressed, several small analyses were performed in response to various requests. On March 1st, at the request of United Airlines, a very preliminary analysis was sent based on the data received to that point. This analysis consisted of plotting failure time against rate of precipitation on 185 useable data points. In addition, significant analysis was performed for the de-icing workshop coordinated by APS during April 1991. Over the summer, two additional analyses were provided to the TDC Project Officer for presentation. One was for the SAE Ad Hoc committee meeting of June 18-19, 1991 in Atlanta and the other was for a presentation/meeting in Ottawa in September, 1991.

In addition to the supplying the results of the analysis, the data set was also transmitted to TDC in both its raw and refined forms. The raw form was the unverified and unconverted data. The refined data set contained data with common units and encompassed all the corrections.

3. DESCRIPTION OF DATA

This section will provide a description of the data collected. Examined are such items as the quantity of data received, from where and for which fluids; and distributions of the basic weather parameters such as temperature, precipitation, wind speed, and humidity over the range of the tests collected.

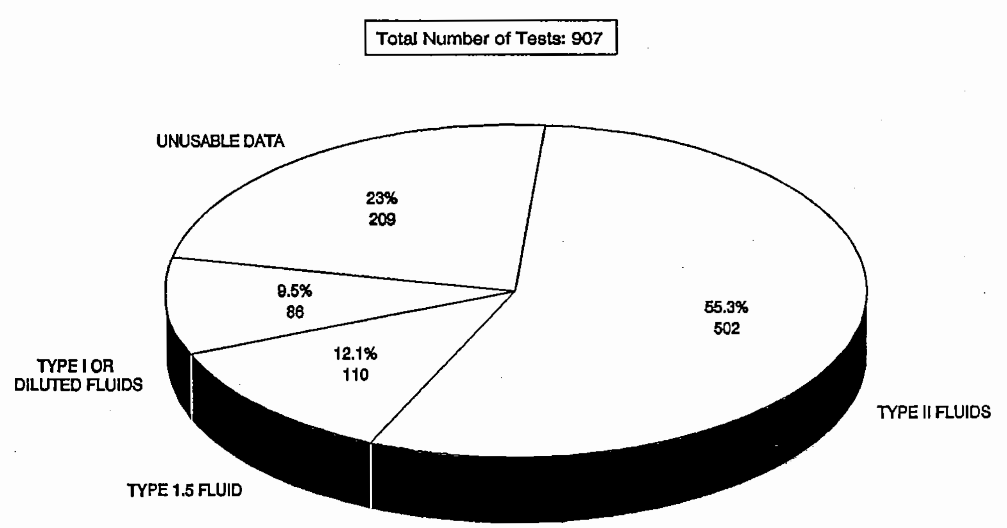
In addition, a meteorological analysis is presented from data received from Atmospheric and Environment Services for five of the six Canadian sites. This analysis will compare the number of tests received with the number of theoretically testable days.

3.1 Classification of Data

3.1.1 Usable and unusable data

During the 1990-1991 test season, APS received 172 test data forms from 13 sites around the world. Each form contained data for up to six test plates. As shown in Figure 3.1, these data forms contained a total of 907 test points of which 295 points were not used because either the tests were aborted, the fluids were diluted,

FIGURE 3.1
DISTRIBUTION OF USABLE/NON-USABLE DATA
ALL FLUIDS

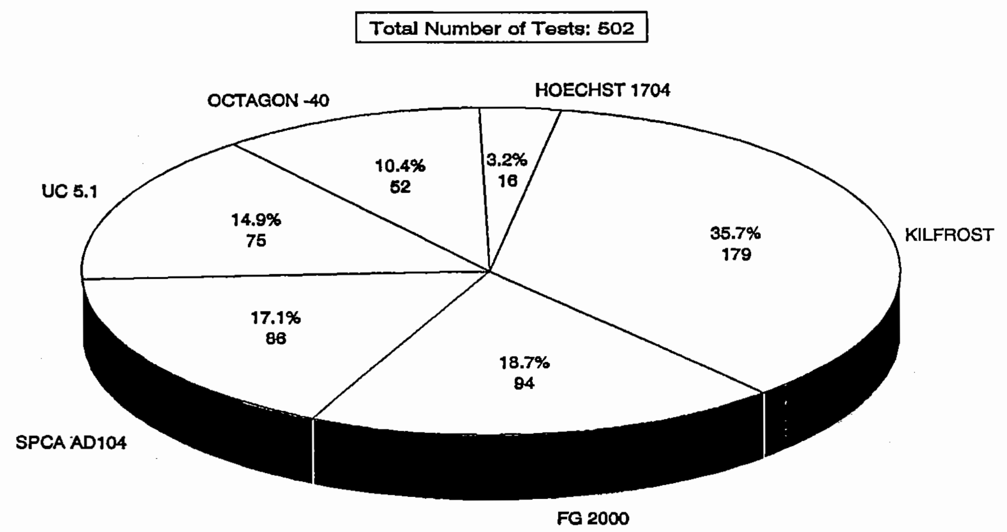


or Type I fluids were tested. Of the remaining 612 points, 502 were of Type II and 110 were of Type I.5 fluids.

3.1.2 Distribution of fluids and test location

For the 502 Type II test points, over 35% were for Kilfrost which was approximately double the number for Union Carbide 5.1, SPCA AD104 or DOW FlightGuard 2000, as seen in Figure 3.2. Octagon was used in only 10% of the cases as it entered the program at a late date. Hoechst 1704, which is the European equivalent of Dow, appeared in only 3% of the tests. This was due to the small number of tests performed outside North America. The reason Kilfrost underwent so much testing was that they were the first to respond to the call for fluids. Also, requests for multiple quantities of fluids, for local distribution to other sites, were promptly complied with.

FIGURE 3.2
DISTRIBUTION OF FLUIDS
TYPE II FLUIDS



In Figure 3.3, the tests are broken down by location as well as by type of fluid used at each location. Almost half of all tests were carried out at Dorval. There are several reasons for this. Dorval had a large number of testable days (second most among the Canadian sites). The Dorval site also had the most people available to perform the tests, which resulted in more tests being performed during extended storm periods. Lastly, the students testing at Dorval were paid a premium for testing at night. This may have provided additional motivation to do testing at some odd hours.

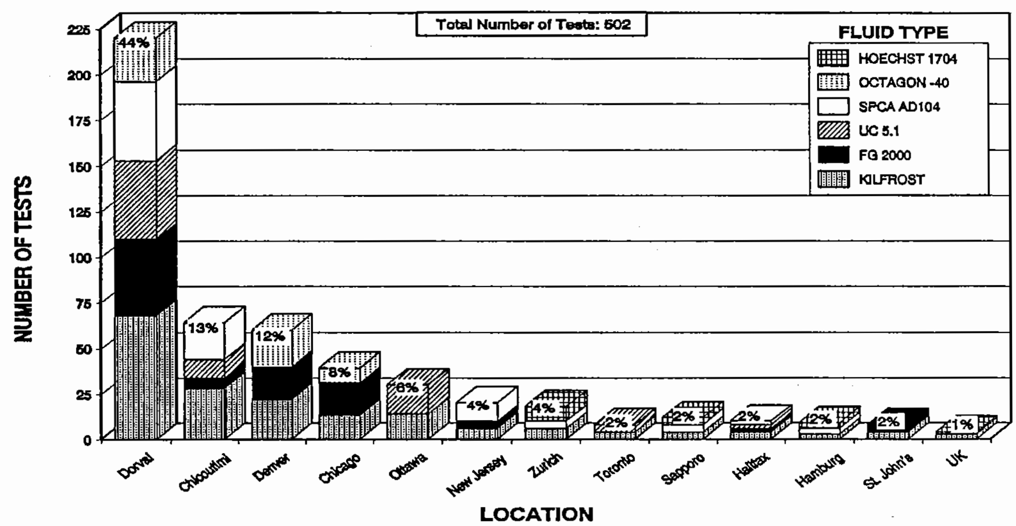
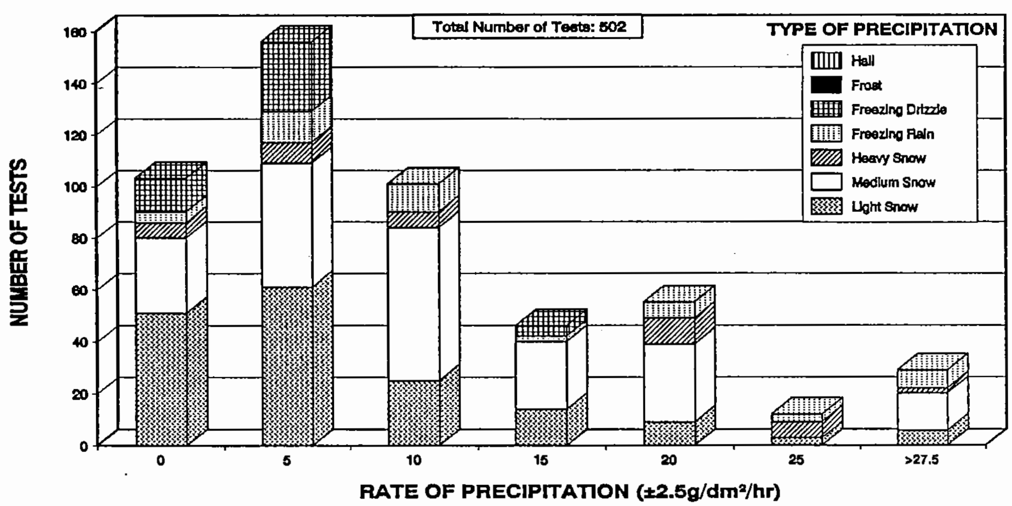


FIGURE 3.3
DISTRIBUTION BY LOCATION AND FLUID TYPE
TYPE II FLUIDS

3.1.3 Frequency of precipitation rates and snowfall classifications

Figure 3.4 shows the distribution of precipitation rates as well as a break down by type of precipitation. It can be seen that the classification of the type of precipitation contained some obvious inconsistencies. Medium and heavy snow were reported at precipitation rates below 5 g/dm²/hr while light snow was reported for precipitation rates above 27.5 g/dm²/hr. There are several reasons why the type of snow may not match the rate. The size of the snow flakes might cause the tester to think that the snow was heavier than was the case. Also the water content of the snow may actually have been very low. The light snow during heavy rates may be due to the snow being mixed with drizzle which would result in a large rate being recorded. In addition, the type of precipitation was recorded at the start of the test and was not necessarily adjusted if the type of precipitation changed during the test.

FIGURE 3.4
DISTRIBUTION OF PRECIPITATION RATES BY PRECIPITATION TYPE
TYPE II FLUIDS



3.1.4 Frequency of meteorological conditions

The distribution of other factors such as temperature, relative humidity and wind speed were within the expected values, as shown in Figures 3.5, 3.6 and 3.7. Air temperatures were mild, mostly between -5°C and +1°C. Winds were present during most tests, though tests were not performed in winds above 27.5 mph. The relative humidity was generally above 80%, however there were a number of tests which recorded relative humidities below 55%. One possible explanation for this is that the hygrometer had a response time of 30-45 minutes. If the testers did not allow sufficient time for the hygrometer to reach a steady state before beginning the test, errors in measurement would occur.

3.1.5 Frequency of failure modes

As presented in Figure 3.8, the failure mode for the majority of tests (57%) was due to snow accumulation. Ice Formation was the failure mode 26% of the time, and loss of gloss accounted for the remaining 17%.

FIGURE 3.5
DISTRIBUTION OF AIR TEMPERATURES
TYPE II FLUIDS

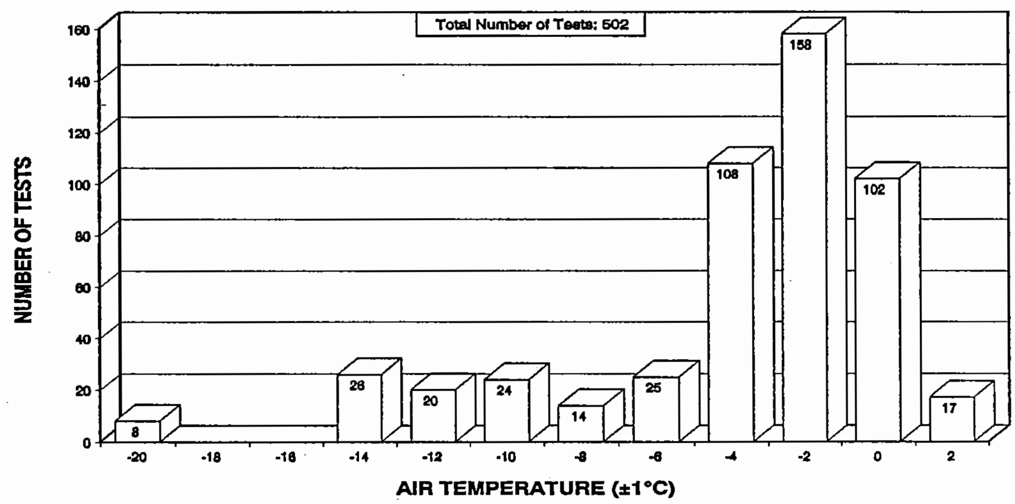


FIGURE 3.6
DISTRIBUTION OF RELATIVE HUMIDITY
TYPE II FLUIDS

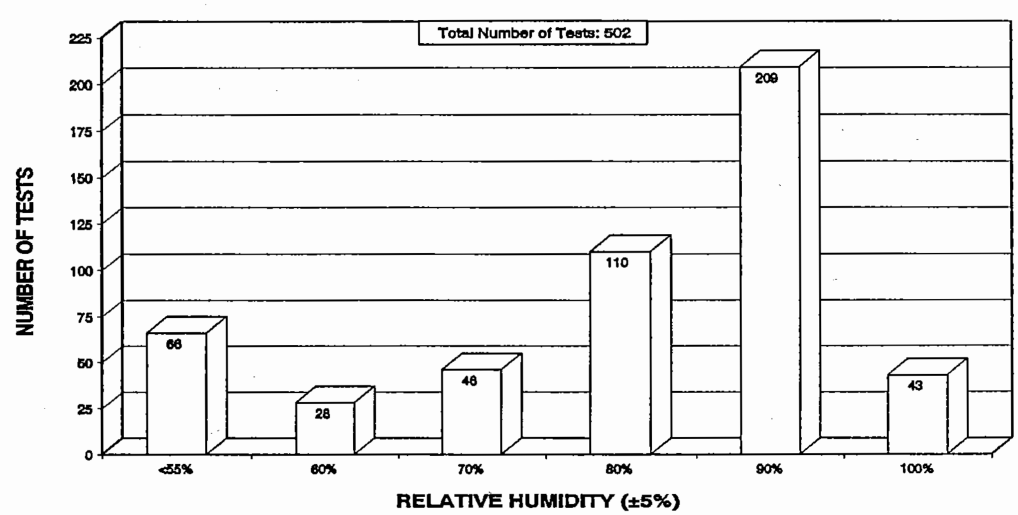


FIGURE 3.7
DISTRIBUTION OF WIND SPEED
TYPE II FLUIDS

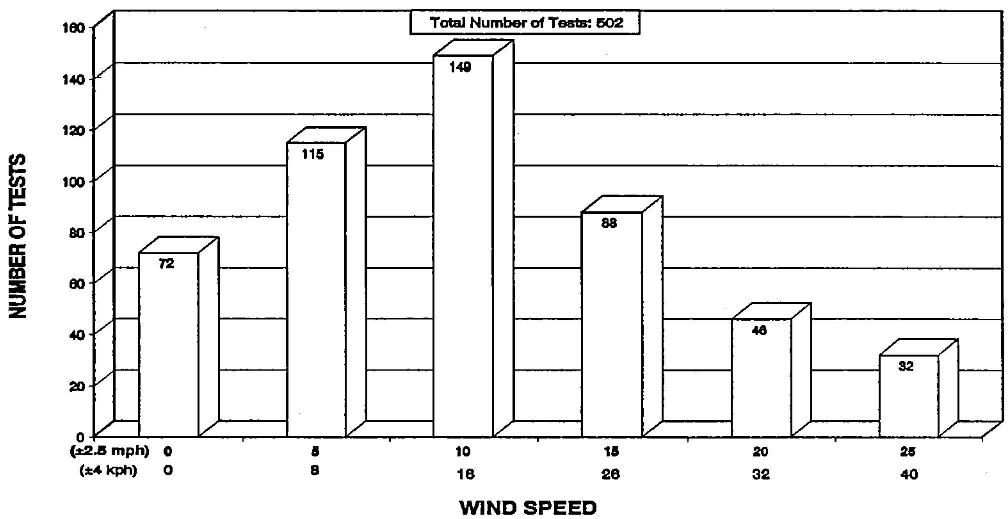
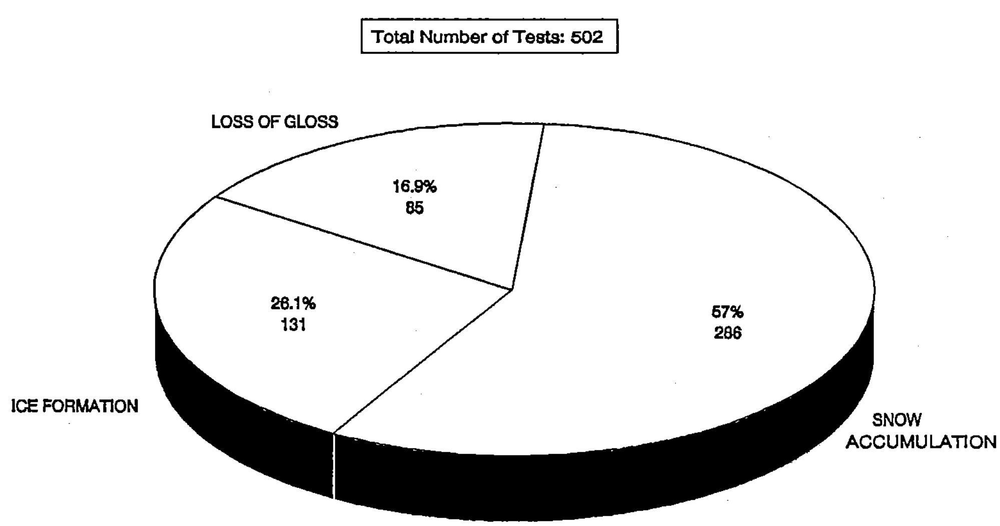


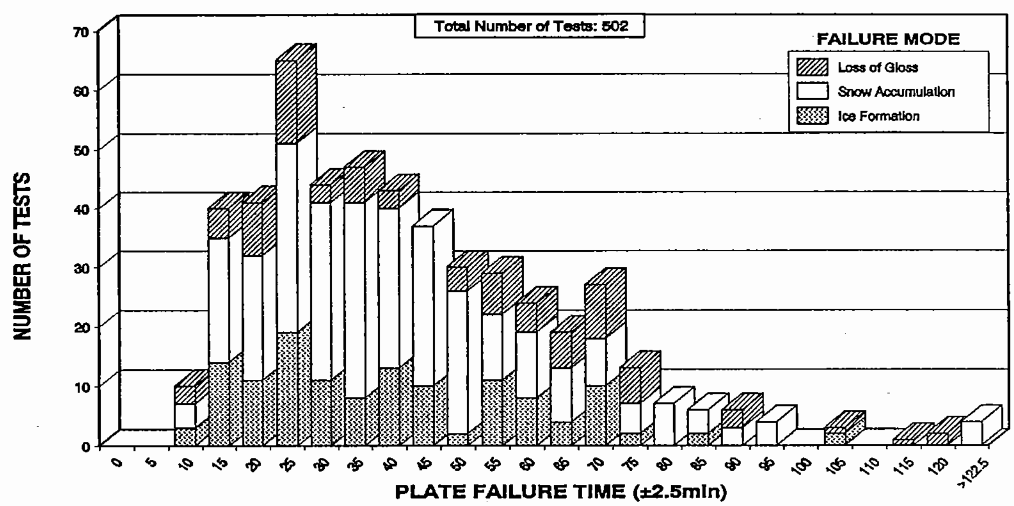
FIGURE 3.8
DISTRIBUTION OF FAILURE MODE
TYPE II FLUIDS



3.1.6 Distribution of failure times

The distribution of failure times is shown in Figure 3.9. The failure modes have been identified within the distribution. A more detailed analysis relating this figure to the European tables is presented in Section 4.3 of this report.

FIGURE 3.9
DISTRIBUTION OF FAILURE TIME BY FAILURE MODE
TYPE II FLUIDS

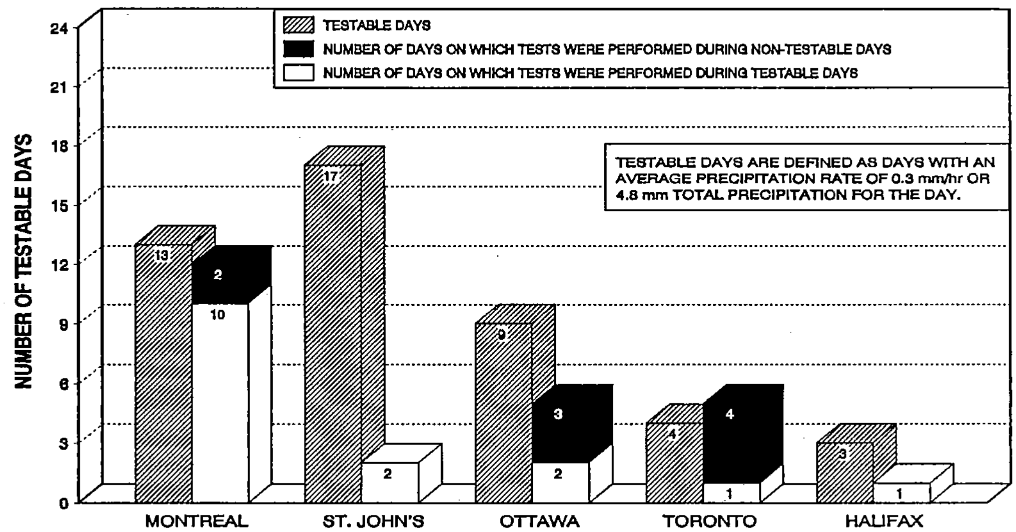


3.2 Meteorological Analysis

With the assistance of Atmospheric Environment Services Canada, the Consultants were able to obtain relatively detailed meteorological information for all of the Canadian sites except Chicoutimi. This data was used to determine days on which tests could have taken place.

It was found that, from January to March 1991, the number of testable days at the Canadian sites varied from three to 17. For fluid testing it was assumed that a testable day required a minimum of 3 g/dm²/hr averaged throughout the precipitation period. For an individual hour, this value would be too low to obtain usable test data but with the inherent fluctuations during an extended period of precipitation, acceptable test results should be obtainable. For sites where the hourly rate could not be computed, (Halifax and St. John's), a 48 g/dm² total precipitation was set as the minimum lower limit. This is equivalent to 4.8 millimetres of liquid precipitation which is equivalent to about 3 to 7 cm of snow depending on the moisture content of the snow. While this value may exclude some testable days and include some non-testable days, it was felt to be a reasonable cut off point. Figure 3.10 displays the distribution and various success rates of testable days at the five Canadian sites.

FIGURE 3.10
NUMBER OF TESTABLE DAYS
JANUARY 1991 TO MARCH 1991



Toronto, with only four testable days, only tested on one of those days. Four other tests were performed on days classified as non-testable and were characterized by failure times of two or three hours duration.

Ottawa, which had nine testable days, performed tests on two of those days. Tests were performed on three other days, which resulted in failure times in excess of 70 minutes. One usable test was performed during a short burst of precipitation which was not covered by the definition of a testable day. The Ottawa students may not have been able to test during the evening, which is when the precipitation occurred for a majority of the missed testable days.

Halifax, with only three testable days, managed to test on one of those days. During the testing season, the majority of the precipitation fell as rain. Halifax's climate was very warm during the winter season with monthly average highs ranging from -1°C to +5°C. During the 1990-1991 winter season, Halifax received less than 60% of its normal snowfall.

St. John's had 17 testable days but only tested on two of these days. Five of the testable days occurred before the end of January, when the site was first ready. Another problem at the St. John's site was the wind. The average wind speeds went as high as 70 kph with sustained maximum wind speeds of 89 kph. Average wind speeds over 25 kph with maximum sustained winds over 45 kph proved to be too strong to install the cover or perform tests on a majority of untested "testable" days.

Montreal had thirteen testable days and performed tests on ten of those days. Montreal, the test coordination centre, was the first site ready to perform testing. Montreal also had the most available people to staff the site. Seven APS professionals, including the project coordinator and project manager, plus four additional students tested at various times throughout the winter.

While meteorological information was not obtained for Chicoutimi, it should be noted that Chicoutimi was the second most proficient site in the worldwide program. It is probable that the site did not miss a large number of testable days.

4. ANALYSIS

Several analyses were performed on the data described in Section 3. The first step was to ascertain whether there were any clearly visible relationships between time to plate failure and any of the other variables. This is documented in Section 4.1. Another analysis tried to establish if any bivariate relationships were visible. This was performed by plotting failure time against total precipitation and one of the other parameters. This is discussed in Section 4.2. Section 4.3 compares the results of all analyses to the values presented in the European holdover tables. Section 4.4 provides an analysis of the Type I.5 data. In Section 4.5, given the results of Sections 4.1 and 4.2, a strictly statistical analysis was performed on a small set of data (Type I.5) to try and root out any complex, interactive relationships between plate failure and the meteorological parameters. The final analysis tried to validate one of the procedural assumptions used in the experimentation. This assumption was that the thickness of the fluid would be constant after five minutes of settling on the plate. This analysis, which provided some rather interesting insight into fluid properties, is presented in Section 4.6.

4.1 General Analysis, Type II Fluids

Failure time was plotted against each variable (as listed in Section 2.6) to determine if failure time could be predicted by one of these variables. This analysis is divided into several sub-sections, one which compares failure time of all Type II data to total precipitation and precipitation rate and another which compares failure time to the rest of the recorded variables. Other sub-sections examine tipping bucket data as well as effects of type of precipitation.

4.1.1 Total precipitation and precipitation rate

Figure 4.1 is a scatter diagram of failure time vs total precipitation for all Type II fluids. The diagram does not seem to indicate that there is a strong relationship between them, and as such, other factors must be influencing failure time.

Figure 4.2 plots the failure time vs the rate of precipitation. This graph indicates an inverse relationship, failure time is reduced as the rate of the precipitation

FIGURE 4.1
SCATTER OF FAILURE TIME vs TOTAL PRECIPITATION
TYPE II FLUIDS

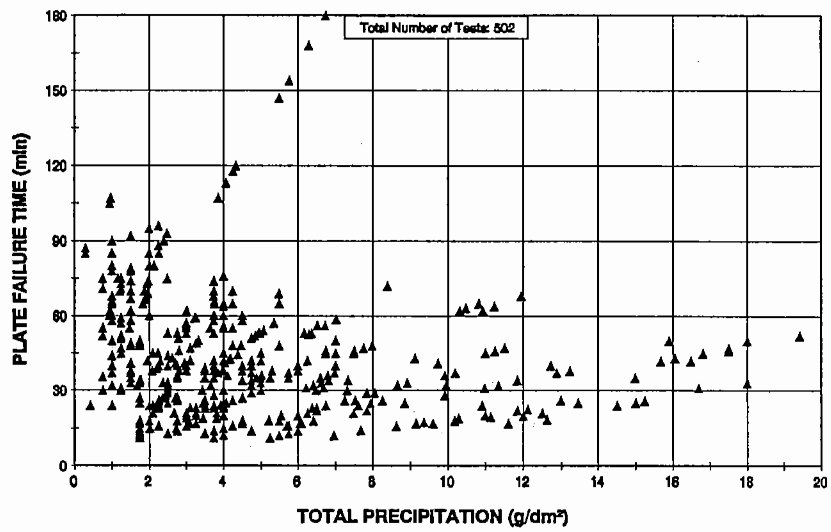
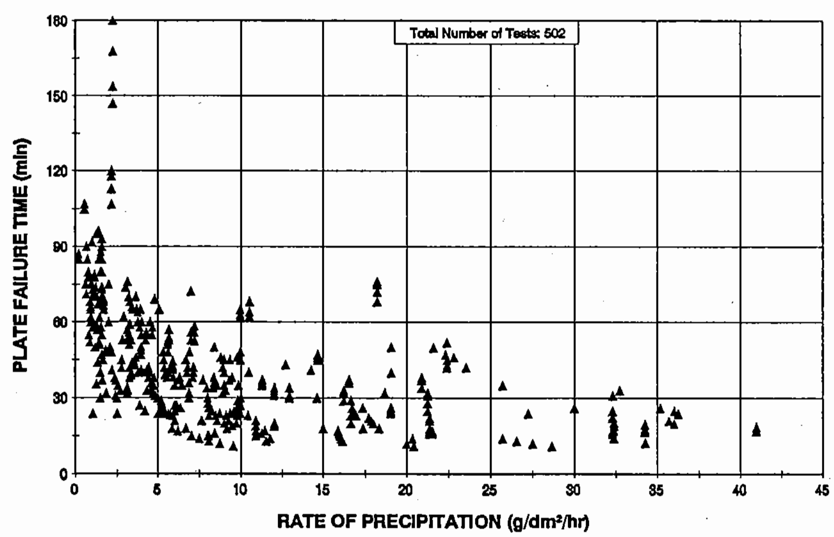


FIGURE 4.2
SCATTER OF FAILURE TIME vs RATE OF PRECIPITATION
TYPE II FLUIDS

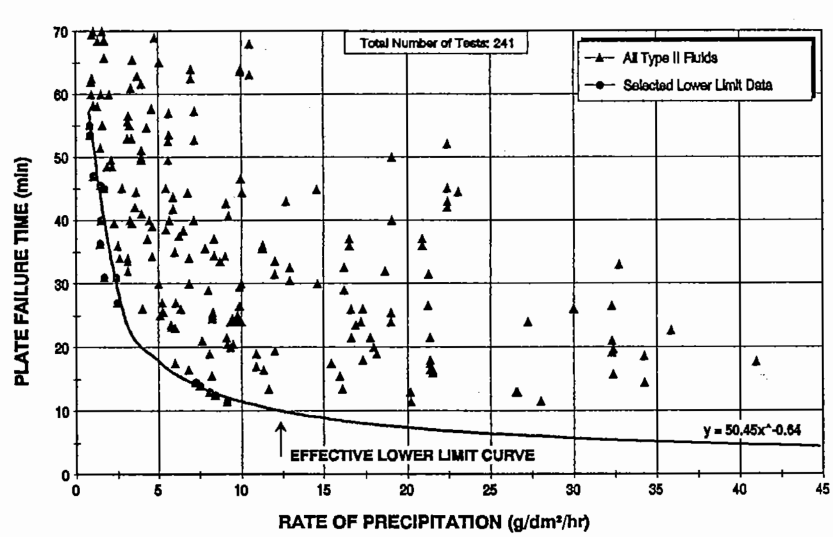


increases. However, the data points are widely scattered and as such, it is not possible to determine a predictor equation for failure time based on precipitation rate which would satisfy a majority of the points.

For each test there were at least two plates (out of 6) with the same fluid. Averaging these data points produced a chart with fewer data points and slightly less scatter. For the remainder of the analysis, the averaged values will be used. Furthermore, all charts produced after this point will have failure time upper bound of 70 minutes, however points above are still considered in the numerical analysis unless otherwise noted.

The data does suggest that there may be a lower boundary or minimum limit to failure time for a given precipitation rate[1]. By subjectively selecting a series of points which appear to accurately describe the lower boundary, and by plotting an exponential regression line through those points it was possible to obtain a predictor equation of the form $Y = 50.45X^{-.64}$ as shown in Figure 4.3. "X" is the measured precipitation rate and "Y" is the predicted lower limit failure time.

FIGURE 4.3
SCATTER OF FAILURE TIME vs RATE OF PRECIPITATION
TYPE II FLUIDS



There are two things to note about this equation. First, the inverse relationship is somewhat artificial. The method in which the precipitation rate was calculated provided the equation with an X^{-1} relationship. This strongly influences the predictor equation. Second, the curve was created after the subjective selection

1. Rate of Precipitation was calculated in one of two ways depending on the method used to collect precipitation. For sites which used the tipping bucket, Rate of Precipitation was calculated as the Total Precipitation collected prior to failure of the plate, divided by the failure time of the plate. For sites which used the cake pan method, the Rate of Precipitation was the total precipitation collected during the tests divided by the time the cake pan was exposed to precipitation.

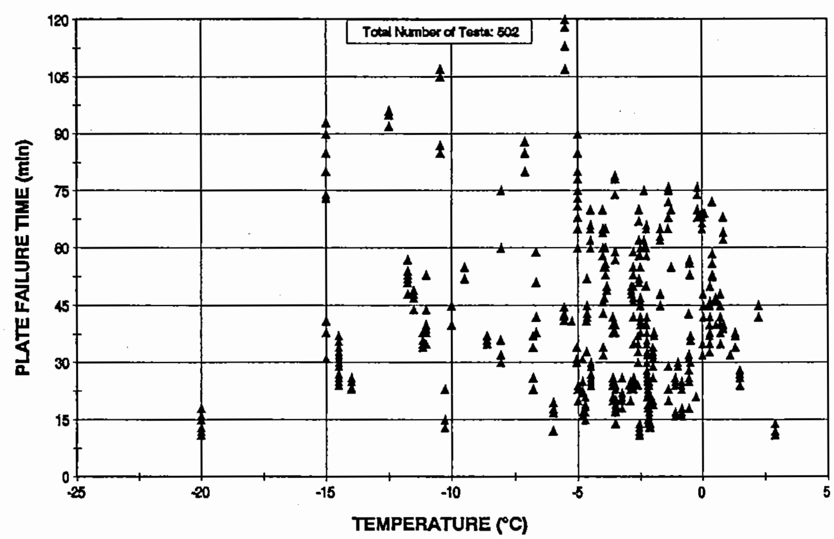
of relevant data points by the Consultants[2]. Other non-selected data may have been relevant.

Although the lower limit curve may have questionable validity, it establishes an extremely important concept. If all of the data collected for this study were such that it could be used to predict actual holdover time, then the average value at a particular rate of precipitation would not be useful. In determining how much holdover time is available to a pilot under a particular set of conditions, an average value which would be correct only half the time, could be very dangerous. The requirement for predicting holdover time should be that such a predicted time would be safe with nearly one hundred percent certainty. Therefore, establishing a conservative lower limit should be the goal of future analyses.

4.1.2 Other data parameters

To determine if any of the other factors had a strong influence on failure time, the other variables were plotted against failure time. Individually, temperature does not appear to have an effect on failure time, as shown in Figure 4.4. On its

FIGURE 4.4
SCATTER OF FAILURE TIME vs TEMPERATURE
TYPE II FLUIDS



[2] The curve was created by plotting the natural log of Failure Time vs the natural log of Rate of Precipitation and choosing the lower points which best described this boundary.

own, wind speed, as shown in Figure 4.5, does not appear to be a contributing factor to failure time.

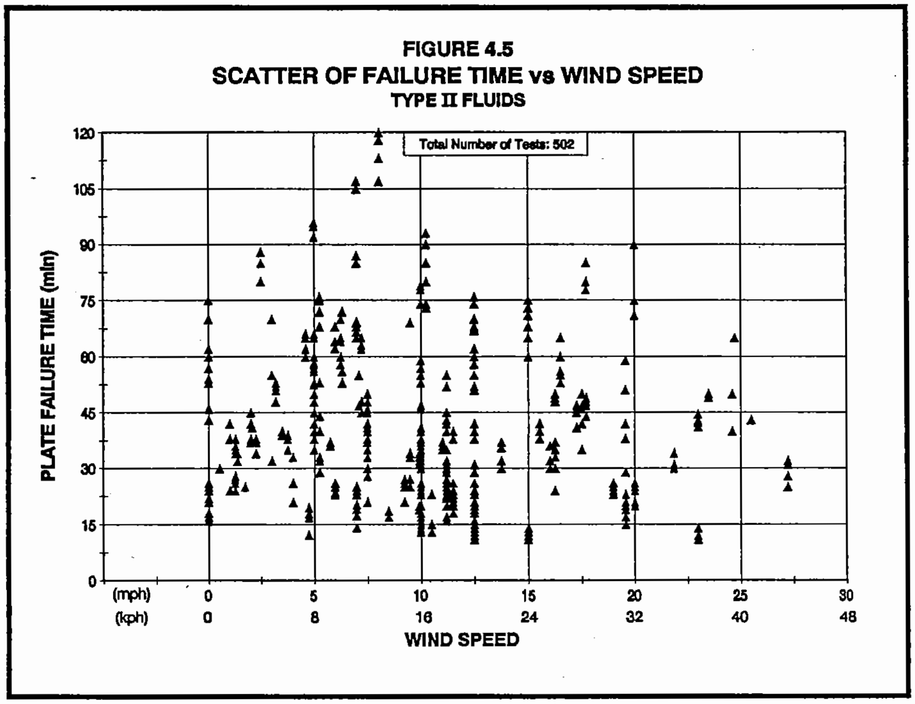
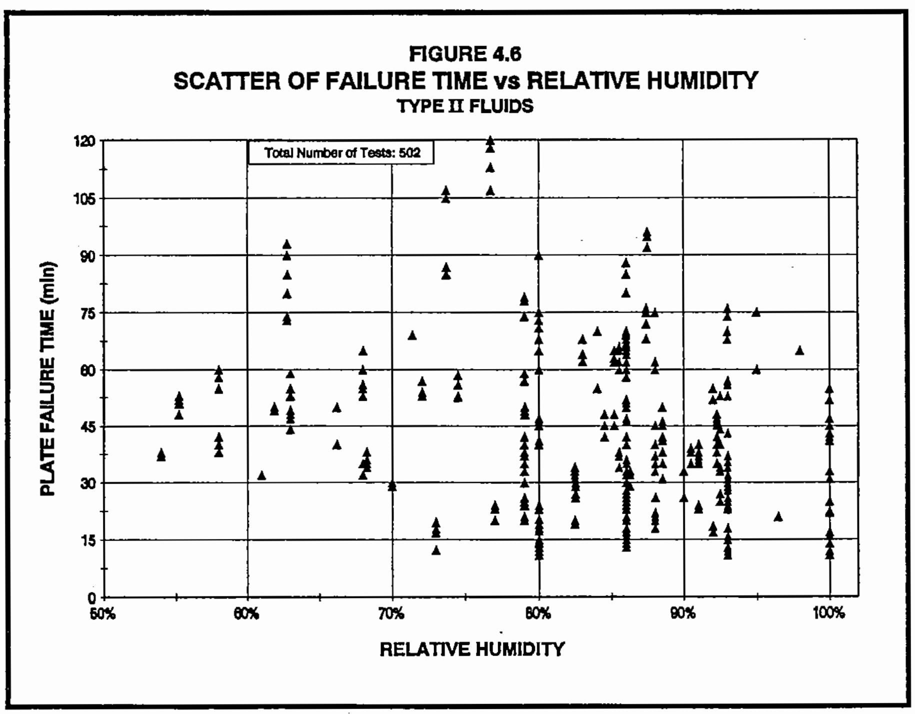


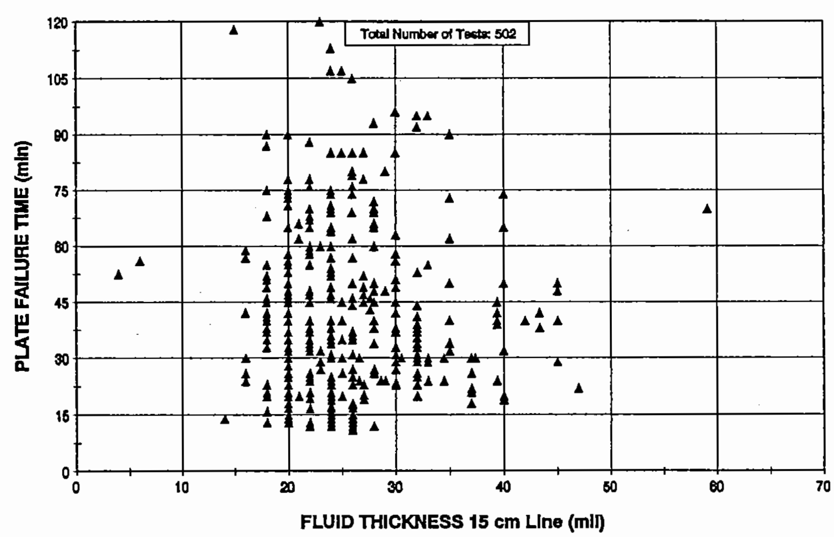
Figure 4.6 plots failure time versus relative humidity. While the data has slightly more form to it, there is not enough to speculate on any possible relationships.



Fluid thickness also does not appear to have any influence on failure time. Figure 4.7 plots failure time against fluid thickness at the 6"(15 cm) line. This is representative of the behaviours at both the 1" (2.5 cm) and 12" (30 cm) lines. A further discussion of fluid thickness is included in Section 4.6.

The data does not show a clear and definite correlation between failure time and any one variable.

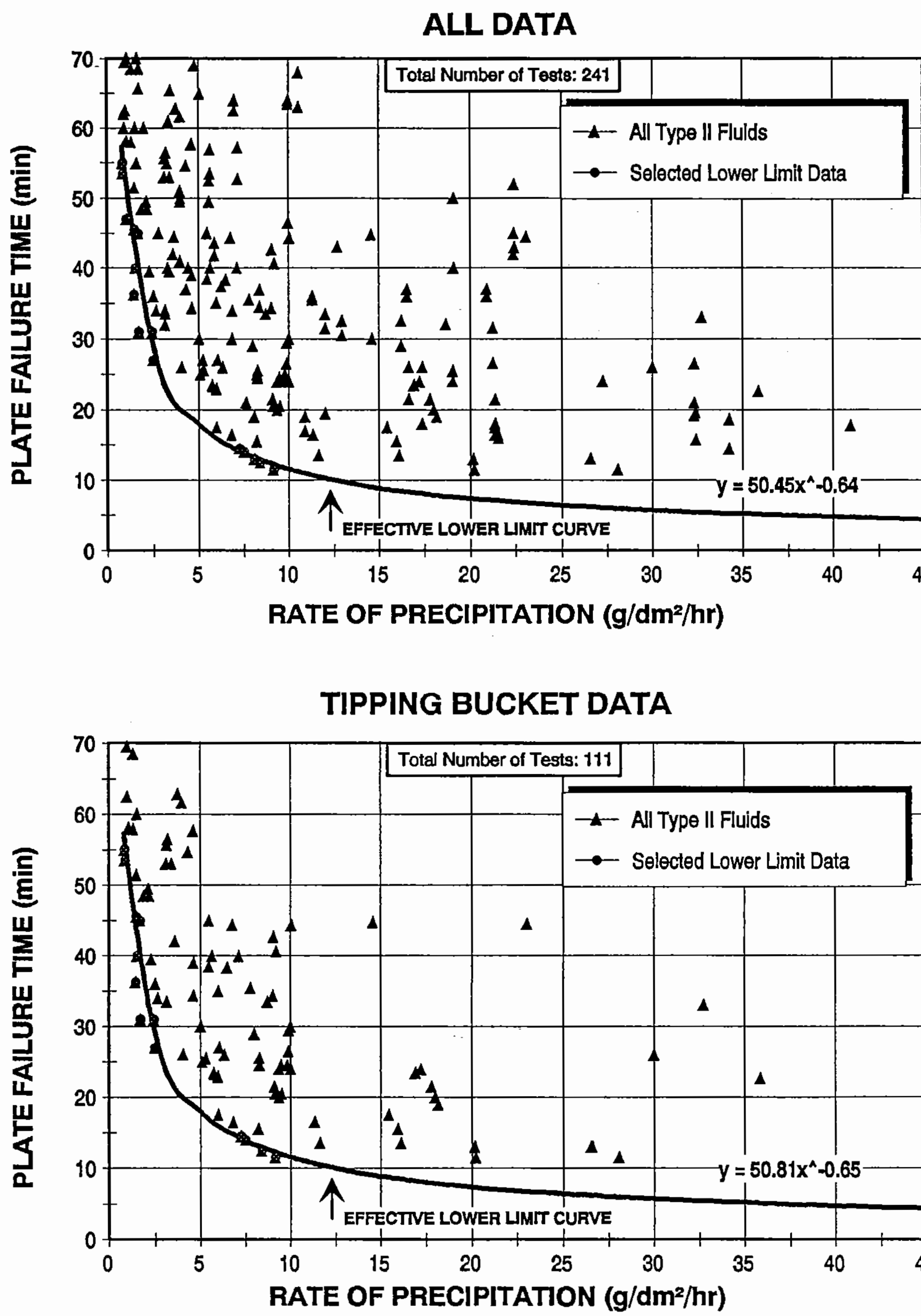
FIGURE 4.7
SCATTER OF FAILURE TIME vs FLUID THICKNESS AT 15 cm LINE
TYPE II FLUIDS



4.1.3 Tipping Bucket Data

Figure 4.8 shows two scatter plots of failure time against rate of precipitation. The case where all collected data points were plotted can be compared to the one with only tipping bucket data plotted. In the latter plot, a significant number of outlying points which were present in the first plot no longer appear. The missing points were measured using the cake pan method. This highlights that using a cake pan is a potential source of inaccuracy. It can be seen that the lower boundary remained essentially unchanged. It should be noted that any analysis beyond this point is presented with tipping bucket data only.

FIGURE 4.8
FAILURE TIME vs RATE OF PRECIPITATION
TYPE II FLUIDS



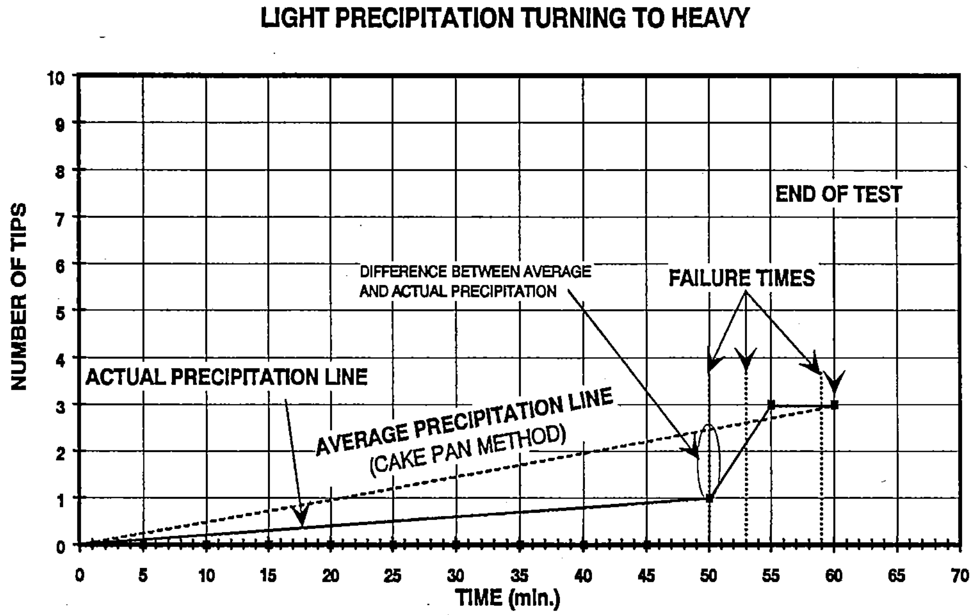
The tipping bucket data was able to provide a history of the precipitation during the test period. While most of the precipitation rates were relatively constant, there were a significant number which had large variations in the rate during a test. There were two types of observed variations. The first was a case where there was light precipitation at the beginning of the test which turned into heavy precipitation near the end. The second was strictly the opposite - heavy precipitation which tapered off as the test progressed. Figure 4.9 provides good examples of each type. The dotted lines in the figures mark the actual plate failure times for different plates during the specific test. The dashed line represents the average precipitation throughout the test. The average precipitation is calculated by dividing the total precipitation collected by the total test time. This is the same method used when precipitation is collected using a cake pan. The difference between the dashed and solid (actual) lines can be very significant depending on the method used. Estimating precipitation using the cake pan method can result in very large errors, in the order of twice or half the actual values.

Each tipping bucket test history was examined individually in order to obtain a reasonable approximation of the actual precipitation. For the specific values of total precipitation involved in this analysis, the tipping bucket data was "corrected" to account for variations such as those described in Figure 4.9. The "corrected" value attempted to assess the effect of the variation in the rate of precipitation throughout a test. There may still exist smaller inaccuracies, even after this adjustment, due to the coarseness of the tipping bucket.

4.1.4 Effects of Precipitation Type

Precipitation was divided into two types: snow conditions and freezing rain/drizzle. Figure 4.10 compares the failure time vs precipitation rate for each type of precipitation. Freezing rain/drizzle accounted for most of the high precipitation rates. It was also expected that freezing rain conditions would result in lower failure times. The effective lower limit curves do not support this hypothesis but it should be noted that there were relatively few points used the calculation of the freezing rain lower limit curve. The location of this curve would undoubtedly shift if more data were available.

FIGURE 4.9
TIPPING BUCKET COLLECTION CURVE



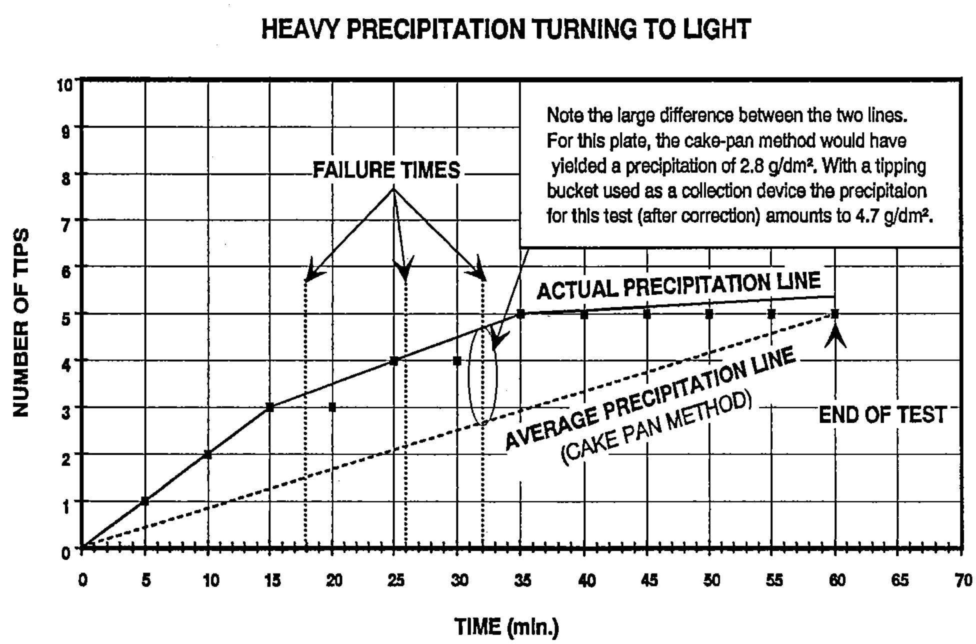


FIGURE 4.10
FAILURE TIME vs RATE OF PRECIPITATION
TYPE II FLUIDS

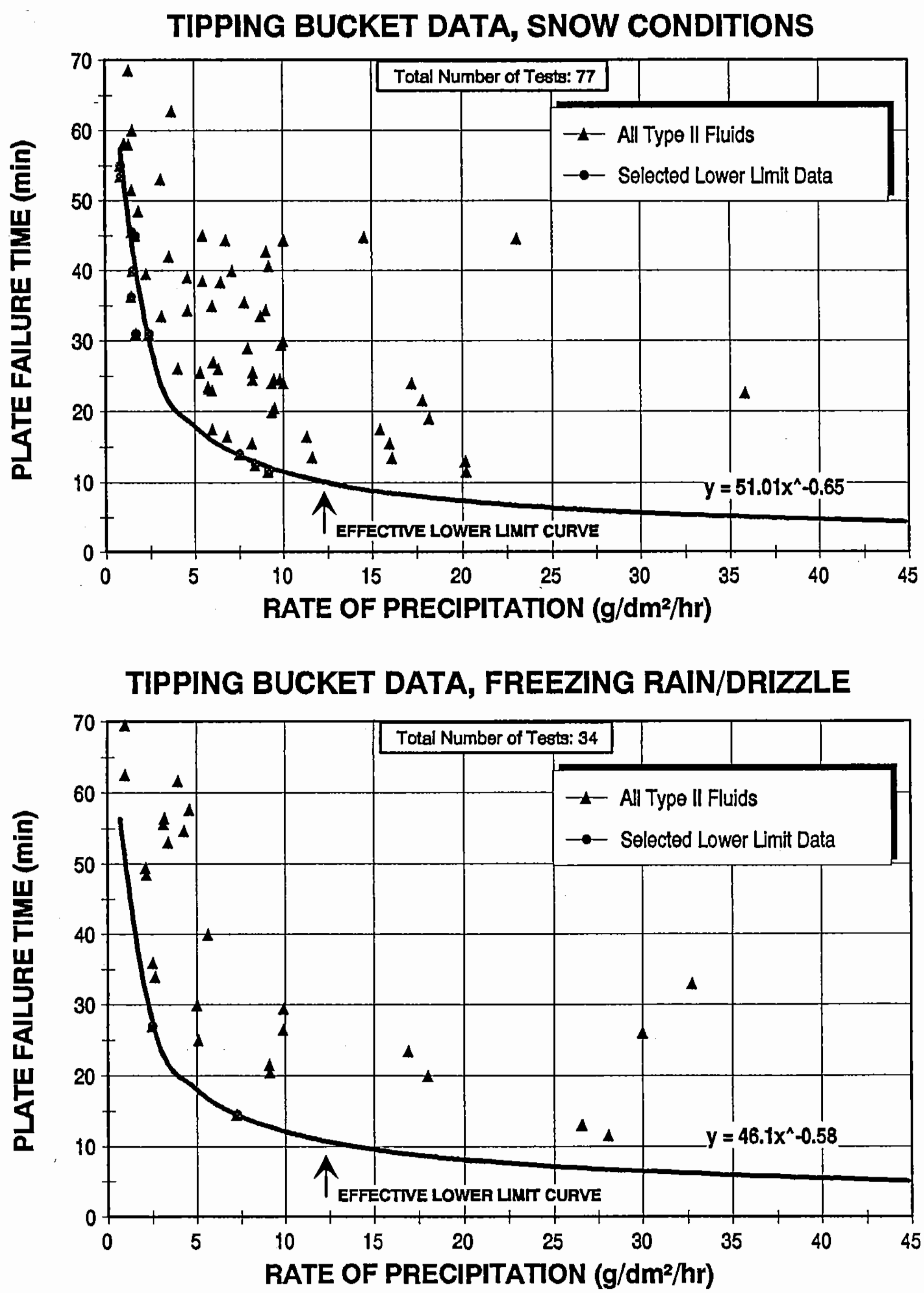
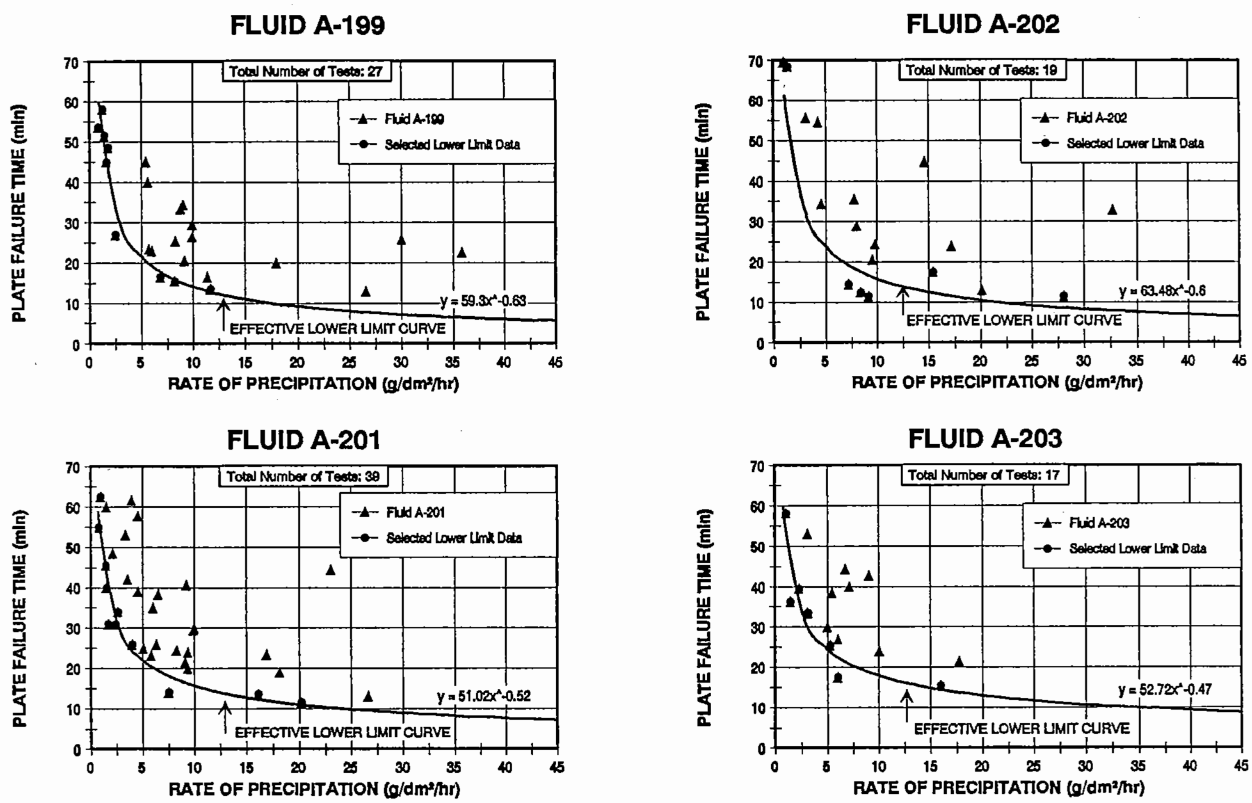


Figure 4.11 breaks the graphs by fluid type. There seems to be variations between the results of different types of fluids although the general behaviours are consistent.

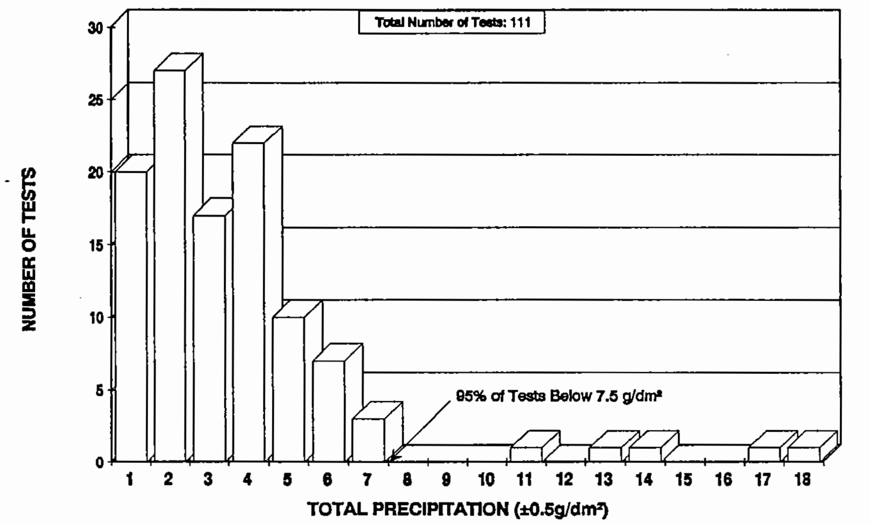
FIGURE 4.11
FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA



4.1.5 Upper Bound of Precipitation

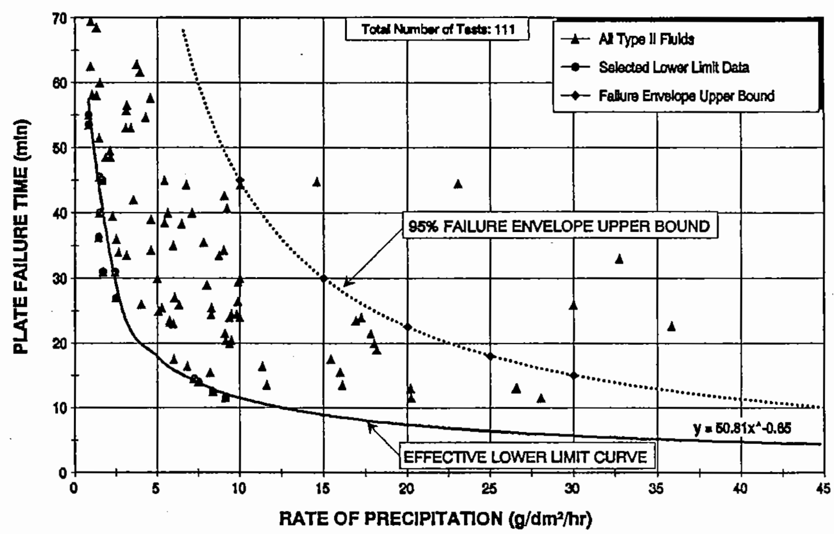
In the Failure Time vs Total Precipitation graphs, there appeared to be an upper level of precipitation for the tests. Figure 4.12 indicates that for 95% of the time, failure occurred before 7.5 g/dm² had accumulated on the plate. For Type I.5 fluids, discussed in a subsequent section, 95% of the failures occur before 5.5 g/dm². If one combines this upper limit with the selected lower bound defined

FIGURE 4.12
DISTRIBUTION OF TOTAL PRECIPITATION
TIPPING BUCKET DATA, TYPE II FLUIDS



earlier, the failure time will, in the majority of cases, fall between the envelope delineated by these two extremes as shown in Figure 4.13.

FIGURE 4.13
SCATTER OF FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA, TYPE II FLUIDS



4.1.6 Other Scatter Diagrams

Appendix B plots the graphs for Failure Time vs Rate of Precipitation for various types of data. The data was separated into 3 categories: 1) All Data; 2) Tipping Bucket Data; 3) Dorval Data. Each of these categories was further broken down by weather type (ie. All Weather, Snow Conditions or Freezing Rain/Drizzle). Individual fluids were examined within each of these divisions so as to exhaust all possibilities. The entire process was repeated for Failure Time vs Total Precipitation. A comprehensive list of all 92 plots produced for Appendix B is given in Table 4.1.

TABLE 4.1

LIST OF GRAPHS CONTAINED IN APPENDIX B

			NUMBER OF GRAPHS	ALL TYPE II	ALL TYPE 1.5	A-199 FLUID	A-201 FLUID	A-202 FLUID	A-203 FLUID	A-205 FLUID
RATE OF PRECIPITATION	ALL DATA	ALL WEATHER	7	*	*	*	*	*	*	*
		SNOW CONDITIONS	7	*	*	*	*	*	*	*
		FREEZING RAIN/DRIZZLE	5	*	*	*	*	*		
	TIPPING BUCKET DATA	ALL WEATHER	6	*	*	*	*	*	*	
		SNOW CONDITIONS	6	*	*	*	*	*	*	
		FREEZING RAIN/DRIZZLE	2	*			*			
	DORVAL DATA	ALL WEATHER	6	*	*	*	*	*	*	
		SNOW CONDITIONS	5	*	*	*	*		*	
		FREEZING RAIN/DRIZZLE	2	*			*			
TOTAL PRECIPITATION	ALL DATA	ALL WEATHER	7	*	*	*	*	*	*	*
		SNOW CONDITIONS	7	*	*	*	*	*	*	*
		FREEZING RAIN/DRIZZLE	5	*	*	*	*	*		
	TIPPING BUCKET DATA	ALL WEATHER	6	*	*	*	*	*	*	
		SNOW CONDITIONS	6	*	*	*	*	*	*	
		FREEZING RAIN/DRIZZLE	2	*			*			
	DORVAL DATA	ALL WEATHER	6	*	*	*	*	*	*	
		SNOW CONDITIONS	5	*	*	*	*		*	
		FREEZING RAIN/DRIZZLE	2	*			*			
		TOTAL	92							

4.2 Secondary Analysis, Type II Fluids

This analysis tried to establish if any bivariate relationships were visible. This was performed by plotting failure time against either rate of precipitation or total precipitation, and one of the other parameters.

For this section, only the Dorval data is being considered, as it may be possible to remove some of the inherent variability caused by having different individuals perform testing. While many individuals participated in the Dorval testing, the supervision and control was at a very high level.

Plotting failure time vs rate of precipitation/total precipitation and identifying the variables within the graph may expose any secondary relationships that exist. This is examined further in the following sub-sections.

4.2.1 Wind Effect

Figure 4.14 examines the effect of wind on the failure time vs rate of precipitation/ total precipitation graph. Short failure times (below 20 min.) were associated with winds above 10 mph (16 kph). Although some tests with longer failure times also had high winds, no short failure times occurred with winds below 10 mph (16 kph).

4.2.2 Fluid Type Effect - All Fluids

Figure 4.15 identifies the different fluids within the failure time vs rate of precipitation/total precipitation graph. Each of the fluids seemed to be well distributed throughout the graph.

4.2.3 Other Variables

The effects of temperature, relative humidity, fluid thickness and failure modes were examined in this bivariate analysis. As the results did not indicate any significant relationship, these graphs are left for Appendix C.

FIGURE 4.14
DORVAL DATA, TYPE II FLUIDS

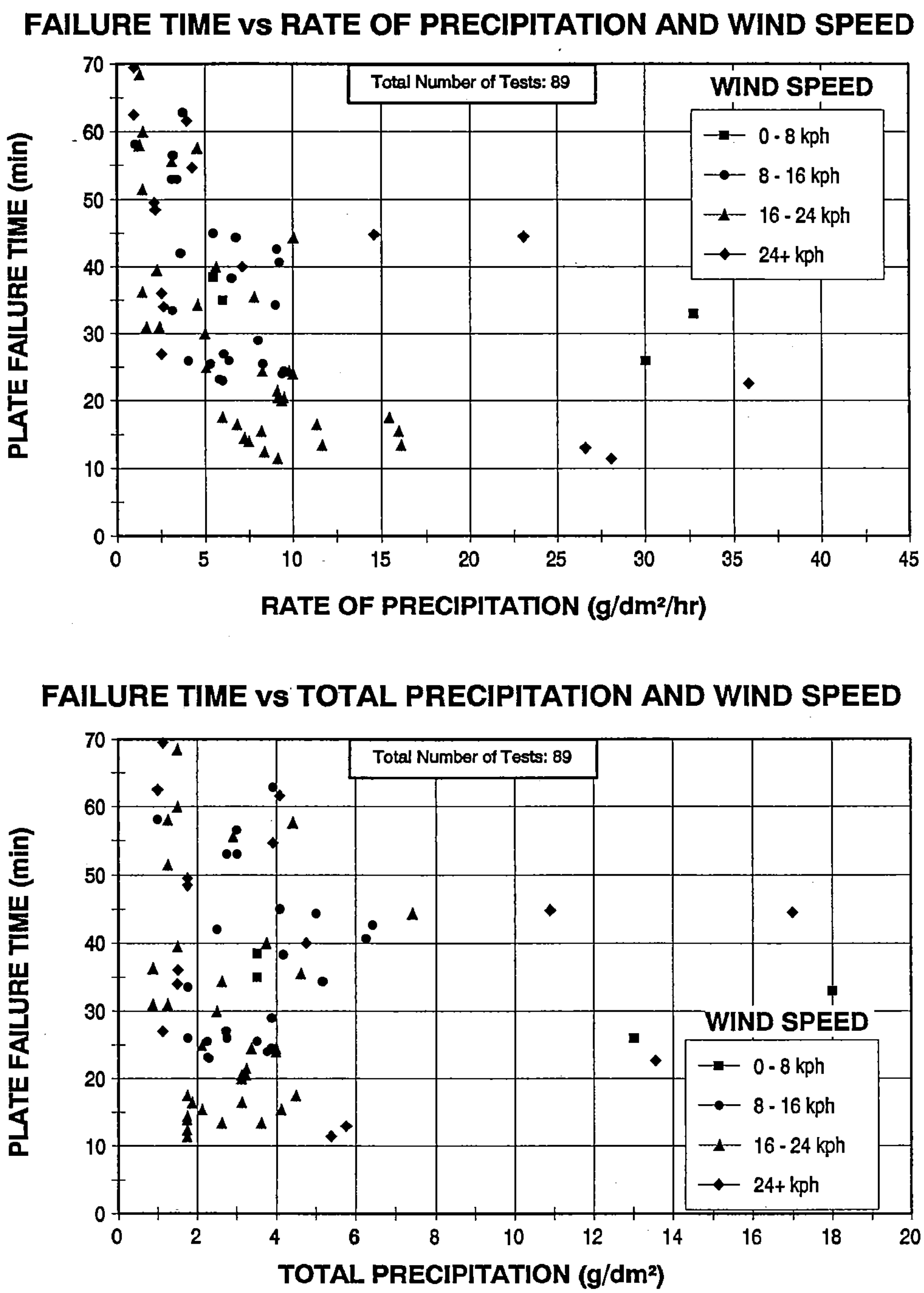
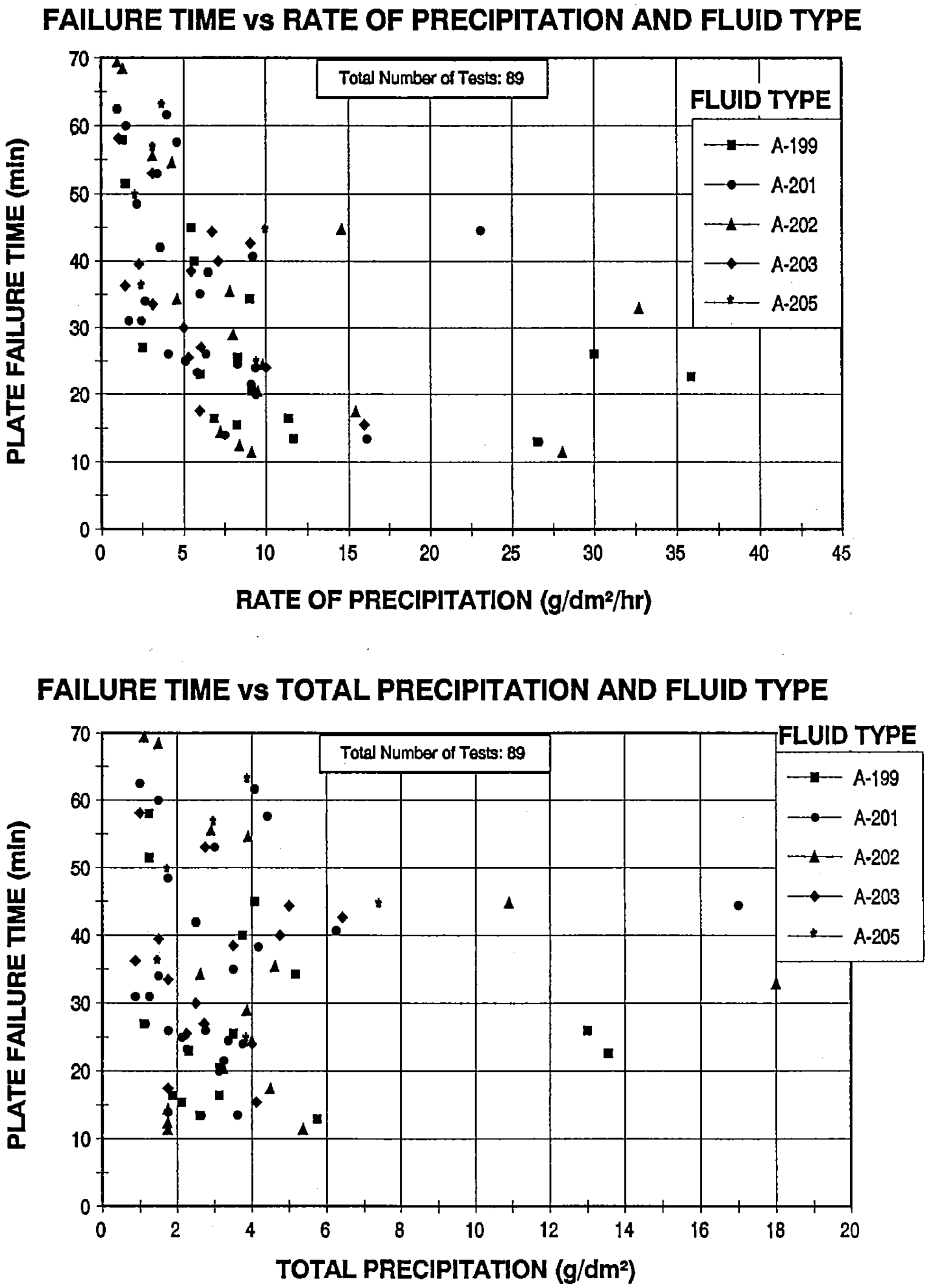


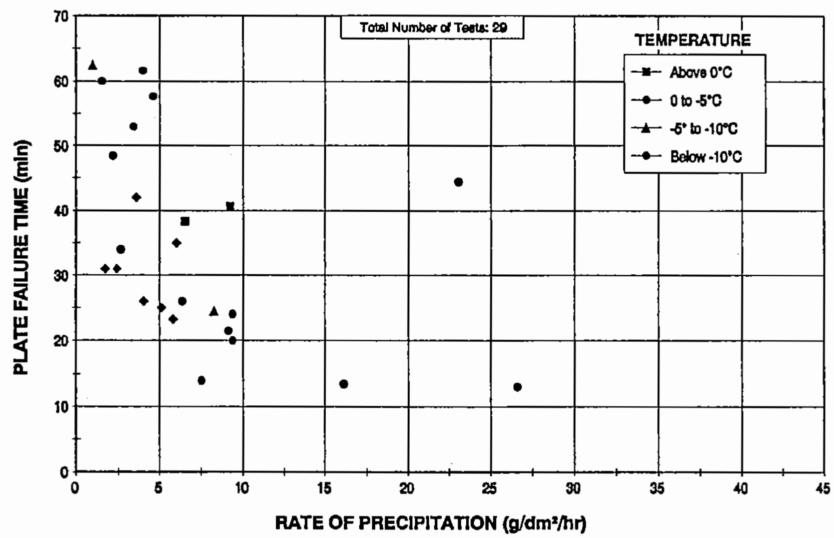
FIGURE 4.15
DORVAL DATA, TYPE II FLUIDS



4.2.4 Example of Individual Fluid: A-201

In order to determine if there were any patterns for failure time hidden within a fluid, individual fluids were analyzed. One example of this is fluid A-201 at Dorval. In Figure 4.16, fluid A-201 was plotted with identifiers for different temperature ranges. The graph does not indicate any trends due to temperature. Plots of the same fluid, with identifiers for wind speed and relative humidity, were also examined, however, as the two graphs do not expose any hidden trends or relationships, these figures are left for Appendix C.

FIGURE 4.16
FAILURE TIME vs PRECIPITATION AND TEMPERATURE
DORVAL DATA, FLUID A-201



4.3 Comparison with AEA/ISO Tables

This section includes a discussion of the European AEA/ISO in 1990, holdover guidline table, and a comparison of the table with the study data.

4.3.1 Discussion of AEA/ISO Table

The guidelines for holdover times (Type II fluids) used by the AEA/ISO, are presented in Table 4.2. Relevant data points are encircled on the table. Three distinct holdover times emerge from this table:

- For steady snow at outside air temperatures above 0°C, the 100% concentrated Type II fluid holdover time is 1 hour (60 minutes);
- For steady snow below the freezing point, the holdover time is 45 minutes;
- For freezing rain precipitation, at any temperature, the holdover value is listed as 20 minutes.

There are notes, cautions and disclaimers at the bottom of the table which indicate that:

- The guidelines are for general information purposes only;
- The information has not been fully substantiated;
- The information should be treated with caution;
- The information should only be used in conjunction with a visual inspection prior to takeoff;
- The time of protection will be shortened in heavy weather conditions;
- The protective film may be degraded by high wind velocity or jet blast;

TABLE 4.2
GUIDELINE FOR HOLDOVER TIMES ACHIEVED BY ISO TYPE II FLUID MIXTURES IN DEPENDENCE OF WEATHER CONDITIONS

(1990 VALUES)

OAT (deg C)	ISO TYPE II FLUID MIXTURE CONCENTRATION NEAT-FLUID/WATER (VOL % / VOL %)	WEATHER CONDITIONS				
		FROST	FREEZING FOG	STEADY SNOW	FREEZING RAIN	RAIN ON COLD SOAKED WING
+ 0 and above	100 / 0	12 h	3 h	1 h	20 min	1 h
	75 / 25	6 h	2 h	45 min	10 min	45 min
	50 / 50	4 h	1.5 h	30 min	5 min	30 min
- 0 to - 7	100 / 0	8 h	1.5 h	45 min	20 min	
	75 / 25	5 h	1 h	30 min	10 min	
	50 / 50	3 h	45 min	15 min	3 min	
- 8 to - 14	100 / 0	8 h	1.5 h	45 min		
	75 / 25	5 h	1 h	30 min		
	50 / 50					
- 15 to - 25	100 / 0	8 h	1.5 h	45 min		
	75 / 25					
	50 / 50					

The time of protection will be shortened in heavy weather conditions. High wind velocity and jet blast may cause a degradation of the protective film. If these conditions occur, the time of protection may be shortened considerably. This is also the case when the fuel temperature is significantly lower than OAT (i.e. 10°C or more).

CAUTION: The times of protection represented in these tables are for general information purposes only, have not been fully substantiated, should be treated with caution and should be used only in conjunction with a visual pretakeoff inspection.

min = minutes
C = Celcius
h = hours
OAT = Outside Air Temperature

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

DATA POINTS RELEVANT TO THIS ANALYSIS

- The time of protection may be shortened considerably when the fuel temperature is significantly lower than outside air temperature.

In themselves, these notes should be sufficient to raise serious doubt about the usefulness of the tabulated numbers. In addition to the above, there is no definition of ''steady snow'' or ''heavy weather conditions''. Although not indicated on the AEA/ISO table, it is believed that ''steady snow'' refers to snow falling at the rate of five grams per square decimeter per hour which is equivalent to 0.5 millimetres of liquid precipitation per hour. This would equate to between 0.25 to 0.75 centimetres of snow per hour depending on the water content of the snow. This is not an excessive amount of snow. Heavy weather should therefore be thought of as any rate of snowfall appreciably above this value. Also, as the limits for high wind are undefined, it can be assumed that any significant wind will degrade the performance of the fluid. Lastly, over a time interval of 45 minutes or an hour, most snowfalls do not occur in a ''steady'' fashion, even if falling at an average rate of five grams per square decimeter per hour. This may result in some degradation of the fluid performance values.

Given the fact that the notes and cautions seem to describe natural conditions during a period of snowfall (eg. heavy weather conditions, high wind velocity, ''unsteady'' snow), it would seem that the most relevant comment which could be made about the European tables is that they can be used as an ideal upper bound to a holdover envelope. This type of presentation concept should not be used when dealing with issues of safety.

4.3.2 Comparison with study data

It is possible to compare these European values to data collected for this study. While it has not been established that the data collected is representative of holdover time, this is also true of the procedure involved in the composition of the European holdover table.

From the data collected for this report, the minimum and average failure times have been listed against the AEA/ISO values for both snow and freezing rain in Table 4.3. For a reasonable comparison, the snow values used were those with rates of precipitation of 5 ± 2.5 g/dm²/hr.

From Table 4.3, it is obvious that the snow values on the AEA/ISO table are unrealistic. While they may be reasonably close to the upper limit of the failure envelope, this is certainly an inappropriate way to present guideline values. For reasons of safety, any published values should be more representative of minimum holdover times. The notes at the bottom of the table should not indicate that the values may be worse under certain conditions, but rather that under certain ideal conditions, the fluid may perform better than indicated.

TABLE 4.3

COMPARISON OF TEST FAILURE TIMES AND AEA/ISO HOLDOVER VALUES
DORVAL DATA, TYPE II FLUIDS
(@ 5 ±2.5gm/dm²/hr)

TEMPERATURE (°C)	SNOW		
	TEST RESULTS - (MINUTES) MINIMUM	AVERAGE	AEA VALUE (MINUTES)
ABOVE 0	38.3	42.6	60
BELOW 0	14	31.6	45

TEMPERATURE (°C)	FREEZING RAIN		
	TEST RESULTS - (MINUTES) MINIMUM	AVERAGE	AEA VALUE (MINUTES)
ABOVE 0	-	-	20
BELOW 0	11.5	37.6	20

The AEA/ISO values for freezing rain correspond somewhat better to the study results, although again, a more conservative approach in the presentation of data would have been more appropriate.

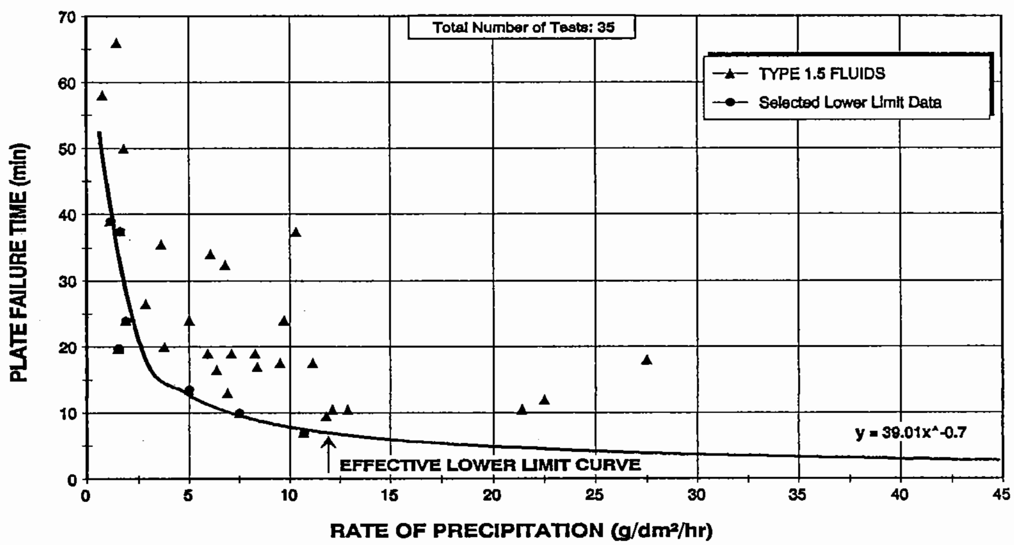
4.3.3 Summary

It should be reiterated that the relationship between holdover time and the failure time obtained during the tests performed for this study has yet to be determined. Nevertheless, the wide differences between the results obtained and the AEA/ISO tables, coupled with the evident flaws in the concept of presentation in the AEA/ISO tables, should result in the AEA/ISO tables not being adopted for use in North America.

4.4 General Analysis, Type 1.5 Fluids

Type 1.5 fluids fall between Type I and Type II fluids in terms of anti-icing capability. These fluids were tested exclusively at the Canadian sites. As can be seen in Figure 4.17, the Type 1.5 fluids can be used to produce a lower limit curve similar to that produced for Type II fluids, except that the curve is shifted down. The following sub-sections examine the effects of temperature, wind and relative humidity on the plate failure times for the Type 1.5 fluid data.

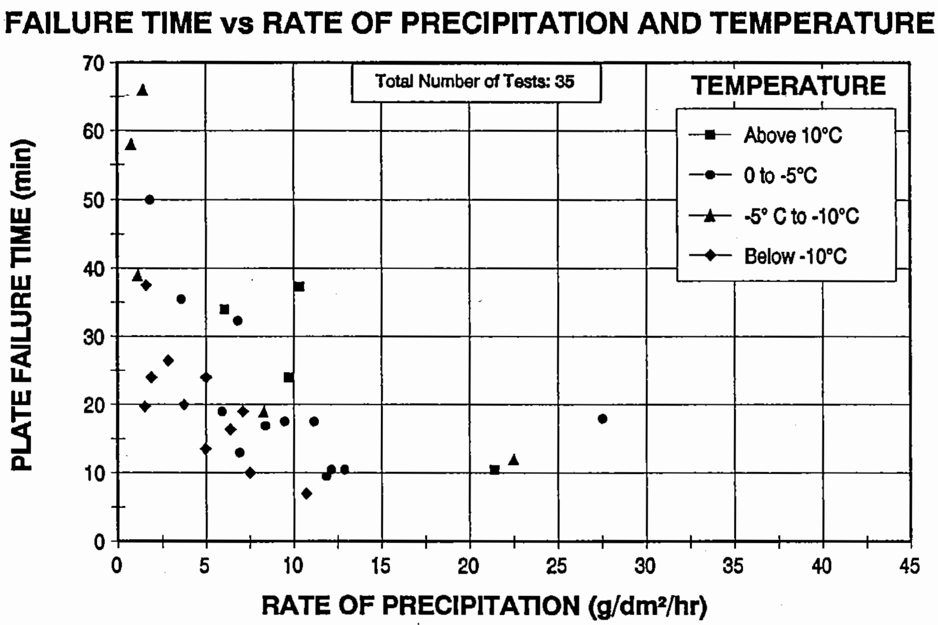
FIGURE 4.17
FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA, TYPE 1.5 FLUID

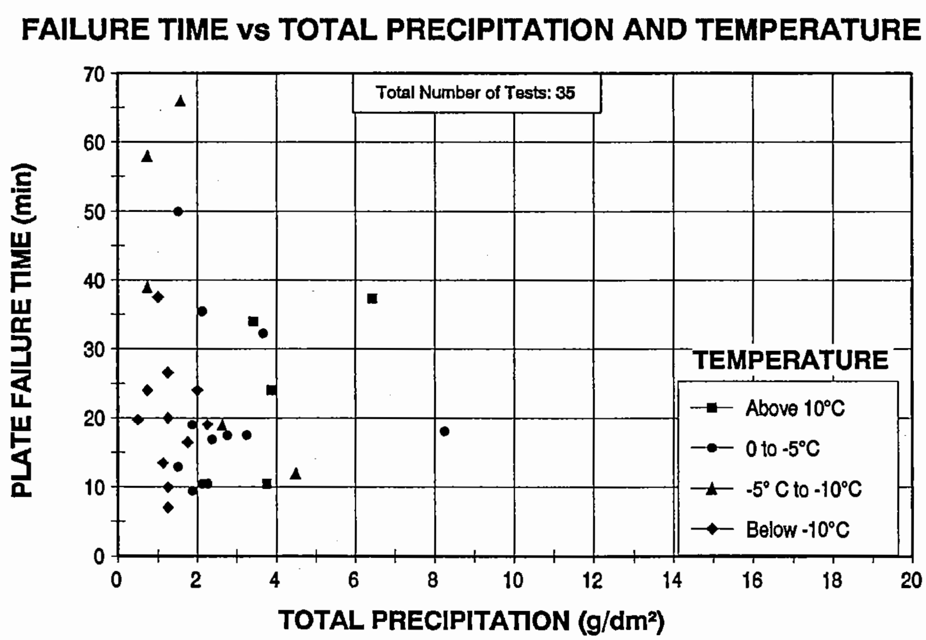


4.4.1 Temperature Effect

In Figure 4.18, the graph of failure time vs precipitation, as a function of temperature, there is an indication that the majority of selected lower boundary points had temperatures below -10°C. This would indicate that the performance of these fluids may be influenced by temperature.

FIGURE 4.18
TIPPING BUCKET DATA, TYPE 1.5 FLUID





4.4.2 Wind Effects

Closer examination of the selected lower boundary points, in Figure 4.19, reveals that they all have recorded wind speeds above 10 mph (16 kph). High wind speeds, while evident throughout the graph, are dominant along the lower boundary. Similar effects occur with Type II fluids, as was discussed in Section 4.2. Wind speed may not be the dominant factor in determining failure time but high winds do appear to exert a negative effect.

4.4.3 Humidity Effects

By referring to Figure 4.20, it is notable that humidity values above 90% seems to occupy the lower boundary points to a greater degree than was the case with Type II Fluids. The surrounding points are mostly above 80%, and lower relative humidity points are generally further away from the lower boundary points. However, due to the limited number of data points with long failure times (above 40 minutes), conclusions such as low humidity being associated with long failure times and high precipitation rates cannot be made.

4.4.4 General

For Type 1.5 Fluids, almost 95% of all failures occurred with less than 5.5 g/dm^2 of total precipitation, as seen in Figure 4.21. For Type II fluids, this value was 7.5 g/dm^2. The lower value is consistent with the fact that the lower boundary limit for Type 1.5 fluids was below that of Type II fluids. Both observations are compatible with the belief that Type 1.5 fluids offer less holdover protection than Type II fluids.

The combination of humidity and wind appear to have some effect on the failure times. This relationship is investigated further in the following section.

FIGURE 4.19
TIPPING BUCKET DATA, TYPE 1.5 FLUID

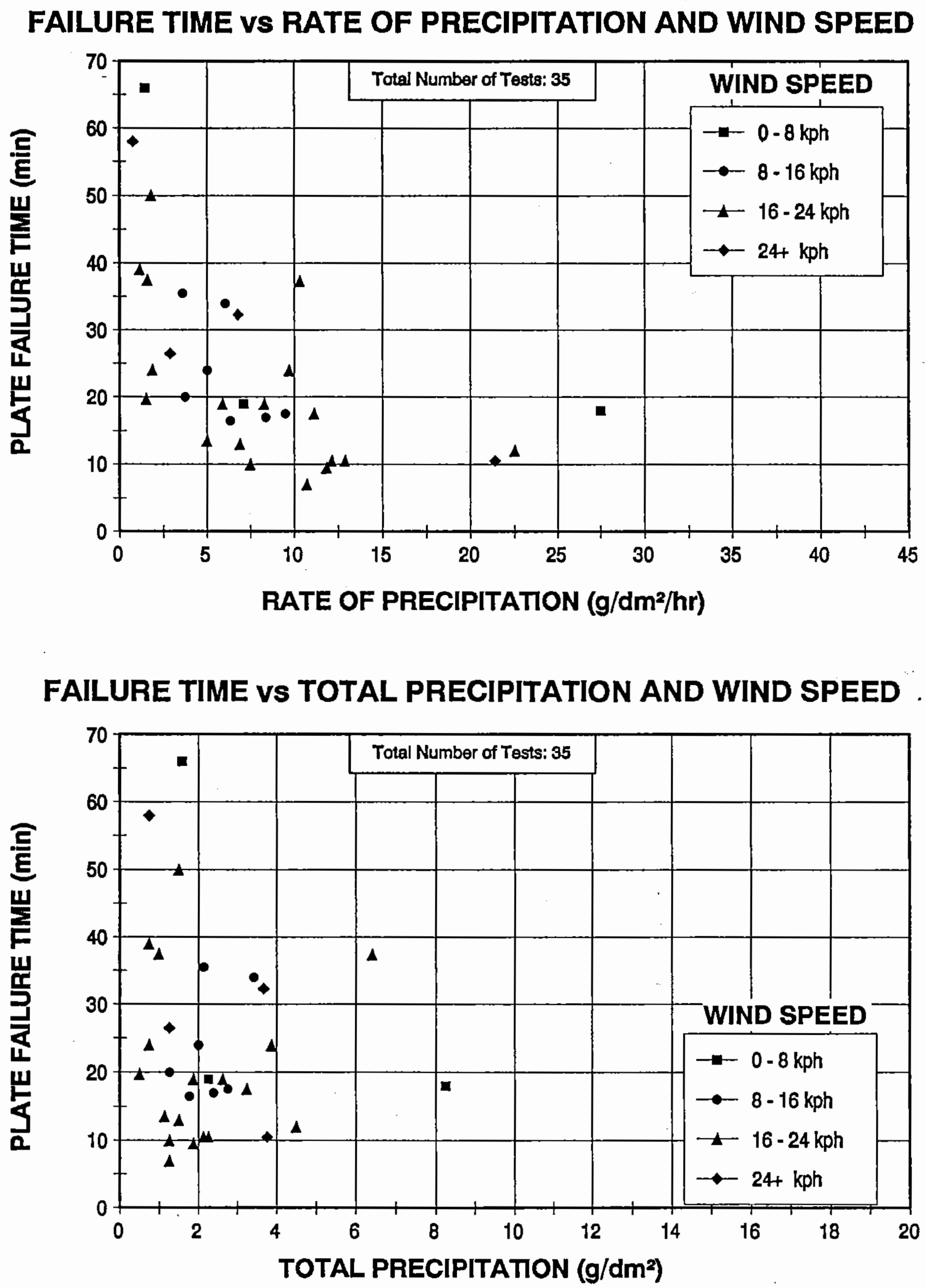
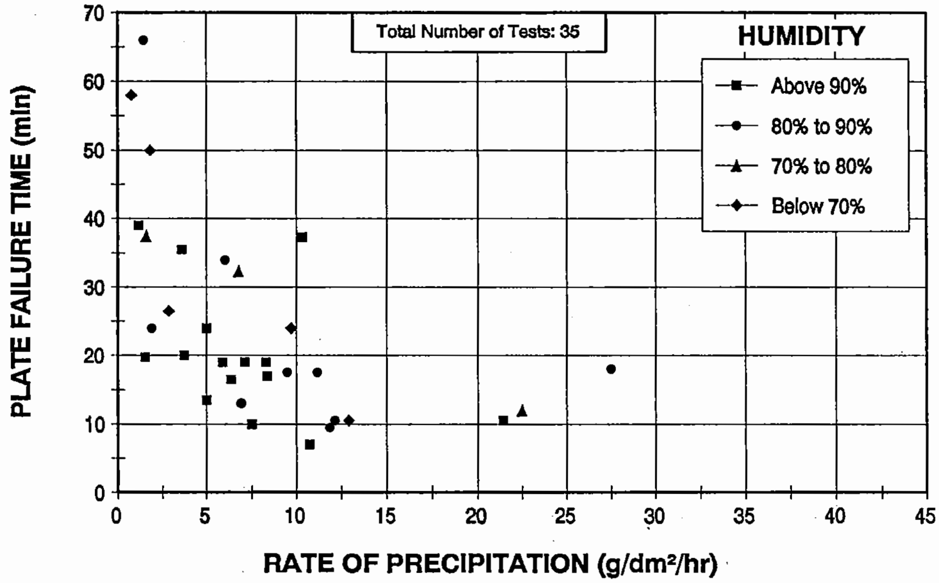


FIGURE 4.20
TIPPING BUCKET DATA, TYPE 1.5 FLUID

FAILURE TIME vs RATE OF PRECIPITATION AND HUMIDITY



FAILURE TIME vs TOTAL PRECIPITATION AND HUMIDITY

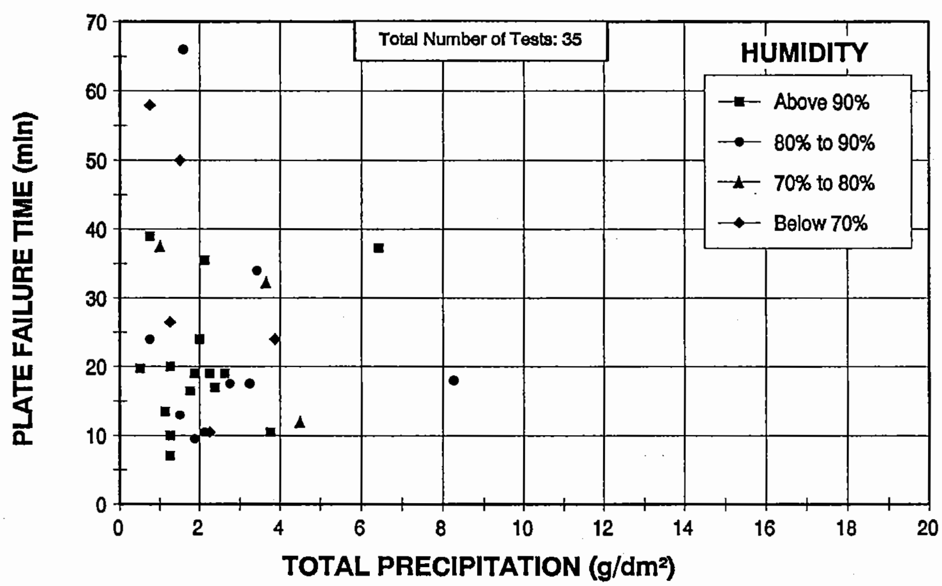
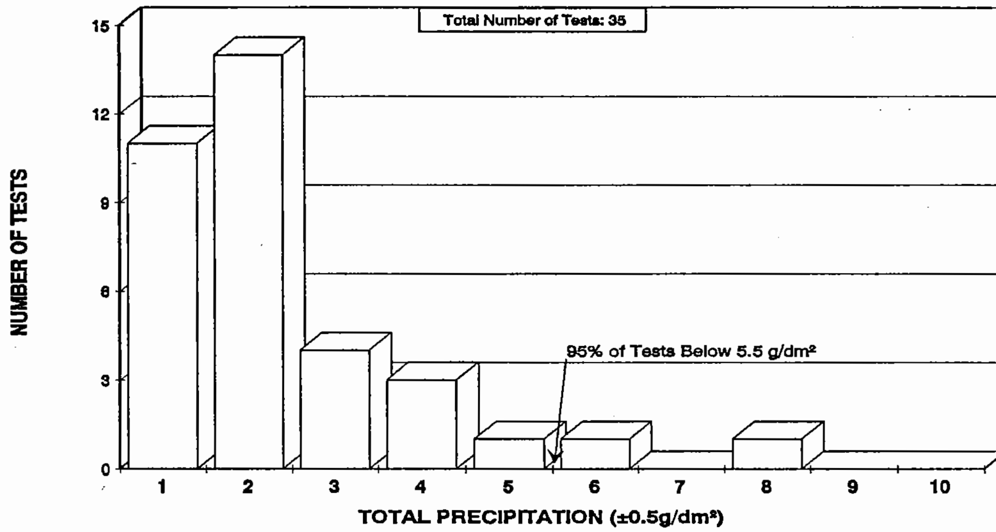


FIGURE 4.21
DISTRIBUTION OF TOTAL PRECIPITATION
TIPPING BUCKET DATA, TYPE 1.5 FLUID



4.5 Statistical Analysis - Type 1.5 Fluids

As the preceding analysis did little in suggesting direct relationships, it was decided to do a purely statistical analysis on some of the data to see if it was possible to reveal some multivariate relationships. The Type 1.5 fluid was chosen and the data analyzed was restricted to that data collected at the Dorval site. It was hoped that this would reduce the magnitude of some of the data collection errors and subjectivities.

As a first step, the extent to which each of the individual data elements depended upon each of the other data elements was assessed. This is presented in Table 4.4 as a correlation matrix[3]. Some interesting correlations can be seen in this table. The fact that precipitation rate correlates well with failure time and total precipitation is artificial because precipitation rate was calculated from the other two variables. Because of this, precipitation rate could not be used as a predictor for failure time in the analysis. Elsewhere in the matrix it is seen that temperature has a reasonably strong negative correlation with fluid thickness, whether measured at the 1"(2.5 cm), 6"(15 cm) or 12"(30 cm) line indicating that the fluid thins at warmer temperatures.

TABLE 4.4
CORRELATION MATRIX
DORVAL DATA, TYPE 1.5 FLUID

	Temp.	Humidity	Wind	2.5 cm lin	15 cm line	30 cm line	Fail. Time	Total Prec	Prec. Type
Humidity	-0.407								
Wind Speed	-0.135	-0.178							
2.5 cm line	-0.632	0.409	-0.033						
15 cm line	-0.6	0.361	-0.074	0.736					
30 cm line	-0.392	0.289	-0.017	0.567	0.797				
Failure Time	0.224	-0.508	-0.262	-0.201	-0.271	-0.215			
Total Precip.	0.524	0.102	-0.151	-0.436	-0.426	-0.397	-0.096		
Precip. Type	0.147	-0.257	-0.111	-0.103	-0.026	-0.157	-0.0000001	-0.187	
Precip.Rate	0.233	0.294	-0.045	-0.21	-0.135	-0.164	-0.572	0.726	0.164

NOTE: 2.5 cm, 15 cm AND 30 cm LINES REFER TO MEASURED FLUID THICKNESS AT THOSE LOCATIONS

SOURCE: APS Analysis

3 In a correlation matrix, all values lie between -1.00 and +1.00. The closer a value is to one of these extremes, the stronger the relationship. A high positive correlation between A and B indicates that as factor A increases, so does B. A very negative correlation indicates that as A increases, B decreases. Correlation values close to zero indicate that there is little linear dependence of B on A or A on B.

As the goal of this analysis was to find a predictor for failure time, the correlation value for each of the other variable versus failure time should be examined. Of these, humidity offers the strongest correlation. One of the weakest correlations resulted from total precipitation. Although intuitively it was felt that total precipitation would be a major contributor to failure, the extremely scattered nature of the data makes the low correlation understandable.

A full regression analysis was performed. Although several different models were assessed, only three were analyzed to completion: a linear relationship using all points; a relationship using the square root of failure time; and another linear relationship using all data with failure times below 60 minutes. Each of these are discussed briefly below, while the full analysis is left for Appendix D.

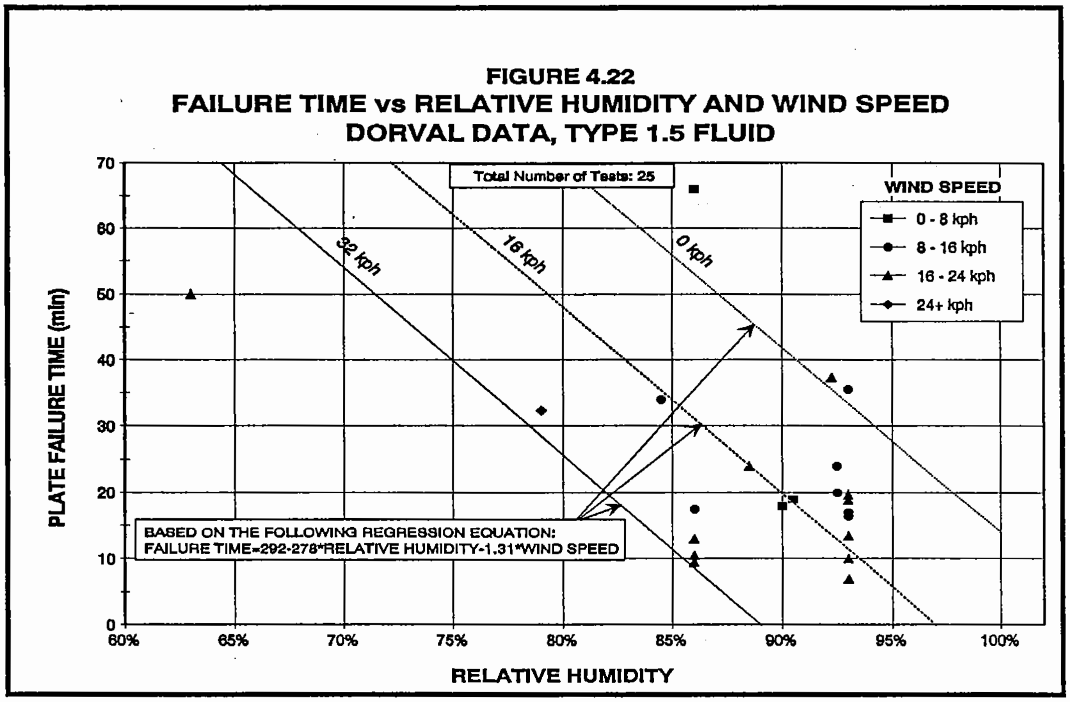
4.5.1 Linear regression - all data

Essentially, the results showed that failure time was most dependent on humidity and wind speed. Figure 4.22 is a graph of failure times vs relative humidity with wind speed identified.

$$TIME_{failure} = 292 - (278 * Humidity) - (1.31 * Wind)$$

where $TIME_{failure}$ = failure time (minutes)
$Humidity$ = relative humidity (percent)
$Wind$ = wind speed (kph)

The given equation could only account for 49% of the variation in the data. For a physical experiment such as this, a 49% "R^2" value is not satisfactory. One would like to be able to account for three quarters or more of the variation before feeling comfortable about the results.



The absence of variables like temperature and precipitation from the equation does not mean that plate failures can be expected with no snow on a warm summer day. What it does indicate is that over the range of data used in the analysis, changes in temperature and precipitation do not affect the failure time. Again, there is too much unaccounted for variation to rely on the predictor equation. This unaccounted for variation indicates that the data collected contained a large degree of variability and/or, there are some other variables which play a key role in the performance of the fluids that has not been accounted for.

4.5.2 Square root of failure time regression

The preceding analysis looked at a strictly linear relationship between failure timè and the other variables. This section deals with an analysis relating the square root of failure time to the other variables. This type of relationship may be more difficult to conceptualize but the purpose for its investigation was to see what kind of statistical results were obtained.

The equation is presented below:

$$(TIME_{failure})^{1/2} = 27.7 - (23.7 * Humidity) - (0.124 * Wind)$$

This equation accounts for just over half of the variation in the data ($R^2 = 50.5\%$), which is not substantially higher than the previous case.

4.5.3 Linear regression - failure times less than one hour

It would seem reasonable to assert that data collected which indicated a fluid failure time in excess of one hour were probably recorded on days where testing need not have occured. Therefore, a linear multiple regression was performed on the data set after all observations with failure times greater than one hour were removed. The resulting relationship had a lower R^2 than the previous analysis and as such the equation is not reproduced here.

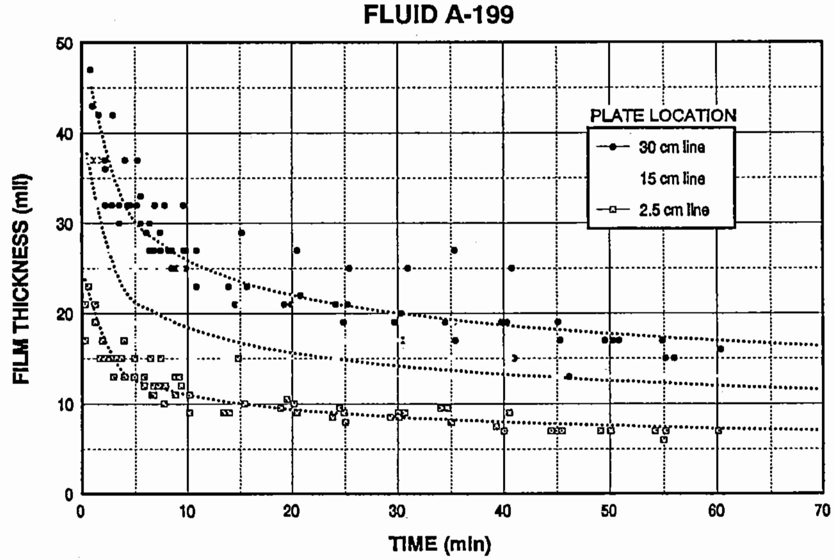
4.6 Fluid Thickness Tests

Tests were performed in order to investigate fluid thickness behaviour without the effects of precipitation. The methodology consisted of applying fluid on the test plates and measuring thickness at regular time intervals over a period of an hour. Measurements were taken at the 1" (2.5 cm), 6" (15 cm) and 12" (30 cm) lines on the plates. Environmental factors such as temperature and relative humidity were also noted. There were 32 such tests using fluids A-199, A-200, A-201, A-202 and A-203. The sites were Halifax, Ottawa, St. John's and Toronto. These tests revealed important information on the time required for the fluid thickness to stabilize. Also, some interesting properties related to the deicing fluids were brought to light.

4.6.1 Fluid Thickness Stability

A procedural assumption was that the fluid thickness would stabilize within five minutes of being poured onto the plate. In general, fluid thickness observed an exponential decay with time. The results revealed that fluid thickness stabilized after ten to fifteen minutes from the start of trial, which is more than twice the time stated in the procedure manual. An example of this exponential decay can be seen from Figure 4.23, which leads to two observations.

FIGURE 4.23
FILM THICKNESS vs TIME
FLUID A-199



The first observation was that fluid thickness changed between the time of being measured and the time of exposure to precipitation. A tarp was used to shelter the plates during initial set up. After the last fluid thickness measurement, the tarp was removed and testing commenced. The time required to remove the tarp was sufficient for a measurable reduction of thickness to be unaccounted for in the data.

The second observation was that the first measured thickness was different than the last. A finite time was required in order to measure fluid thickness on all plates. Therefore, the last measurements were closer to their stable value than the first measurements.

4.6.2 Fluid Properties

A detailed analysis was performed for A-199 and A-201 owing to an extensive number of measurements for these fluids. The main influence on thickness was time, although environmental factors also entered into play.

Film thickness as a function of time is depicted for fluid A-199 in Figure 4.23. The general exponential decay is well represented for this fluid as it seems to be invariant with respect to temperature and humidity within the range of measurements. The thickness starts to stabilize after 10 minutes. As usual, the 1 inch (2.5 cm) line had the smallest value for thickness and the 12 inch (30 cm) line had the largest. This is a well observed characteristic of fluid run-off. As the fluid flows down the plate, it tends to accumulate, yielding thicker coverage on lower parts of the plate.

Fluid A-201 presented some interesting features as can be seen in Figure 4.24. Not only did the thickness decay with time as with fluid A-199, but it also varied with relative humidity. As the ambient humidity dropped, the thickness decreased rapidly. Figure 4.25 illustrates that a 10% loss of water reduces viscosity to a tenth of its original value. This would account for an accelerated run-off and reduction of fluid thickness. Depending on the relative humidity,

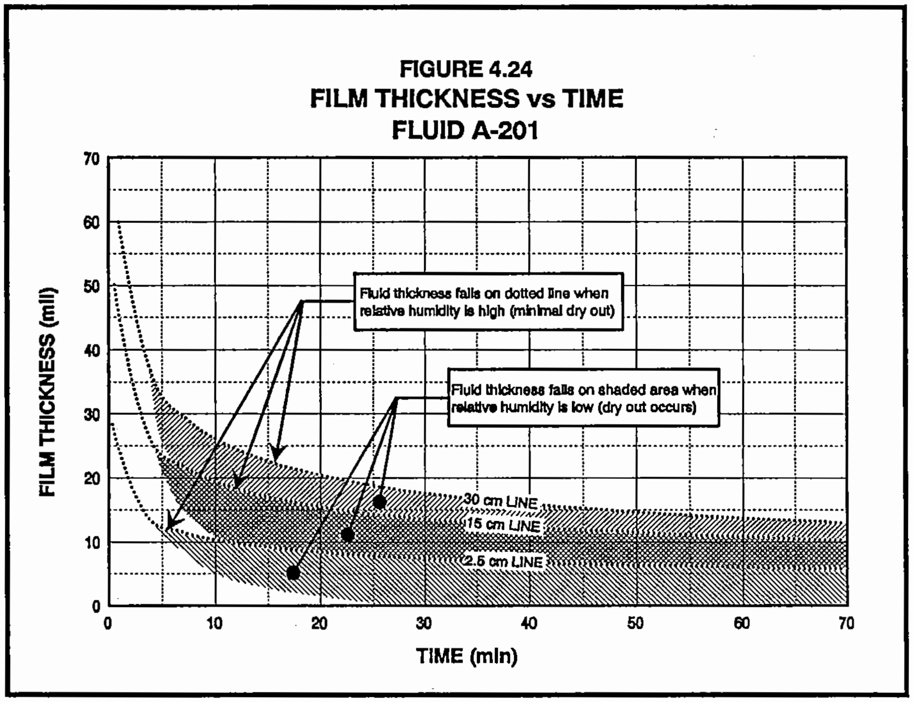


FIGURE 4.24
FILM THICKNESS vs TIME
FLUID A-201
FILM THICKNESS (mil)
TIME (min)
0
10
20
30
40
50
60
70
Fluid thickness falls on dotted line when relative humidity is high (minimal dry out)
Fluid thickness falls on shaded area when relative humidity is low (dry out occurs)
30 cm LINE
15 cm LINE
2.5 cm LINE

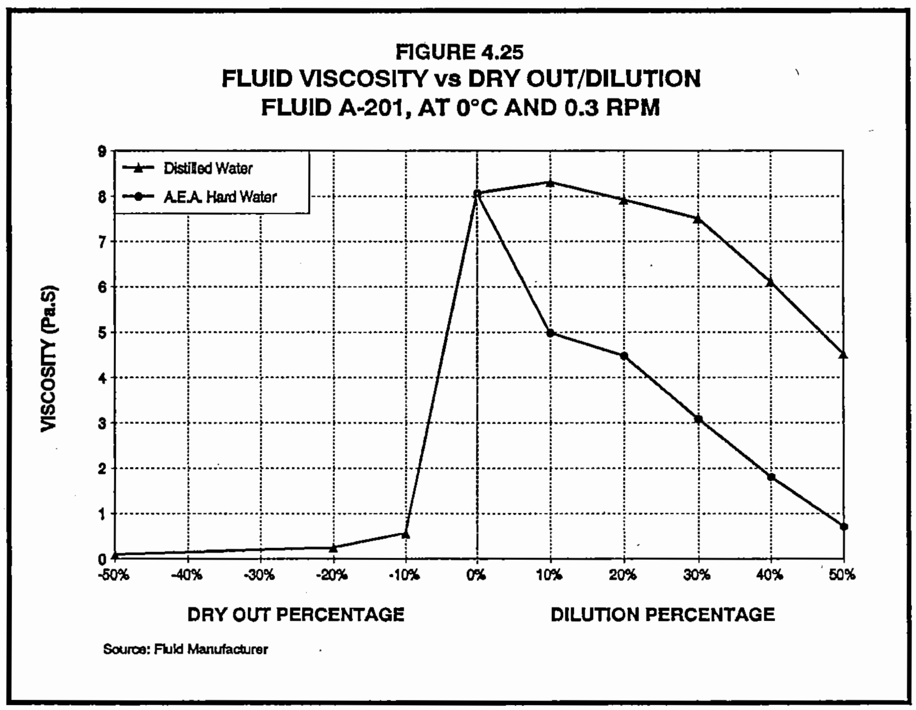


FIGURE 4.25
FLUID VISCOSITY vs DRY OUT/DILUTION
FLUID A-201, AT 0°C AND 0.3 RPM
Distilled Water
A.E.A. Hard Water
VISCOSITY (Pa.S)
0
1
2
3
4
5
6
7
8
9
-50%
-40%
-30%
-20%
-10%
0%
10%
20%
30%
40%
50%
DRY OUT PERCENTAGE
DILUTION PERCENTAGE
Source: Fluid Manufacturer

dry out could take place as soon as 30 minutes into the test. The fluid thickness would then drop near to zero in the following ten minutes as can be seen in Figure 4.26. Since dry out time varies with humidity levels, a spread can be observed in the data as indicated by the shaded areas as shown in Figure 4.24.

Temperature also plays a role in fluid viscosity. However, temperature did not vary much throughout the fluid thickness tests such that a correlation was not observed. Nevertheless, manufacturer data for fluid A-199 shows that viscosity increases as temperature decreases. Figure 4.27 also indicates how fluid viscosity for A-201 decreases with temperature.

On an aircraft wing, variations in viscosity could have beneficial consequences. On acceleration along the runway, airflow over the wing would cause a dry out and cooling of the fluid. Both of these would reduce viscosity in the case of fluid A-201. The fluid would then run off more easily and a clean wing lift off could take place.

FIGURE 4.26
FILM THICKNESS vs TIME
FLUID A-201 - 15 cm LINE

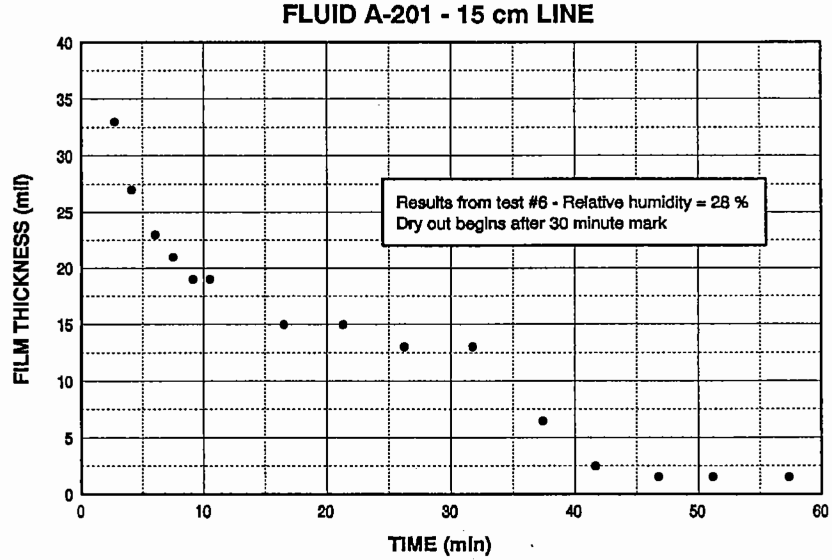
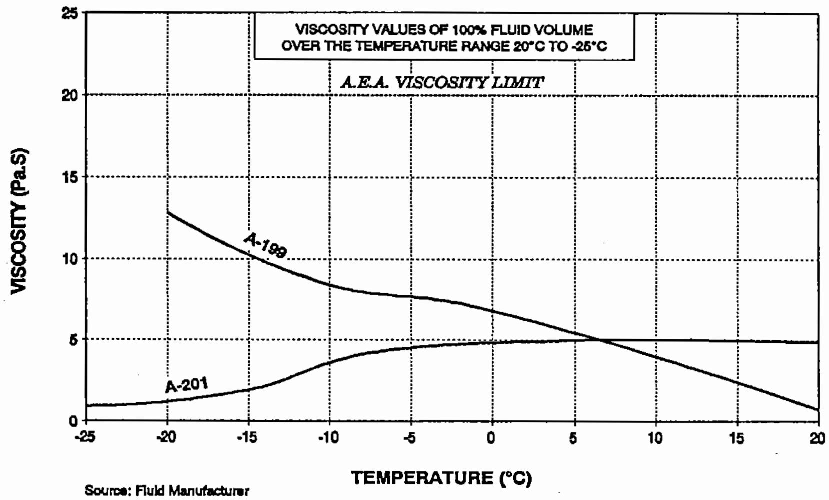


FIGURE 4.27
COMPARISON OF VISCOSITY VALUES
FLUID A-199 AND FLUID A-201



Source: Fluid Manufacturer

5. NECESSARY PROCEDURAL AND EQUIPMENT ENHANCEMENTS

This section will discuss the procedural and equipment difficulties encountered during testing phases of the project, and where problems are correctable, solutions are proposed.

Included within this section is a discussion of the following:

- Precipitation Measurements
- Anti-icing Fluids
- Fluid Application
- Wind Measurements
- Humidity Measurements
- Test Stand
- Test Plate
- Human Factors

5.1 Precipitation Measurements

- The resolution of the tipping bucket is only one g/dm^2 which, under light precipitation, resulted in long time durations between tips. Also, residual fluid may be present in the bucket at the beginning and end of the test. The combination of these two could result in an under estimation or over estimation by as much as one g/dm^2 over the test. This is a potentially large error given that some of the lower precipitation rates produced only two or three g/dm^2 for the entire test. It should be noted that these errors may counteract each other.

To correct this problem some investment is required. There are tipping buckets available (at a substantially higher cost) which have a precision twenty times that of the apparatus used for this testing year. While the specific problem would still exist, the magnitude of the error could, at worst, reach one out of 40 tips (2.5%) as opposed to one out of two tips (50%). An automated data acquisition system could remove the error entirely by providing a detailed, accurate history of precipitation.

Assuring an empty bucket (by emptying the tipper), covering the bucket, and then exposing it to the precipitation only at the start of the test may seem to be an option but, in reality, has several flaws. First, to empty the tipper, one would have to either add water to the bucket very slowly (drops at a time) until a tip occurs or one would have to open the bucket and manually tip the tipper. This may damage the internal mechanism or possibly unbalance the bucket. Also, the problem of having residual fluid unaccounted for at the end of the test would remain. The potential error would still exist but would be strictly one-sided.

- The interval at which the tipping bucket was monitored was supposed to be exactly five minutes. Given the fact that the test personnel had other duties while the test was taking place, it is likely that this interval was not always exactly five minutes.

The error this introduces is relatively minor, and can be corrected through an automated data acquisition system.

- Sites employing the cake pan precipitation measurement method were only able to compute an average precipitation over the duration of the test. As it has been shown in Section 4.1.3, the precipitation rate can vary significantly over a thirty minute test.

This flaw is only correctable by replacing the cake pan method with a tipping bucket type precipitation gauge.

5.2 Anti-icing Fluids

- Except for Kilfrost, none of the fluids were dyed. This made it more difficult for the tester to see contamination on the plate, especially during night testing.

If the dyeing process does not degrade from the performance of the fluids, then requesting that the fluid manufacturers dye their fluids would make it easier to perform testing.

5.3 Application of the Fluid

- There is an incongruity between the procedural assumption that the fluids reach a constant thickness after about five minutes and the results of the fluid thickness analysis (Section 4.6) which indicates that this time may in reality be between 10 and 15 minutes. This incongruity creates two problems:

1) Given the amount of time required to perform the fluid thickness measurements, the thickness of the fluid when measured would not be the same as its thickness when the fluid is first exposed to precipitation; and

2) When the plates are exposed to the precipitation, the fluids which were applied last were probably slightly thicker than those which were applied first.

The easy solution would be to increase the time in between pouring the fluids and measuring the fluid thickness to at least ten minutes.

5.4 Wind Measurements

- The method of recording wind speed over the duration of a test was to simply take a reading at the beginning and end of a test and to calculate an average value from this data. This would not account for periods of high or low wind which may occur during the test.

There are two possible solutions. The first would be to take readings at regular intervals throughout the test, perhaps whenever the tipping bucket is monitored. This may still not accurately describe the wind pattern during the test. The best solution would be to computerize the wind data acquisition system. This would monitor all changes in wind speed throughout the test.

5.5 Relative Humidity Meter (Hygrometer)

- Most available hygrometers do not function at temperatures below the freezing point. The hygrometer used in this test was suitable for sub-zero testing but required in the order of 30 to 45 minutes to come to ambient conditions. If the testers did not immediately place the hygrometer outside before setting up the rest of the test equipment, the humidity results for the first test of the day may have been inaccurate.

If it is desired to use the same equipment, the best solution would be to mount the hygrometer permanently at the test site. It would then always reflect the ambient humidity, although extremely cold temperatures (below operating specifications) could damage the instrument. Another option would be to purchase a hygrometer with a much smaller response time.

5.6 Test Stand and Cover

- Placing a tarp over the test stand in moderate to heavy winds became a difficult or impossible task. The tarp could act as a sail and it could move against the lower test plates. The tarp would also rip from time to time, making it even more difficult to deal with.

Some corrective measures were employed during the testing season to fix this problem. The site at Chicoutimi built extensions onto the test stand. This eliminated any contact between the tarp and the test plates. The tarp was still difficult to deal with under high winds and was still susceptible to being ripped. Sites at Montreal and St. John's tested with a tent-like covering, as previously shown in Photo 2.3. While this was a substantial improvement, it was still difficult to deal with under very high winds such as those experienced in St. John's.

- Although at the beginning of the test, the stand was positioned such that it faced into the wind (i.e. the wind would flow up the plates), subsequent changes in wind direction were not compensated for. Wind approaching from the side or from behind the plates may blow the fluid off and reduce failure times.

This is one problem which could not be accommodated for. It would not be possible to move the stand during a test without disrupting the experiment and possibly disturbing the fluids.

5.7 Test Plates

- A fine tip paint marker was found to be the most resilient against the combination of wetness, fluids and isopropyl alcohol. Despite this resilience, the visibility of the crosshairs on the plate was reduced after several cleanings. Eventually, a reapplication of the paint was required. Performing some tests with very clear markings and others with more faint, or incomplete, markings could have some effect on the determination of failure time during a test.

The best way to solve this problem would be to have permanent markings affixed to the plate. Perhaps using a heat treatment to bond the paint to the plate would be satisfactory. A more temporary solution would be to reapply the paint marker after every test day. This would be a very time consuming task.

- The test panels themselves were only supported at the upper and lower edges. The lack of a middle support resulted in some plate sag under the weight of the fluids, the precipitation and the plate itself.

Modifying the test stand so that it provides support along the length of the panel would solve this problem. This was done for the portable test stand, designed and constructed during the middle of the winter season for the snow making experiment.

5.8 Human Factors

- The staffing of the sites introduced some other variables to the testing. All the Canadian sites used university or college students to perform the testing. The students had to balance their study time and class schedules with the testing. If the storms occurred during their class time, or during heavy study periods, some of the testing may not have been performed. In addition, it was difficult to motivate students to perform testing at odd hours such as the middle of the night. If weather broadcasts indicated only a chance of snow beginning in the middle of the night, it is not very likely that the student would set the alarm for two a.m. to see if it was actually snowing.

- If a snowstorm were to last in excess of four or five hours, it was unlikely that testers would have the stamina to withstand the unpleasant conditions for a longer period of time.

At Dorval, there were 2 coordinators/managers and 8-10 people available to perform the testing (including APS professionals). Weather conditions were monitored daily (hourly when a storm was expected) so that the site could be staffed during the storm. If a storm was expected to last more than 4 or 5 hours, a relief shift was scheduled. By having such a large personnel base to draw from, Dorval was able to capture most significant snow storms.

In addition, student testers at Dorval were given a premium for testing during the middle of the night. This financial motivator certainly played a role in their appearance at the test site.

- Sites set up by the airlines were staffed by airline personnel. These employees had other tasks to perform throughout their work day and it is unlikely that a significant number could be convinced to perform testing after their shift, or at odd hours of the night. The fact that these sites provided relatively few data points is then not surprising.

Unless the airlines are able to dedicate a few staff members to man the site when precipitation conditions require, it does not seem to be worthwhile for the airlines to continue testing.

6. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE TESTING

Due to the voluminous amount of information included in this report, this section will be sub-divided into conclusions based on the analysis and results, and recommendations for future testing. These sections in turn may be further separated. As there was extensive discussion of the procedures and equipment in Section 5, no further mention of those two test aspects will be included here.

6.1 Conclusions

The main conclusion which can be derived from this report is that there was too much variation in the data. Testing at 13 sites in 6 countries on 3 continents is difficult to regulate. Testing numerous fluids concurrently may have been the correct thing to do, but without a very clear understanding of the dynamics involved in fluid failure, it only served to add yet another element of variation. Section 5 has summarized many difficulties with the procedures and equipment which can be compensated for. Reducing the number of sites and testing only a single fluid will provide a more meaningful, consistent data base with which to work. Despite this comment, the analysis was still able to supply some useful insight into the fluid behaviour. These conclusions are presented in point form below.

6.1.1 Type II fluids

- The results of the Type II fluid tests seem to indicate the existence of a lower limit which follows the form of a $\mathbf{Y = aX^{-b}}$ equation. Within the confines of these tests, this limit can be thought of as the working safe limit of the fluids.

- Dorval results also indicate that there is a maximum amount of precipitation which can be accommodated by the fluid before the test would fail. For this data, 95% of the tests failed before a total of 7.5 g/dm^2 precipitation had fallen.

- The extreme variability statistically masked any potential clear relationships or dependencies between failure time and the other recorded variables.

- The results do provide enough insight to cast doubt upon the validity of the data used in the AEA/ISO holdover tables. Those AEA/ISO tables should provide more substantial information with respect to snowfall, humidity, wind, etc... The holdover times indicated should be conservative in nature and not based on ideal behaviour.

- Most tests with short failure times were characterized by winds above 10 mph (16 kph). While some tests with high winds also resulted in long failure times, very few low wind tests failed quickly.

- The viscosity of Fluid A-201 was heavily dependant on its water content. A ten percent dryout could result in the fluids viscosity dropping to as low as 1/10th of its original value. Therefore, if this fluid was allowed to sit in low humidity surroundings, without the addition of any precipitation, there is the possibility that it could lose enough water so that its thickness would experience a significant reduction. These low humidity situations are unlikely to occur during precipitation.

6.1.2 <u>Type I.5 fluids</u>

- The results of the Type I.5 fluid analysis point to a lower bound similar to the one established for the Type II fluids. In magnitude, this bound falls below the Type II bound.

- As with Type II fluids, the existence of a maximum amount of precipitation which the fluid could accommodate was discovered for the data recorded at Dorval. 95% of the Type I.5 fluid tests failed before 5.5 g/dm^2 of precipitation fell compared to the 7.5 g/dm^2 found for the Type II fluids.

- While the variability within the Type I.5 data was also high, a purely statistical analysis was able to reveal some relationships between the test failure time and the other recorded parameters. Humidity and wind were shown to have some affect on the plate failure time. The magnitude of the effect was not very high as the multiple regression coefficient of variation was only in the order of 50%.

- Were the variability in the data collection reduced, it may be possible to explain a greater amount of the variation. It is also a possibility that some key parameters which affect fluid performance may not be measured.

- As with Type II fluids, most short failure time tests were characterized by winds above 10 mph (16 kph).

6.1.3 General

- The larger failure times at some medium to high precipitation rates may be due to the weather favourably reproducing conditions for which the fluid was designed.

- Ice formation failure times (for failures at the 1" line) may have been incorrectly recorded. In reality, it was difficult to determine if coverage on the one inch line was ice, slush, snow or a combination of the three. In North American tests, the formation of ice on the plate would only be expected under freezing drizzle conditions which were relatively rare. If coverage of slush or snow were incorrectly called as an "ice failure", the recorded time would be much less than a correctly called snow coverage time.

- The "loss of gloss" failure condition has a somewhat vague description which may change from fluid to fluid depending on whether or not the fluid had been dyed.

6.2 Future Testing

This section will outline the Consultants view of both the direction and the scope of future testing. The issues of what aspects need further investigation and how best to accomplish this investigation are discussed below. To conclude this section, a look at how some of the recommendations of the Workshop on Canadian Research in Aircraft Ground De-icing (held in May, 1991) can be addressed by future research.

6.2.1 Outdoor Testing

From the results of the analysis presented in this report, it does not seem wise to continue testing on a large scale until two factors are clarified:

1) A test procedure is developed which involves far less subjectivity, particularly in the determination of the end of the test (failure time);

2) A better understanding of holdover time is gained.

The first point is obvious given the nature of these results. The second identifies a more elementary concern. Although a well controlled, objective test procedure may make it possible to identify and quantify a relationship between failure time and the various meteorological data elements, the relationship between the test failure time and actual holdover time must still be established. Without such a relationship, the results would have as much validity as the results used to formulate the European holdover tables. The data used for those tables reflect results from laboratory cold chamber tests. Fluid was poured onto an inclined flat plate which was then subjected to a sort of freezing drizzle at a constant intensity and temperature. The time it took for a front of ice to progress across a line located one inch from the top edge of the plate was considered to be the holdover time.

It is precisely because one eventually wants to understand holdover, that future testing should be continued outdoors. It is not possible to generate "natural conditions" in a cold chamber. Unfortunately it is also not possible to control the outdoor conditions themselves. Appendix E documents research done by APS in an attempt to use other means to create a snowfall. Snowblowers and snow making machines were considered. The statistical analysis identified humidity as a potential key parameter, yet one recommendation of the snowblower study was to perform testing on clear, dry days.

The type of outdoor testing is certainly open for discussion. Perhaps using a curved plate or representative wing section could give a little more insight into the whole phenomenon than the flat plate.

It would be useful to obtain a better understanding of the meteorological mechanics of a snowfall. How does precipitation vary? What happens to the wind? Do temperature and humidity fluctuate or are they relatively constant?

Some of these questions can be answered by additional equipment and a constant monitoring system. By computerizing the data acquisition system it would be possible to monitor such data over the entire season, whether or not there is precipitation. There are also rain/snow gauges with a higher degree of precision than the model used for this experiment. For each "tip" of the gauge used during this year's testing, 20 "drops" would occur for the alternate gauge. Although the alternate gauge costs about four times as much, the increased precision is a necessity.

The investigation of de-icing sensors could also play a major role in the process of understanding the behaviour of de-icing fluids under actual conditions. The sensor currently being developed by Instrumar is said to have the potential of determining not only that its sensor is contaminated, but it may also be able to determine the type and extent of the contamination. Incorporating the ice sensor into an outdoor test program could not only provide useful insight into fluid behaviour but could also be an excellent development tool for the sensor's manufacturer.

6.2.2 Laboratory Testing

As has been stated repeatedly, it is not possible to generate the natural, varying conditions which occur during a snowstorm inside a laboratory. This does not preclude the use of laboratory testing though. Such testing could give additional insight into some of the fluid behaviours noticed in exterior testing. Fluid reactions to certain naturally occurring changes in meteorological parameters would be useful information. Some fluid manufacturers do make available data on fluid viscosity at a few distinct conditions (set temperatures and percentage of dilution/dryout). It would be useful if experiments could be custom designed to investigate the fluid response to combined changes in humidity and temperature.

6.2.3 Workshop recommendations

A workshop "Canadian Research in Aircraft Ground Deicing", sponsored by TDC, NRC and CASI, was held at ICAO in Montreal in May 1991. The goals of the workshop were: to disseminate the knowledge currently available on deicing aircraft; to identify the important gaps in knowledge that need research; to make recommendations and propriortize research areas; and finally to publish any recommendations. The details of the workshop are provided in Appendix F.

The top five recommendations which resulted from the Workshop on Canadian Research in Aircraft Ground De-icing were:

1) Create an overall industry Aircraft Ground De-icing Committee (AGDC) to include representation from Airport Operators, Airlines, Fluid Manufacturers, Research Groups, Industry Associations, Environmental Groups.

2) Develop a total system, suitable for all aircraft types and all airports, that would provide last minute ''clean wing'' information to the captain.

3) Improve information regarding holdover times, including effects of meteorological conditions.

4) Use the AGDC as a clearing house for information on all ground de/anti-icing research and development activities in North America and Europe.

5) Explore concepts for complete systems, including industry operational guidelines, for ground de-icing and establish whether national or site specific systems are more appropriate to Canadian needs.

It is possible for future testing to address at least parts of three of these five recommendations. A thorough testing program which encompasses accurate meteorological data collection, realistic de-icing fluid testing and the investigation of ice sensors could play a significant role in satisfying recommendations two, three and five. Furthermore, an extended testing program would develop expertise which could contribute to an Aircraft Ground De-icing Committee whose formation is proposed in recommendation one.

APPENDICES

APPENDIX A
TESTING DOCUMENTATION

A-1 Extracts from Manobs

A-2 Test Procedure and Equipment List

A-3 Original and Revised Data Forms

APPENDIX A-1

EXTRACTS FROM MANOBS

APPENDIX A

Environment Canada / Environnement Canada

Atmospheric Environment Service / Service de l'environnement atmosphérique

EXTRACTS FROM

MANOBS

MANUAL OF SURFACE WEATHER OBSERVATIONS

SEVENTH EDITION

JANUARY 1977

ORIGINATING AUTHORITY : WEATHER SERVICES DIRECTORATE

ISSUED UNDER THE AUTHORITY OF THE DEPUTY MINISTER

3.4 PRECIPITATION. Any product of the condensation of atmospheric water vapour which is deposited on the earth's surface is a type of precipitation. The types of precipitation which originate aloft are classified in the following sections under Liquid Precipitation, Freezing Precipitation, and Frozen Precipitation.

3.4.1 Liquid Precipitation.

3.4.1.1 Drizzle. Fairly uniform precipitation, composed exclusively of fine drops of water (diameter less than 0.5 mm). Drizzle drops are too small to cause appreciable ripples on the surface of still water. The drops appear almost to float in the air, thus making visible even slight movements of the air.

3.4.1.1.1 Drizzle falls from fairly continuous and dense layers of Stratus, usually low, sometimes even touching the ground (fog).

3.4.1.2 Rain. Precipitation of liquid water particles, either in the form of drops of larger diameter than 0.5 mm, or of smaller widely scattered drops.

3.4.1.2.1 Rain drops are normally larger than drops of drizzle. Nevertheless, drops falling on the edgė of a rain zone may be as small as drizzle drops, owing to partial evaporation.

3.4.2 Freezing Precipitation.

3.4.2.1 Freezing Drizzle. Drizzle, the drops of which freeze on impact with the ground or with other objects at or near the earth's surface.*

3.4.2.2 Freezing Rain. Rain, the drops of which freeze on impact with the ground or with other objects at or near the earth's surface.*

3.4.2.3 Freezing Drizzle or Freezing Rain shall be reported when rain or drizzle is freezing on the Ice Accretion Indicator or on other objects at or near the earth's surface.*

3.4.3 Frozen Precipitation.

3.4.3.1 Snow. Precipitation of mainly hexagonal ice crystals, most of which are branched (star-shaped). The branched crystals are sometimes mixed with unbranched crystals. At temperatures higher than about -5°C, the crystals are generally clustered to form snow flakes.

3.4.3.2 Snow Pellets. Precipitation of white and opaque particles of ice. These ice particles are either spherical or conical; their diameter is about 2 - 5 mm.

3.4.3.2.1 Snow pellets are brittle and easily crushed; when they fall on hard ground, they bounce and often break up. Snow pellets always occur in showers and are often accompanied by snow flakes or rain drops, when the surface temperature is around 0°C.

3.4.3.3 Snow Grains. Precipitation of very small white and opaque grains of ice. These grains are fairly flat or elongated; their diameter is generally less than 1 mm. When the grains hit hard ground, they do not bounce or shatter. They usually fall in very small quantities, mostly from Stratus or occasionally from fog, and never in the form of a shower.

3.4.3.4 Ice Pellets. Precipitation of transparent or translucent pellets of ice which are spherical or irregular, rarely conical, having a diameter of 5 mm or less. Ice Pellets are subdivided into two main types:

(a) Frozen raindrops, or snowflakes which have largely melted and then refrozen, the freezing process usually taking place near the ground.

(b) Pellets of snow encased in a thin layer of ice, which has formed from the freezing, either of droplets intercepted by the pellets, or of water resulting from the partial melting of the pellets.

3.4.3.4.1 The pellets of ice usually bounce when hitting hard ground and make a sound on impact. Ice pellets type (a) generally fall as continuous precipitation; ice pellets type (b) occur in showers.

3.4.3.5 Hail. Precipitation of small balls or pieces of ice (hailstones) with a diameter ranging from 5 to 50 mm or sometimes more, and which fall either separately or fused into irregular lumps.

3.4.3.5.1 Hailstones are composed almost exclusively of transparent ice, or of a series of transparent layers of ice at least 1 mm in thickness, alternating with translucent layers. Hail is generally observed during heavy thunderstorms.

3.4.3.6 Ice Crystals. A fall of unbranched ice crystals, in the form of needles, columns or plates, often so tiny that they seem to be suspended in the air. These crystals may fall from cloud or from a cloudless sky. (In WMO terminology, Ice Crystals are referred to as Diamond Dust).

3.4.4 OTHER HYDROMETEOROLOGICAL DEPOSITS

3.4.4.1 Dew. Dew forms when water is condensed on grass and other objects near the ground. The surface on which the dew forms has been cooled by radiation during the night, to a temperature below the dew point of the surrounding air, but is still above freezing.

3.4.4.2 Hoar Frost. Hoar Frost (commonly called frost), forms when air with a dew point temperature below freezing is brought to saturation by cooling. Hoar Frost is a deposit of interlocking ice crystals formed by direct sublimation on objects, usually of small diameter such as tree branches, plant stems, leaf edges, wires, poles, etc.

3.4.4.3 Rime. Rime is a white or milky and opaque GRANULAR deposit of ice formed by the rapid freezing of super-cooled water drops as they contact an exposed object.

3.4.4.4 Glaze. Glaze is a coating of ice, generally clear and smooth, formed on exposed objects by the freezing of a film of supercooled water deposited by rain, drizzle, fog or possibly condensed from supercooled water vapour. Glaze is denser, harder and more transparent then either rime or frost.

3.5.4 Blowing Snow. Snow particles raised by the wind to sufficient heights above the ground to reduce the horizontal visibility at eye level to 6 miles or less. The concentration of snow particles may sometimes be sufficient to veil the sky and even the sun. The snow particles are nearly always violently stirred up by the wind. The observer should use great caution in reporting a combination of falling snow and blowing snow.

3.9 INTENSITY OF PRECIPITATION

3.9.1 The precipitations classified above as Liquid, Freezing and Frozen (with the exception of ice crystals) are always qualified as to intensity, viz., very light, light, moderate or heavy.

3.9.2 VERY LIGHT is used to indicate the intensity when scattered drops, flakes, grains, pellets or stones are occurring at a rate which would not wet or cover a surface, regardless of the duration.

3.9.3 The intensities LIGHT, MODERATE and HEAVY are determined by considering either the effect on visibility or the rate of fall.

3.9.4 Intensity by Visibility Criteria.

Snow Snow Shower Snow Grains Snow Pellets Drizzle Freezing Drizzle	LIGHT if visibility 5/8 mile or more MODERATE if ALONE* and the visibility reduced to 1/2 or 3/8 mile. HEAVY if ALONE* and visibility reduced to 1/4, 1/8 or 0 mile.

*ALONE, i.e., no other precipitation and/or obstruction to vision is present.

3.9.4.1 Mixed Precipitation. When two or more of the above precipitations are occurring together without any "Obstruction to Vision", the intensity of the predominant type shall be determined according to the visibility and the intensity of the less dominant type/s shall be judged, as well as possible on a rate of fall basis.

3.9.5.4 When the intensity of rain, rain showers or freezing rain must be determined without the aid of instrument measurements, the following table may be used as a guide:

	Light Rain	Moderate Rain	Heavy Rain
Individual Drops	Easily seen	Not easily seen	Not identifiable (Rain in sheets)
Spray Over Hard Surface	Hardly any	Noticeable	Heavy, to a height of several centimetres
Puddles	Form slowly	Form rapidly	Form very rapidly

APPENDIX A-2

TEST PROCEDURE AND EQUIPMENT LIST

FIELD TESTING DE/ANTI-ICING FLUID
HOLDOVER TIME
VERSION 2.2

1 SCOPE:

This procedure describes the equipment and generalized steps to follow in order to standardize the method to be used to determine holdover time of anti-icing fluids during inclement weather such as freezing rain or snow.

2 EQUIPMENT:

2.1 RAIN/SNOW GAUGE

2.1.1 Tipping Bucket

2.1.1.1 Electrically heated gauge - Weathertronics Model 6021-B

collector orifice	200 mm diameter
sensitivity	1 tip/0.1mm accuracy 0.5% @ 13 mm/hr
output	0.1 sec switch closure
voltage	115 v (model -D 230 v)
switch	A reed mercury wetted

2.1.1.2 Electromechanical Event Counter option

Event counter (112 V DC # 115 V AC) Weathertronics Model 6422

2.1.1.3 Digital Display option

(A) Event Accumulator - Weathertronics Model 1600
range 0-1000 counts linearity 0.05%
(B) Power Supply & Enclosure - Weathertronics Model 1020
(C) LCD Digital Display - Weathertronics Model 1991

2.1.1.4 PC Interface option

(A) Event Accumulator - Weathertronics Model 1600
(B) Power Supply & Enclosure - Weathertronics Model 1025
(C) PC Interface module - Weathertronics Model 1799

2.1.2 Manual Alternatives

2.1.2.1 A manual standard rain and snow gauge can be used provided that the diameter of the gauge be as close as possible to 208 mm. This may not be possible in Europe therefore the diameter of the gauge must be reported with all tests results.

2.1.2.2 A large low cakepan (6"x6"x2" minimum) may be used to collect and weigh snow.

Note: When this method is used the insides of the pan must be wetted with deicing/anti-icing fluid to prevent the snow from escaping the pan because of blowing wind.

2.2 TEMPERATURE GAUGE

T or K type thermocouple thermometer capable of measuring outside air and panel temperatures to an accuracy of 0.5 degrees C (1F) over the range +10 to -30 C (+50 to -20 F).

2.2.1 Cole Parmer P/N N-08110-25, probe P/N N-08500-55 available from Cole Parmer Instrument Company, Chicago Illinois.

2.2.2 Omega 450AKT Thermocouple thermometer available from Omega Engineering Stamford Connecticut.

2.2.3 or thermocouple thermometer equivalent to 2.2.1 or 2.2.2.

2.3 TEST STAND

A typical test stand is illustrated in figure 1; it may be altered to suit the location and facilities, but the angle for the panels, their arrangement and markings must all conform to figures 1 and 2.

There shall be no flanges or obstructions close to the edges of the panels that could interfere with the airflow over the panels. The stand may also be constructed to the specifications agreed upon in 1988.

2.4 TEST PANELS

Alclad Aluminum 2024-T6 polished standard roll mill finish 30x 50 x 0.32cm, for a working area of 25x40 cm.

Each panel shall be marked with lines at 2.5 and 15 cm from the panel top edge, and fifteen cross-hair points and one vertical line 2 cm from each side to mark off a working area of 26 x 50 cm on each panel as shown in figure 2. All marks shall be made using a 1/8" thick black felt ink marker, whose ink does not come off with Glycol/De-icing fluids, or any of the cleaning agents used.

For attachment to the test stand, at least four holes shall be made, spaced along the two sides of each panel; the holes shall be within 2 cm from the panel edge.

2.5 FLUID APPLICATION

The fluid should be poured on from a beaker or a bottle.

2.6 FILM THICKNESS GAUGE

Painter's wet paint film thickness gauge. 1-16 mil gauge or equivalent available from Paul N. Gardner Company Inc. Pompano Beach Florida.

2.7 VIDEORECORDER

Where feasible a videocamera should be mounted to record salient events during testing. Care must be taken that the camera and any lighting do not interfere with the airflow or ambient temperatures.

2.8 ANEMOMETER

Wind Minder Anemometer Model 2615 or equivalent. Available from Qualimetreies Inc. Princton New Jersey.

2.9 RELATIVE HUMIDITY METER

Cole Parmer RH/ Temperature Indicator P/N N-032321-00 with remote probe P/N N-03321030. Temperature limits for RH -30 to 60C RH range 20 to 100% accuracy +- 7% (20-30%); =-5% (30-100%); or equivalent. Available from Cole Parmer Instrument Company Chicago Illinois.

2.10 ADDITIONAL EQUIPMENT

- Covering plastic sheet or tarp (sufficiently large to cover back, face, and sides of structure).
- Squeegee
- Stop Watch
- Extension cords

2.11 OPTIONAL EQUIPMENT

- Flood lights for nighttime testing
- Tape recorder for data recording

3 DE / ANTI-ICING FLUIDS (INCLUDES INSTRUCTIONS FOR FLUID SUPPLIERS)

3.1 TYPE I MATERIALS

NONE shall be used in the 91/92 tests

3.2 TYPE II MATERIALS

3.2.1 Fluid Suppliers

ONLY 100% CONCENTRATED FLUIDS shall be used

The following suppliers are expected to provide fluid

Dow	
Hoechst	SPCA
Kilfrost	UCAR

3.2.2 Certification

These type II fluids shall be sheared by each manufacturer to that viscosity which would have been obtained by subjecting their fluids to the shear Stability Test found in the AEA Material specification revision C (Oct. 1, 1988) paragraph 4.2.8.2.2.

Each manufacturer shall provide samples and a certificate of compliance showing the viscosity of their test sample of fluid before and after the Shear Stabile Test. Test verifications of each fluid will be made at the University of Quebec at Chicoutimi.

3.2.3 Dye

Aquacet Orange G dye Ciba Geigy at a concentration level of 100 ppm

4 PROCEDURE:

4.1 SETUP

4.1.1 Panel Test Stand

If there is any wind, orient the test fixture such that the aluminum holdover test panels top surfaces are facing into the wind direction at the beginning of the test.

eg. --->
wind panel

If the wind shifts during the test do not move the fixture; simply note the new wind direction.

4.1.2 Rain Gauge

Place the Rain/Gauge on one side of the test fixture at a distance between 1 and 2 meters from the fixture. Ensure the interior level is used to indicate that the bucket is level. Ensure that the gauge is not shadowed by an object which would interfere with the collection for the snow of freezing rain. If there is drifting snow if maybe necessary to raise the snow gauge above the drift level but no higher than the test panel. It maybe preferable to use a rain gauge snow fence such as the Weathertronics wind screen Model 6410.

Keep the opening of the Rain/Snow gauge covered with a plastic sheet to prevent the precipitation from entering the collector orifice before the start of each test.

4.1.3 Manual Cake Pan Method

Add ¼ inch deicing/anti-icing fluid to the bottom or the pan as well as wetting the inner sides of the pan.

Weigh the wetted pan prior to testing to the nearest milligram. Weigh again after test completion to determine the true water content reading of the snow.

4.2 TEST PANEL PREPARATION

4.2.1 It is recommended that no more than three fluids be tested at a given time.

Before the start of each day's testing, wash the panels with a solvent such as isopropyl alcohol followed by a wash with an alkali detergent. Rinse thoroughly with water and dry.

Between tests wash the panels with pure glycol (NOT type I fluid) and wipe dry.

4.2.2 Place the panels on the fixture and attach to frame screws with flat bolts.

4.2.3 Protect the panel from snow or freezing rain by draping and attaching a clear polyethylene plastic sheet or other suitable covering material over the upper frame of the fixture. The plastic sheet should cover the top, sides and face of the fixture.

4.2.4 Allow the panels to cool to outside air temperature.

4.3 FLUID PREPARATION AND APPLICATION

4.3.1 Store fluids in containers at room temperature between 20-24 C.

4.3.2 Before applying test fluid to a panel, squeegee the surface to remove any precipitation or moisture.

4.3.3 Apply the fluid to the panels, commencing at the lower edge of the test panel and working upwards to the top edge. Ensure complete coverage by applying the fluid in a flooding manner. Allow the fluid to settle for five (5) minutes.

4.3.4 Between the 3-5 minutes interval measure the fluid thickness at the 2.5, 15 and 30 cm lines (A, C and E in figure 2). Measure at center of the panel for each line.

4.4 HOLDOVER TIME TESTING

4.4.1 Remove the cover from the stand at the 5 minute mark; set the timer on.

4.4.2 Commence recording the test with a video recorder or take pictures at time 0 and then at one (1) and five (5) minute intervals for freezing rain and snow respectively until the test reaches the END CONDITIONS.

4.4.3 Record the elapsed time (holdover time) required for the precipitation to achieve the test END CONDITION.

4.4.4 In heavy precipitation, continue the test until the precipitation reaches the bottom of the panel. Record the time for this event.

5 END CONDITIONS

The holdover time is that time required for the one of three possible end conditions to be achieved:

5.1 PROGRESSIVE SURFACE FREEZING OR SNOW ACCUMULATION

When freezing conditions first cross the 2.5 cm (1") line (i.e. frost or ice partially obscures the line).

This will occur when frost or precipitation freezing starts at the top of a panel and progresses down the panel. Ignore occurrences within 2cm of the panel sides.

If these conditions occur also measure the time required to cross the 15 cm line.

5.2 RANDOM SNOW ACCUMULATION (Surface obliteration by snow, ice crystals or hail)

When the accumulated precipitation hides from sight any five of the cross-hair marks on the panels.

Under conditions of moderate to heavy snow or hail, coverage may be very uneven; this measure should indicate failure over about one-third of the panel.

5.3 LOSS OF GLOSS (Gradual deterioration to slush)

When precipitation or frosting produces a "loss of gloss" (i.e. a dulling of the surface reflectivity) or a change in colour (dye) to gray or grayish appearance at any five cross-hair box sites.

Under continuous snow, rain or frosting the dilution or erosion of the fluid may result in a less evident growth in ice or slush; this measure should indicate failure over one-third of the surface.

6 REPORTING & OBSERVATIONS

Calculate and record test data, observations and comments in the format of Table 1. Each test must be conducted in duplicate. Therefore for a six panel fixture as shown in figure 2, panels u & x and v & y and w & z are duplicates for three test fluids.

The following definitions shall be used for reporting conditions:

6.1 BLOWING SNOW

No snow falling , but wind drive snow is adhering to sufaces

6.2 LIGHT SNOW

Snowing with visibility at 5/8 statute mile or greater

6.3 MEDIUM SNOW

Snowing with visibility at less than 5/8 miles, but greater than ¼ miles

6.4 HEAVY SNOW

Snowing with visibility at ¼ statute mile or less,

6.5 FREEZING DRIZZLE

Rain freezing on surfaces and visibility greater than 5/8 miles

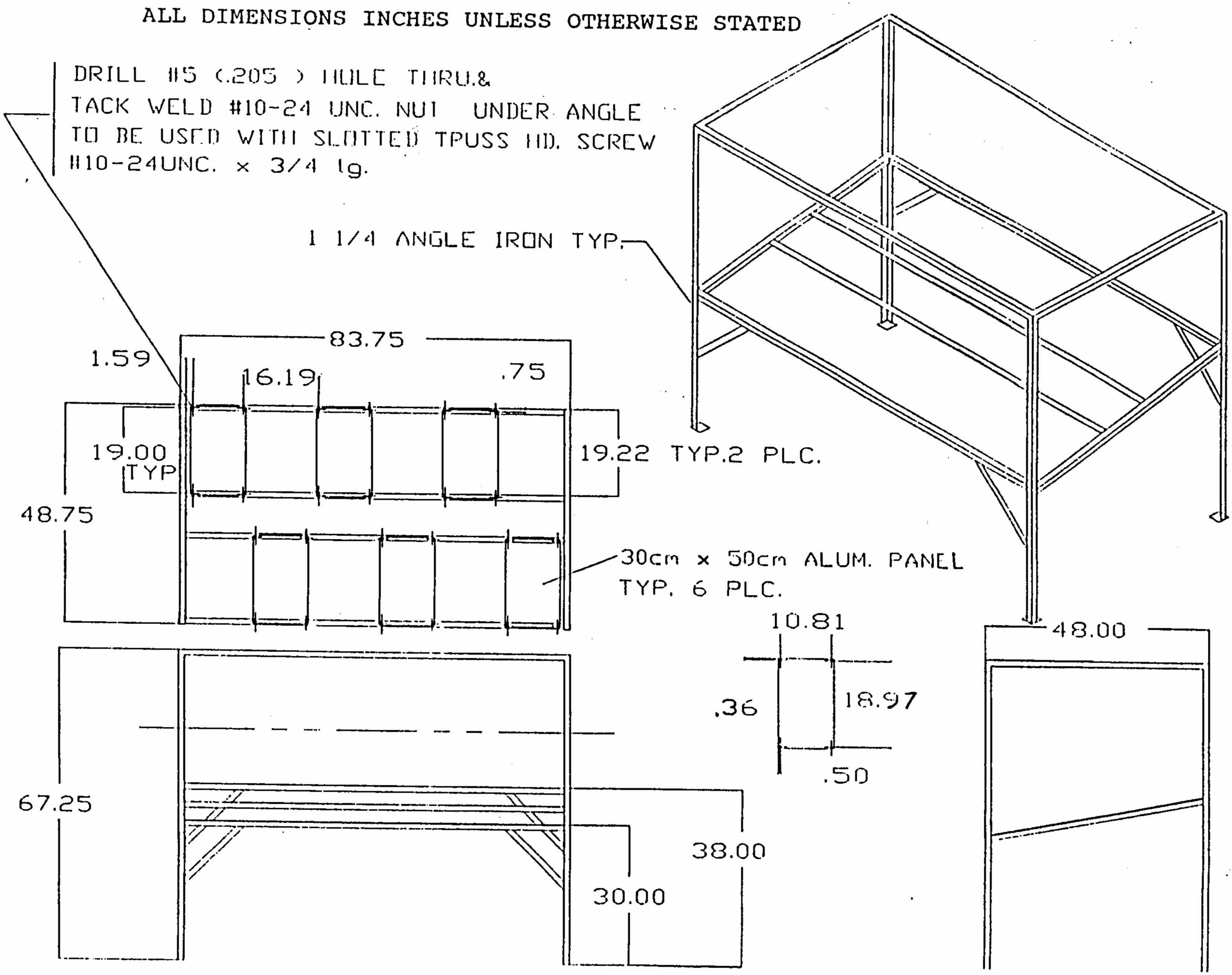
6.6 FREEZING RAIN

Rain freezing on surfaces and visibility less than 5/8 miles

6.7 FROST

No snow or rain: humidity condensing and freezing on surfaces.

* Appendix A contains more detailed definitions and descriptions of meteorological phenomena.



RACK - DEICING FLUID TEST

Figure 1 TEST STAND NOMINAL DIMENSIONS

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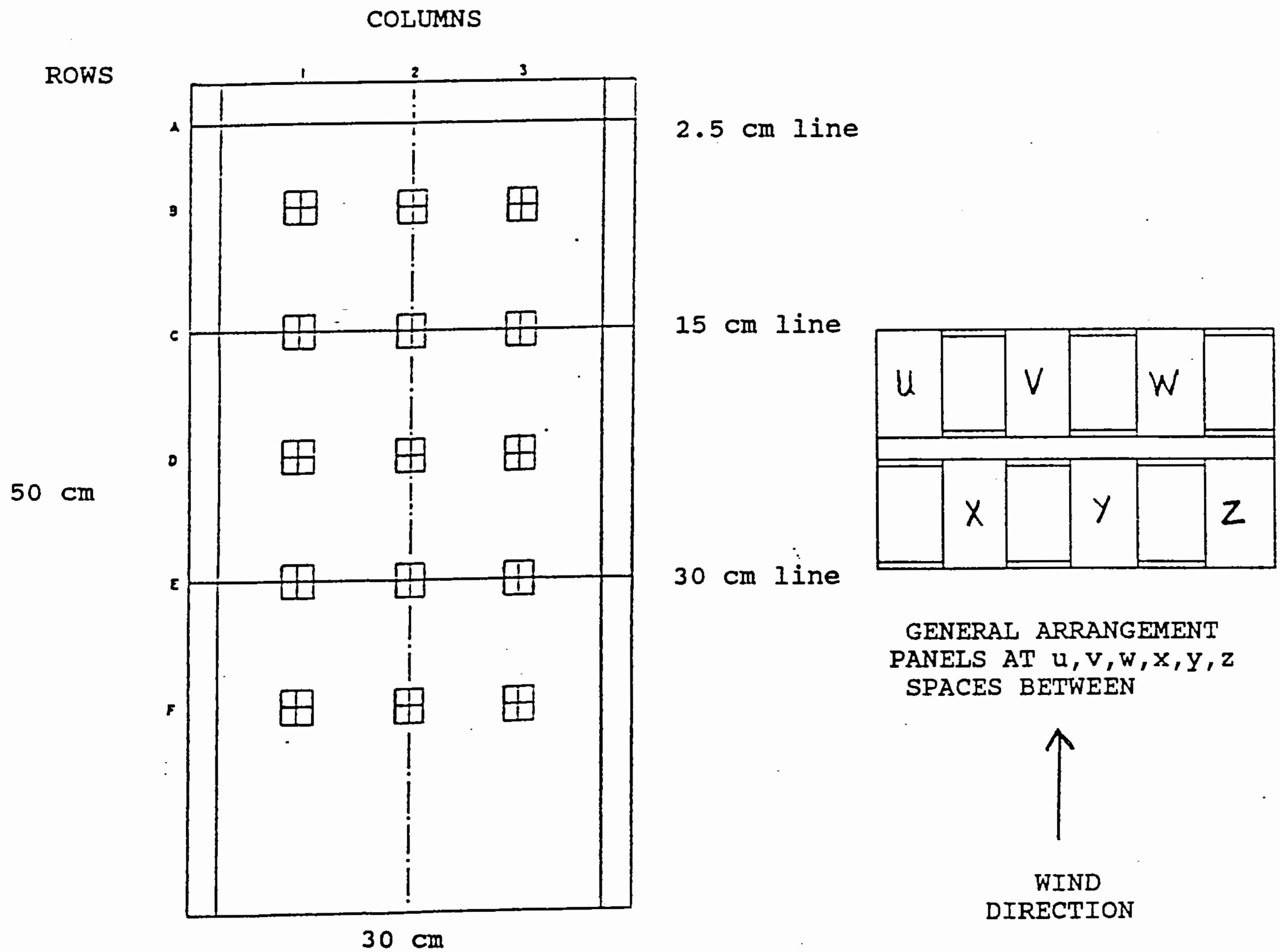
Figure 2 T E S T P A N E L M A R K I N G S T A N D A R D



Line A (known also as the 1-inch line) is 2.5cm from the top edge

Cross-hairs are marked as crosses in a square 2 cm on a side.

The first row of cross-hairs is on line B, 7.5cm from the top edge; subsequent rows are called C, D, E and F

Columns are identified as "1", "2" and "3" from left to right as viewed from the upwind direction. Column 2 is on the centreline of the panel

Cross-hair points are 7.5cm between centres along columns and rows

The line drawn at row C is the 15cm (or 6-inch) line

The line drawn at row E is the 30cm (or 12-inch) line

The general arrangement shows six panels mounted in a staggered fashion.

The wind vector direction is optimal for the panel orientation.

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APPENDIX A-3

ORIGINAL AND REVISED DATA FORMS

NOTE: ORIGINAL FORM REDUCED FROM 8.5" x 14"

HOLDOVER TEST RECORD SHEET

GENERAL OBSERVATIONS

Location: Date: Run #:

Start Time: End Time:

Air Temp C Start :
Finish :

Relative Humidity % :

Windspeed (min / max):

Weather Conditions: (circle)

Light snow
Mediun snow
Heavy snow
Freezing rain

Freezing Drizzle
Frost
Hail

Performed By: (name company)

PRECIPITATION
MANUAL CAKE PAN METHOD

Collection area cm sq :

Collection time minutes :

Initial total weight gm :

Final total weight gm :

PRECIPITATION RATE : gm/dm sq/hr

PRECIPITATION
RAIN GUAGE METHOD

Precipitation Rate (mm/hr) After:

5 min

10 min

20 min

25 min

30 min

35 min

40 min

45 min

50 min

55 min

60 min

65 min

AVERAGE PRECIPITATION RATE (mm/hr):
SNOW GUAGE DIAMETER (cm) :

PANEL NUMBER	PANEL TEMP	FLUID DESIGNATION	CONC.	FILM THICKNESS @ 2.5 CM	15 CM	30 CM	PRECIPITATION FRONT 2.5 cm	15 cm	SNOW (S) OR GLOSS(G) CONDITION CROSS HAIR COLUMN 1	2	3	ROW	REMARKS / COMMENTS
	C		%	um/mils			minutes		specify S or G minutes				use reverse side if necessary
1			100									B C D E F	
2			100									B C D E F	
3			100									B C D E F	
4			100									B C D E F	
5			100									B C D E F	
6			100									B C D E F	

REVISED DE/ANTI ICING DATA FORM

LOCATION:	DATE:	RUN NUMBER:
COMPANY:		START TIME: FINISH TIME:

TEST	AIR TEMPERATURE (c or f)	RELATIVE HUMIDITY (%)	WIND SPEED (knots or m/s)	PRECIPITATION TYPE: (circle)
				LIGHT SNOW FROST
START				MEDIUM SNOW HAIL
				HEAVY SNOW
FINISH				FREEZING RAIN
				FREEZING DRIZZLE

	PANEL u	PANEL v	PANEL w	PANEL x	PANEL y	PANEL z	REMARKS:
FLUID NAME							
FLUID FILM THICKNESS							
(mils) AT: 1 inch line							
6 inch line							
12 inch line							
PANEL TEMP. (c or f)							

--- END CONDITIONS ---

PROGRESSIVE SURFACE FREEZING - TIME FOR ICE FORMATION TO :							REMARKS:
TIME 1 inch line							
6 inch line							
12 inch line							

OR

SNOW ACCUMULATION - TIME TO OBSCURE FIVE CROSS HAIRS (ONE THIRD OF PANEL) - CIRCLE AFFECTED CROSSHAIRS							REMARKS:
	B1 B2 B3 C1 C2 C3 D1 D2 D3 E1 E2 E3 F1 F2 F3	B1 B2 B3 C1 C2 C3 D1 D2 D3 E1 E2 E3 F1 F2 F3	B1 B2 B3 C1 C2 C3 D1 D2 D3 E1 E2 E3 F1 F2 F3	B1 B2 B3 C1 C2 C3 D1 D2 D3 E1 E2 E3 F1 F2 F3	B1 B2 B3 C1 C2 C3 D1 D2 D3 E1 E2 E3 F1 F2 F3	B1 B2 B3 C1 C2 C3 D1 D2 D3 E1 E2 E3 F1 F2 F3	
TIME							

OR

LOSS OF GLOSS OR ICE GROWTH - TIME TO OBSCURE 5 CROSSHAIRS (1/3 OF PANEL) - CIRCLE AFFECTED CROSSHAIRS							REMARKS:
	B1 B2 B3 C1 C2 C3 D1 D2 D3 E1 E2 E3 F1 F2 F3	B1 B2 B3 C1 C2 C3 D1 D2 D3 E1 E2 E3 F1 F2 F3	B1 B2 B3 C1 C2 C3 D1 D2 D3 E1 E2 E3 F1 F2 F3	B1 B2 B3 C1 C2 C3 D1 D2 D3 E1 E2 E3 F1 F2 F3	B1 B2 B3 C1 C2 C3 D1 D2 D3 E1 E2 E3 F1 F2 F3	B1 B2 B3 C1 C2 C3 D1 D2 D3 E1 E2 E3 F1 F2 F3	
TIME							

PRECIP.

RAIN/SNOW GUAGE METHOD number of tips after:			SNOW GUAGE DIAMETER (cm):
5 min	25 min	45 min	______
10 min	30 min	50 min	
15 min	35 min	55 min	SENSITIVITY (mm/tip):
20 min	40 min	60 min	______
AVERAGE PRECIPITATION (mm/hr):			

MANUAL CAKE PAN METHOD	PAN 1	PAN 2
WEIGHT OF PAN AFTER TEST (grams)		
WEIGHT OF PAN BEFORE TEST (grams)		
DIFFERENCE (grams)		
COLLECTION TIME		
COLLECTION AREA (sq. decimeters)		
PRECIPITAITON RATE (g/sq dec/hr)		

TEST PERFORMED BY:

(initials)

______

______

APPENDIX B

FAILURE TIME VS PRECIPITATION CHARTS FOR ALL TEST FLUIDS

FAILURE TIME vs RATE OF PRECIPITATION
ALL DATA, ALL WEATHER
TYPE II FLUIDS

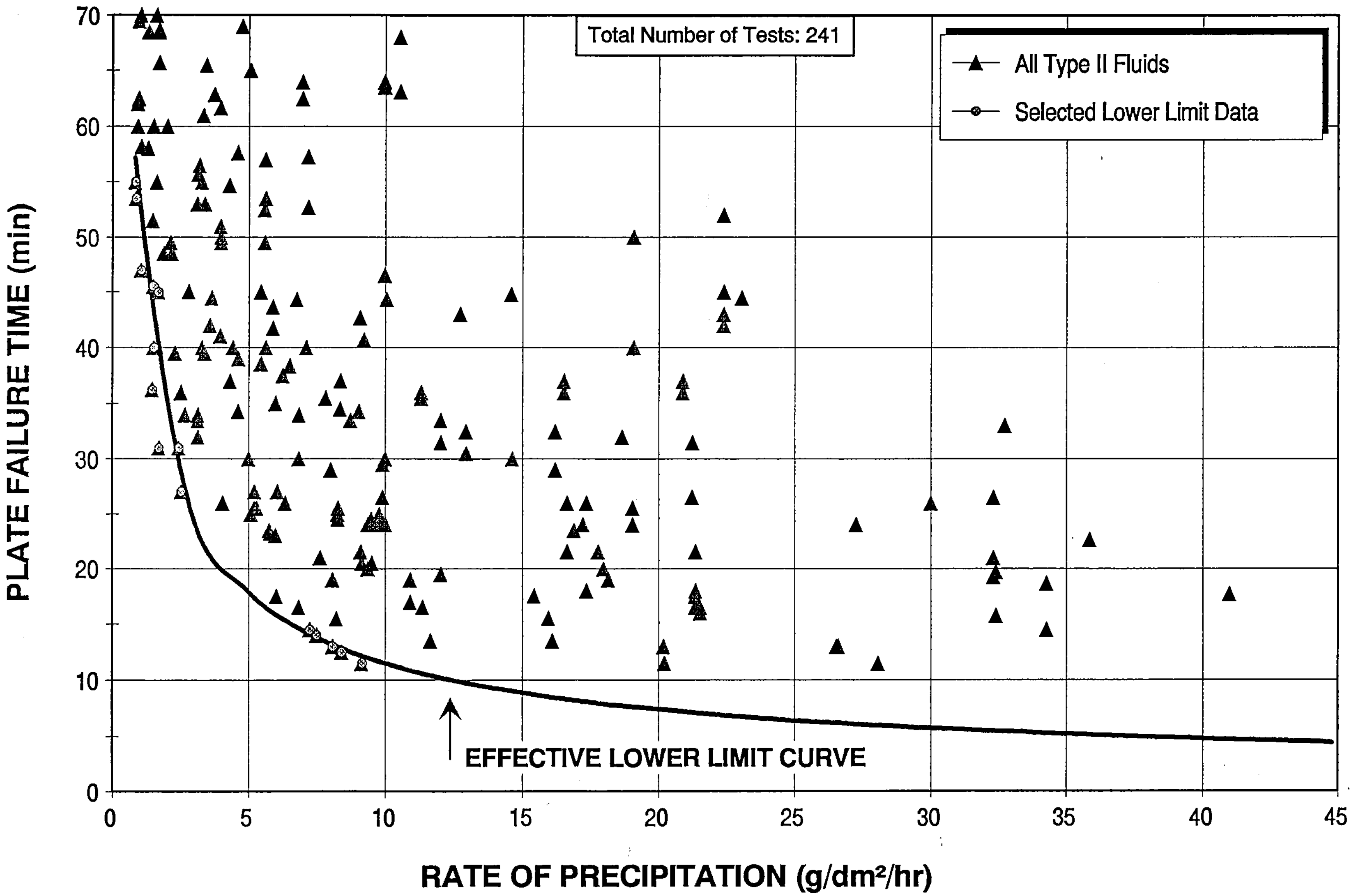


PLATE FAILURE TIMES
ALL DATA, ALL WEATHER
TYPE 1.5 FLUIDS

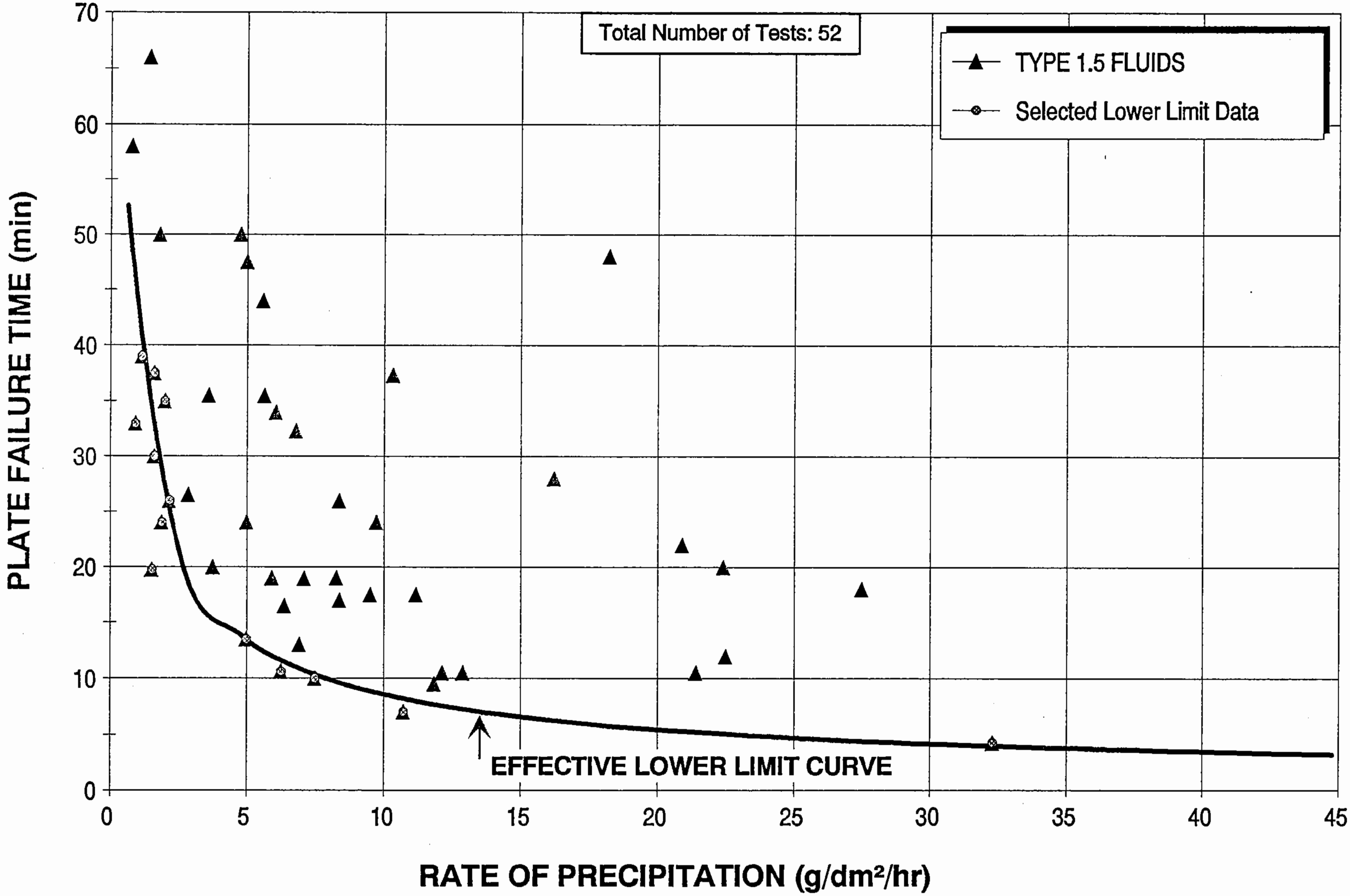
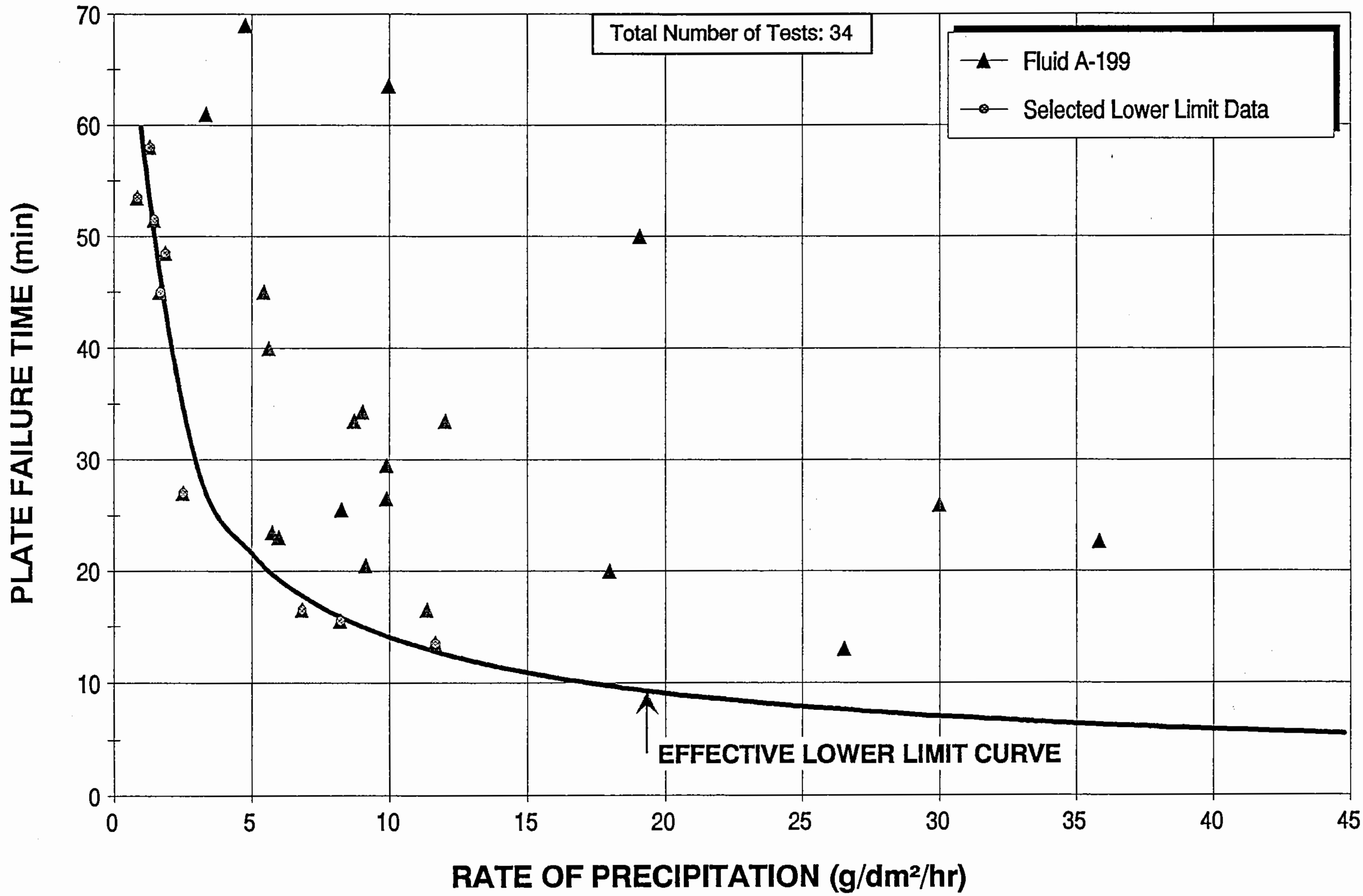


PLATE FAILURE TIMES
ALL DATA, ALL WEATHER
FLUID A-199



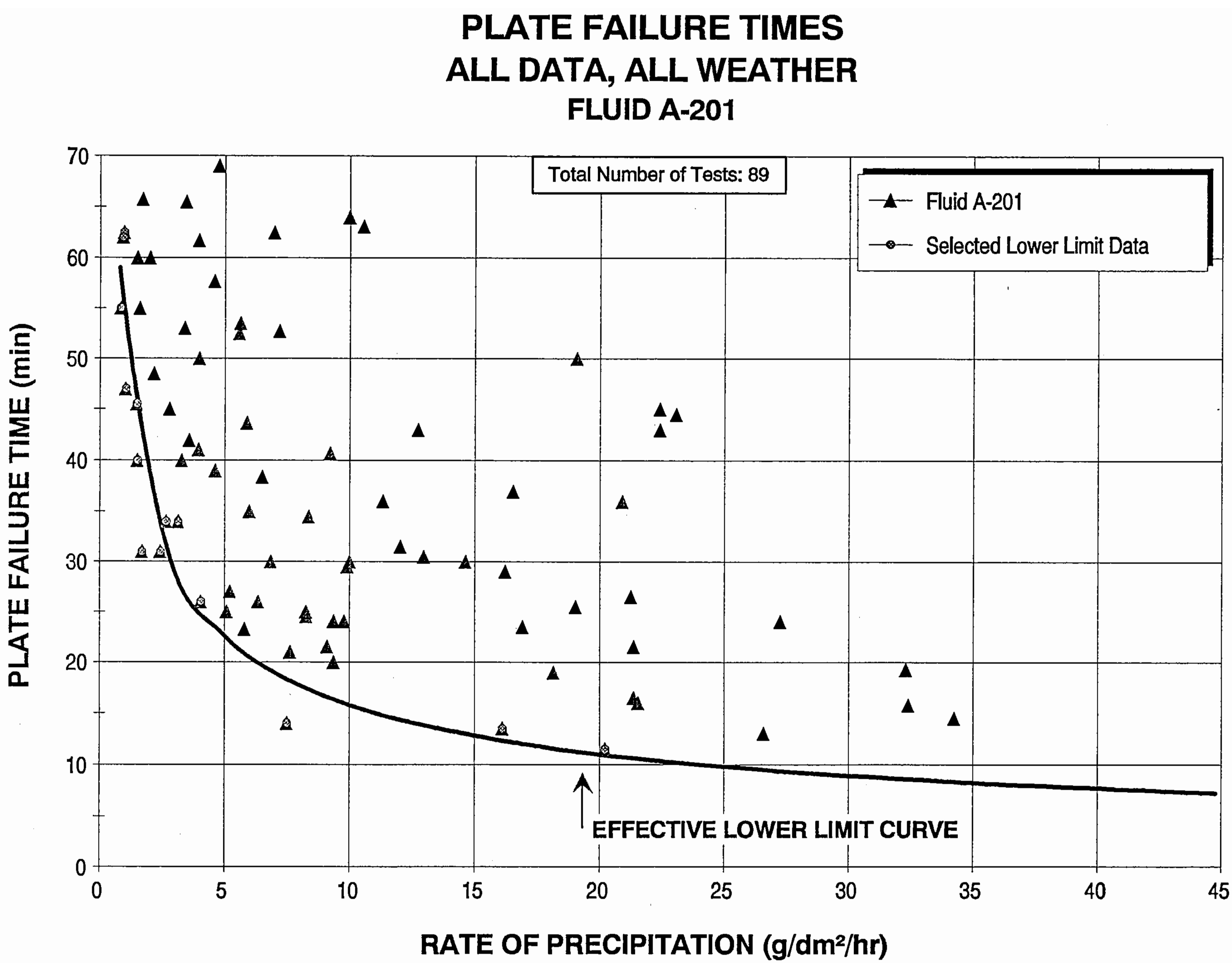


PLATE FAILURE TIMES
ALL DATA, ALL WEATHER
FLUID A-201
Total Number of Tests: 89
Fluid A-201
Selected Lower Limit Data
EFFECTIVE LOWER LIMIT CURVE
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45

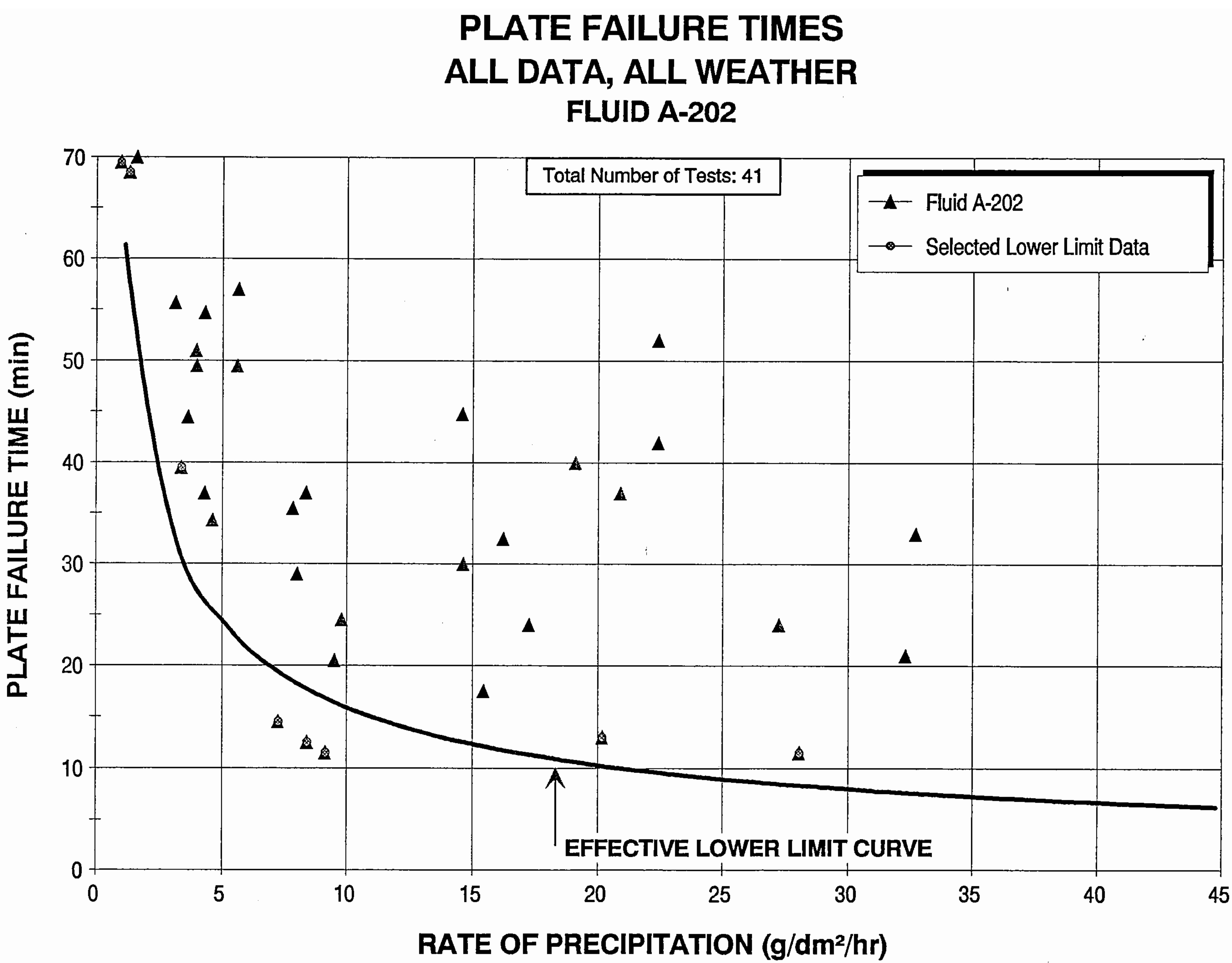


PLATE FAILURE TIMES
ALL DATA, ALL WEATHER
FLUID A-202
Total Number of Tests: 41
Fluid A-202
Selected Lower Limit Data
PLATE FAILURE TIME (min)
0
10
20
30
40
50
60
70
RATE OF PRECIPITATION (g/dm²/hr)
0
5
10
15
20
25
30
35
40
45
EFFECTIVE LOWER LIMIT CURVE

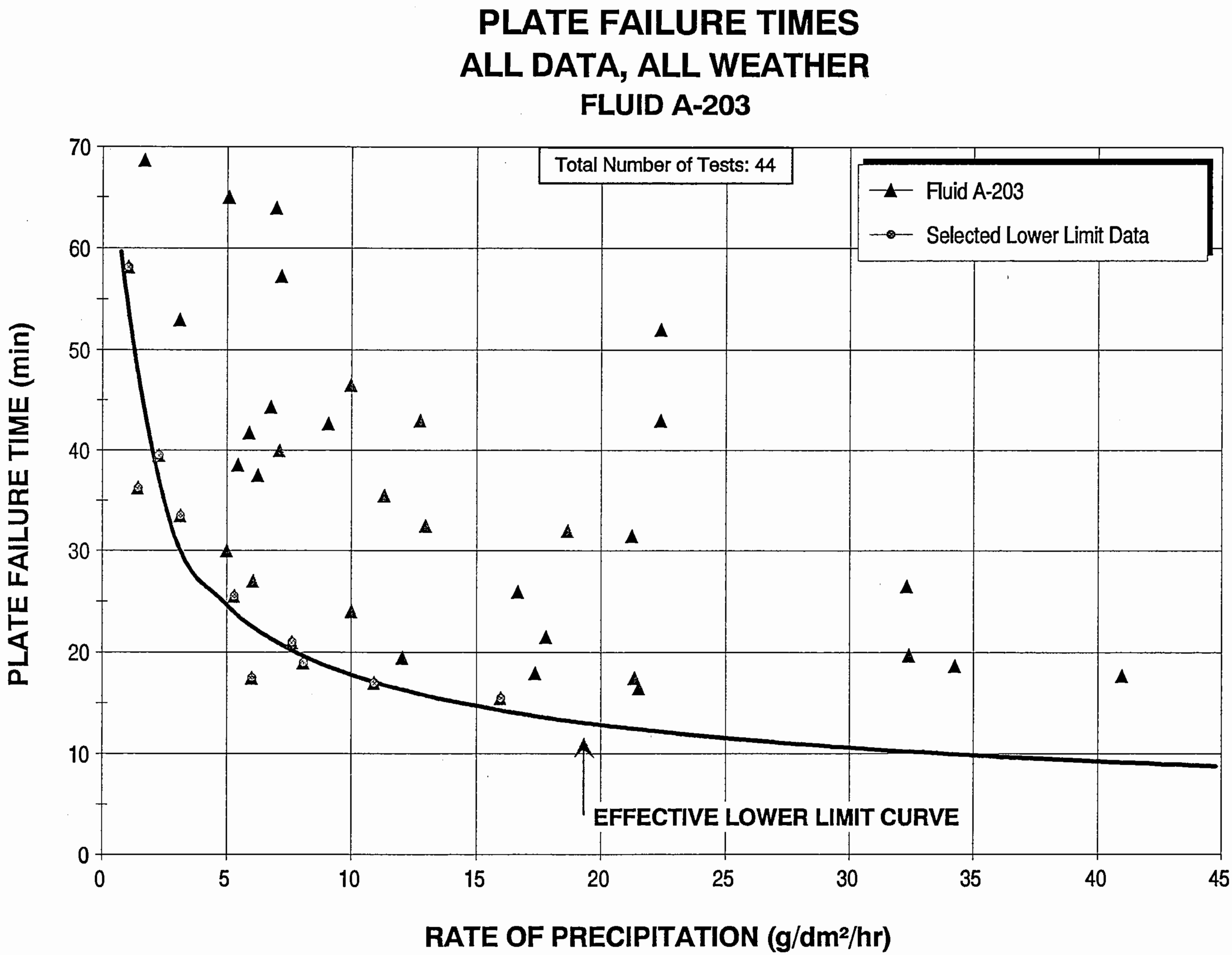


PLATE FAILURE TIMES
ALL DATA, ALL WEATHER
FLUID A-203
Total Number of Tests: 44
Fluid A-203
Selected Lower Limit Data
EFFECTIVE LOWER LIMIT CURVE
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45

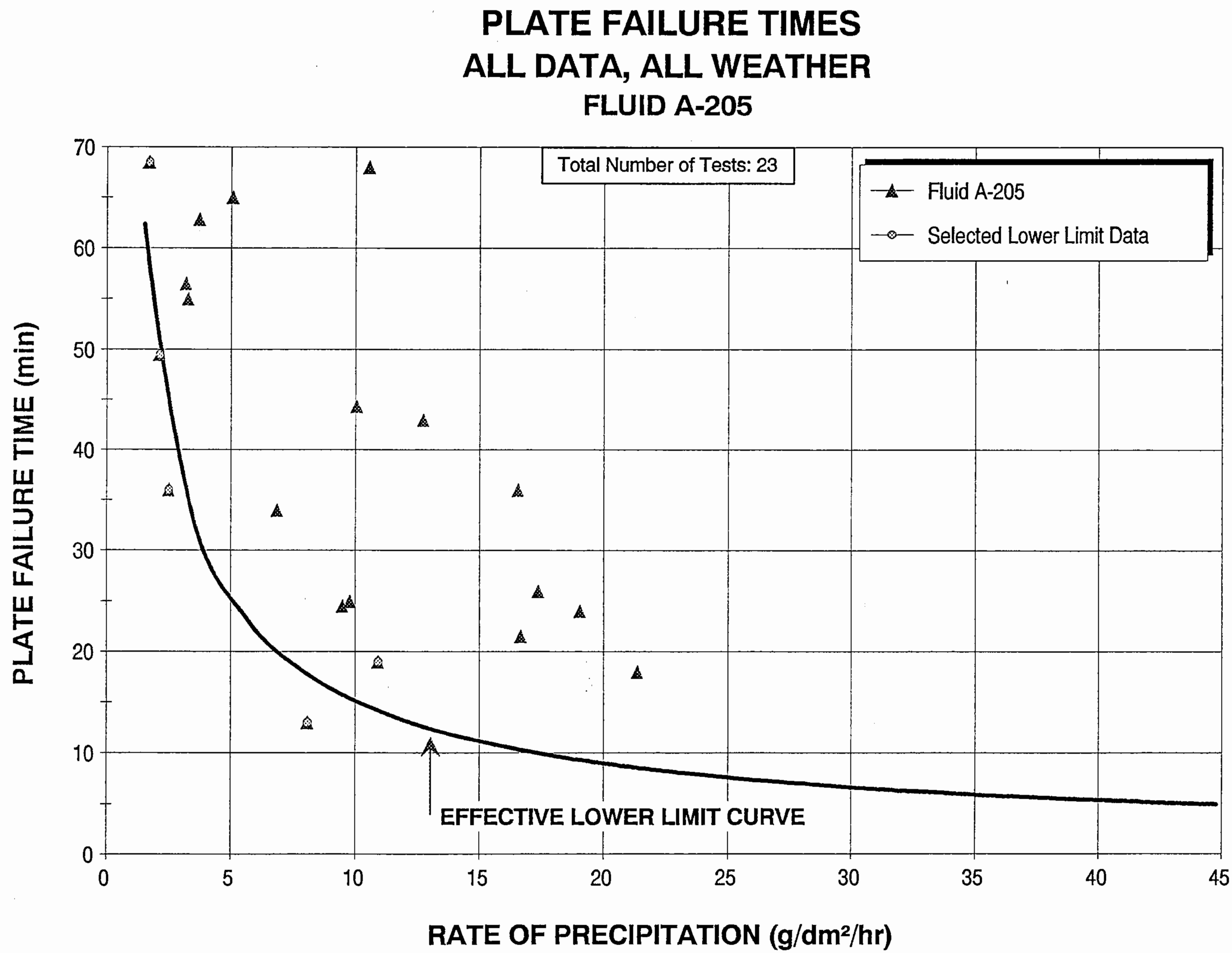


PLATE FAILURE TIMES
ALL DATA, ALL WEATHER
FLUID A-205
Total Number of Tests: 23
Fluid A-205
Selected Lower Limit Data
EFFECTIVE LOWER LIMIT CURVE
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45

PLATE FAILURE TIMES
ALL DATA, SNOW CONDITIONS
TYPE II FLUIDS

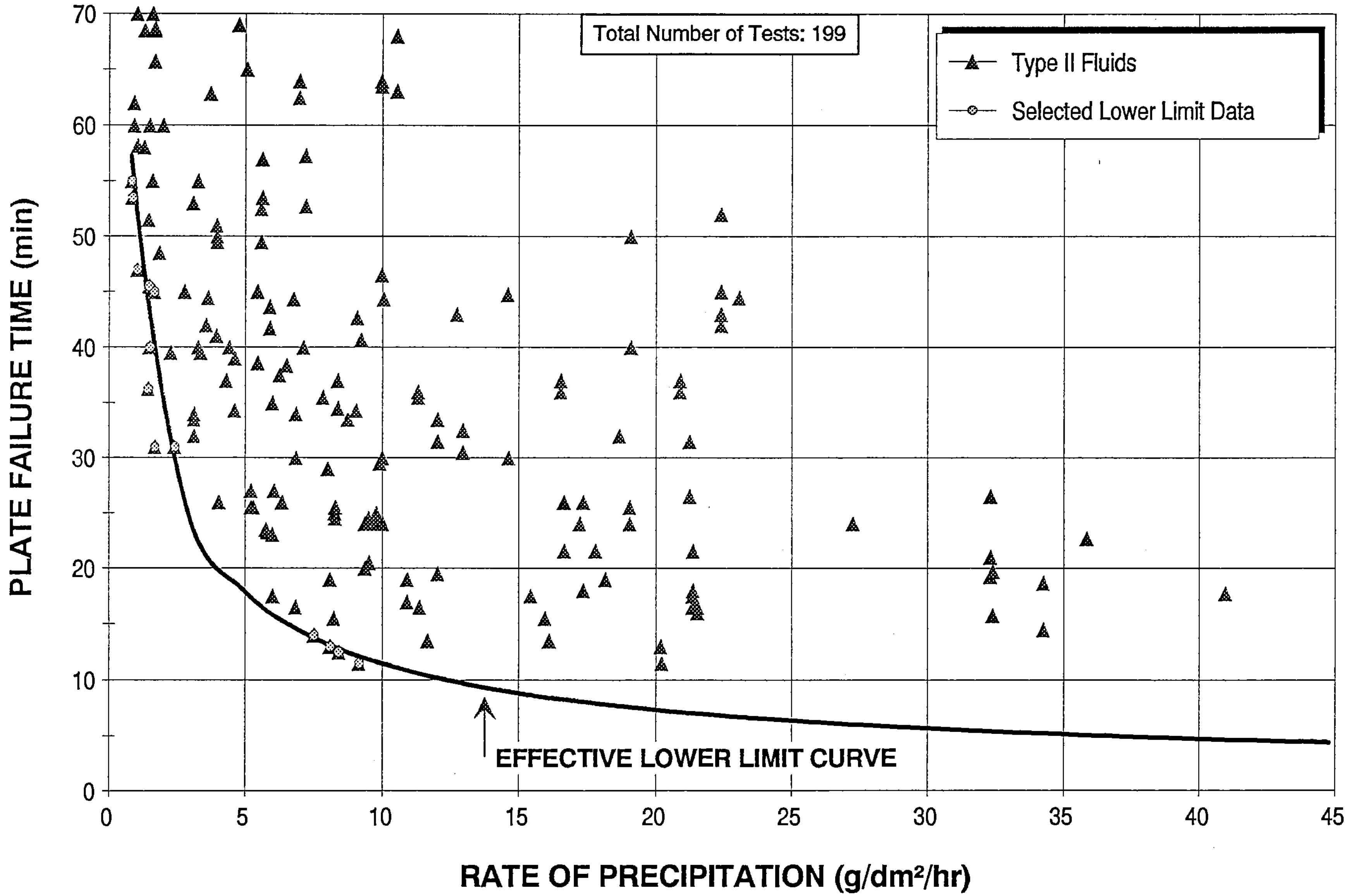


PLATE FAILURE TIMES
ALL DATA, SNOW CONDITIONS
TYPE 1.5 FLUIDS

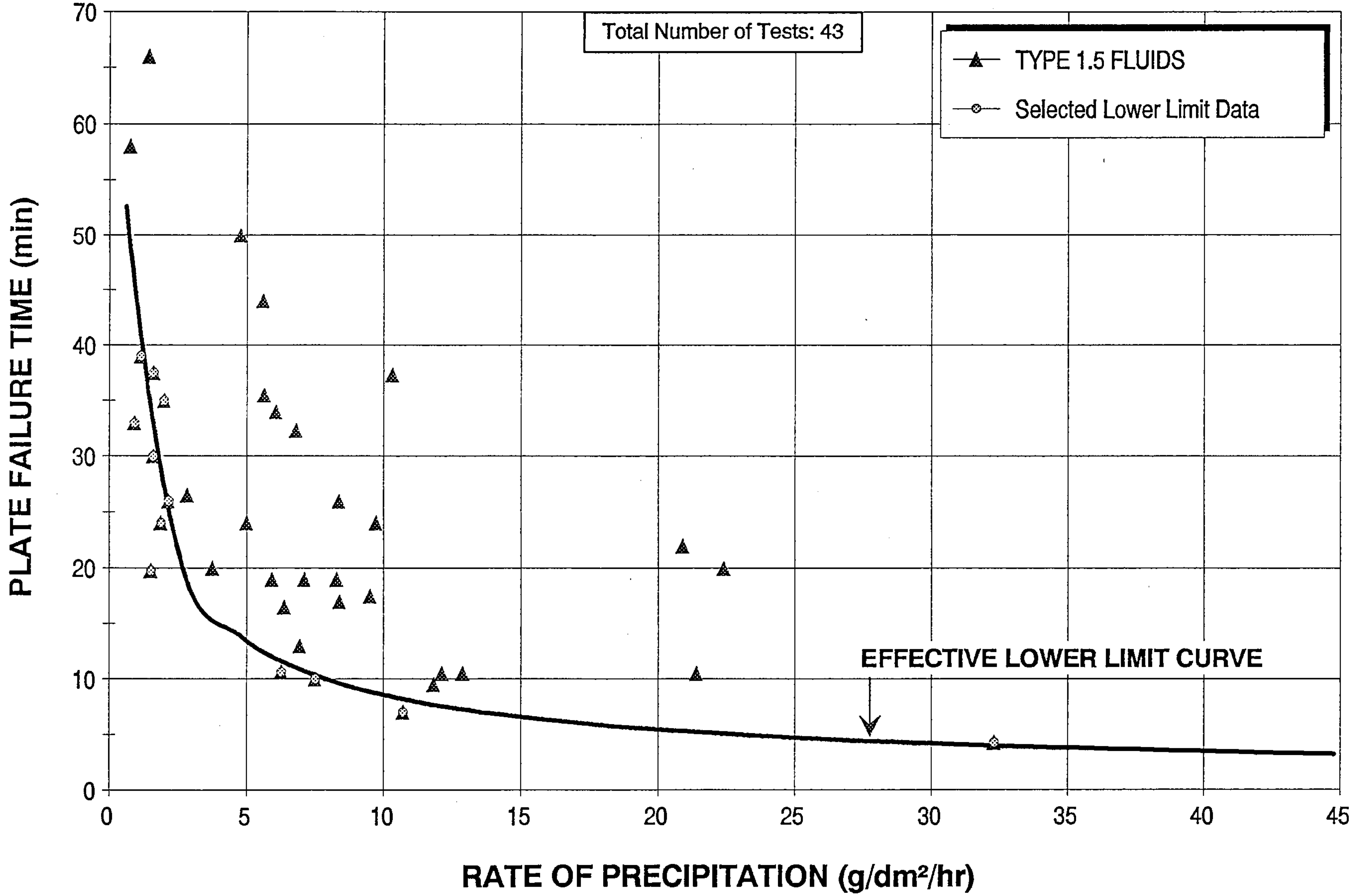


PLATE FAILURE TIMES
ALL DATA, SNOW CONDITIONS
FLUID A-199

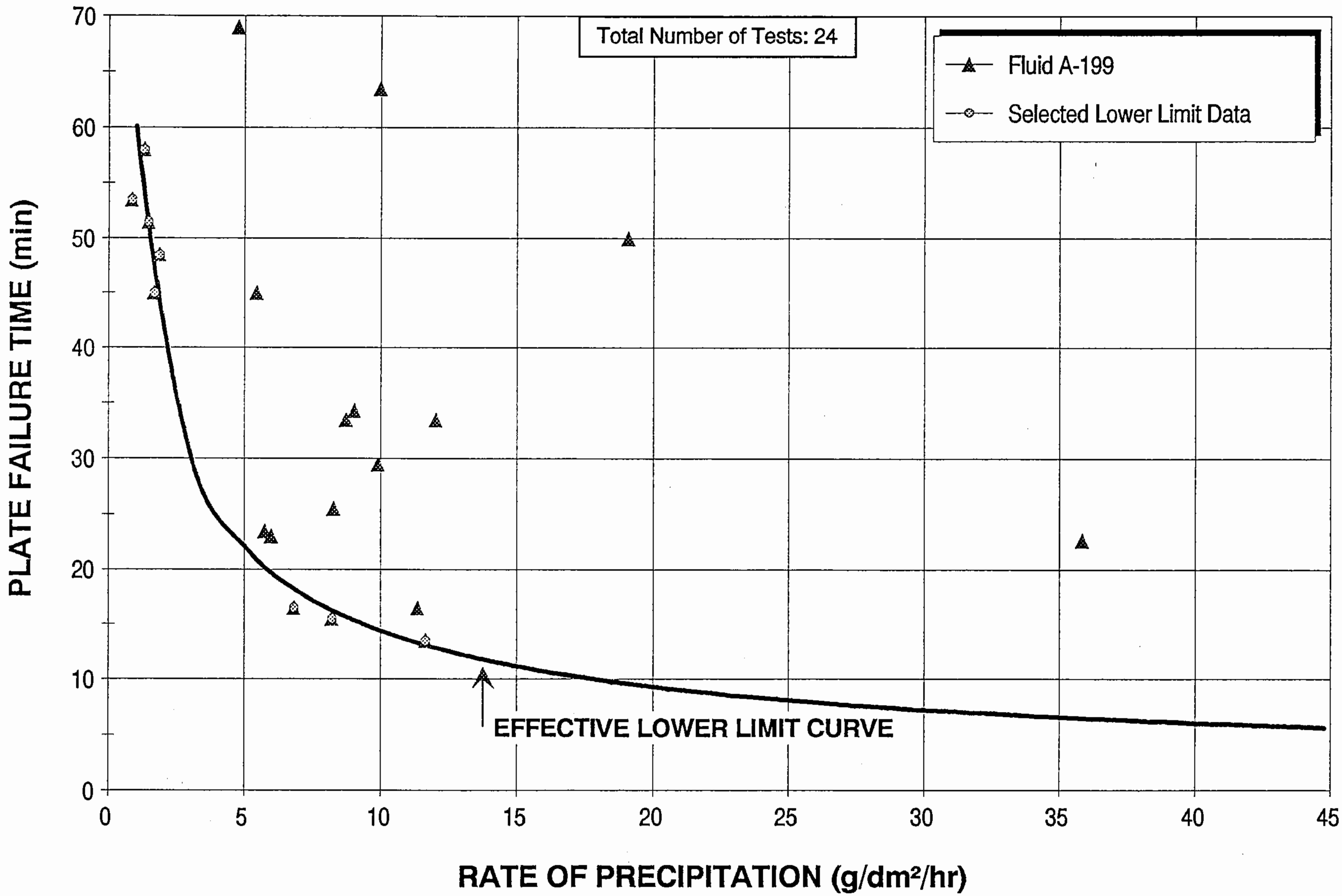


PLATE FAILURE TIMES
ALL DATA, SNOW CONDITIONS
FLUID A-201

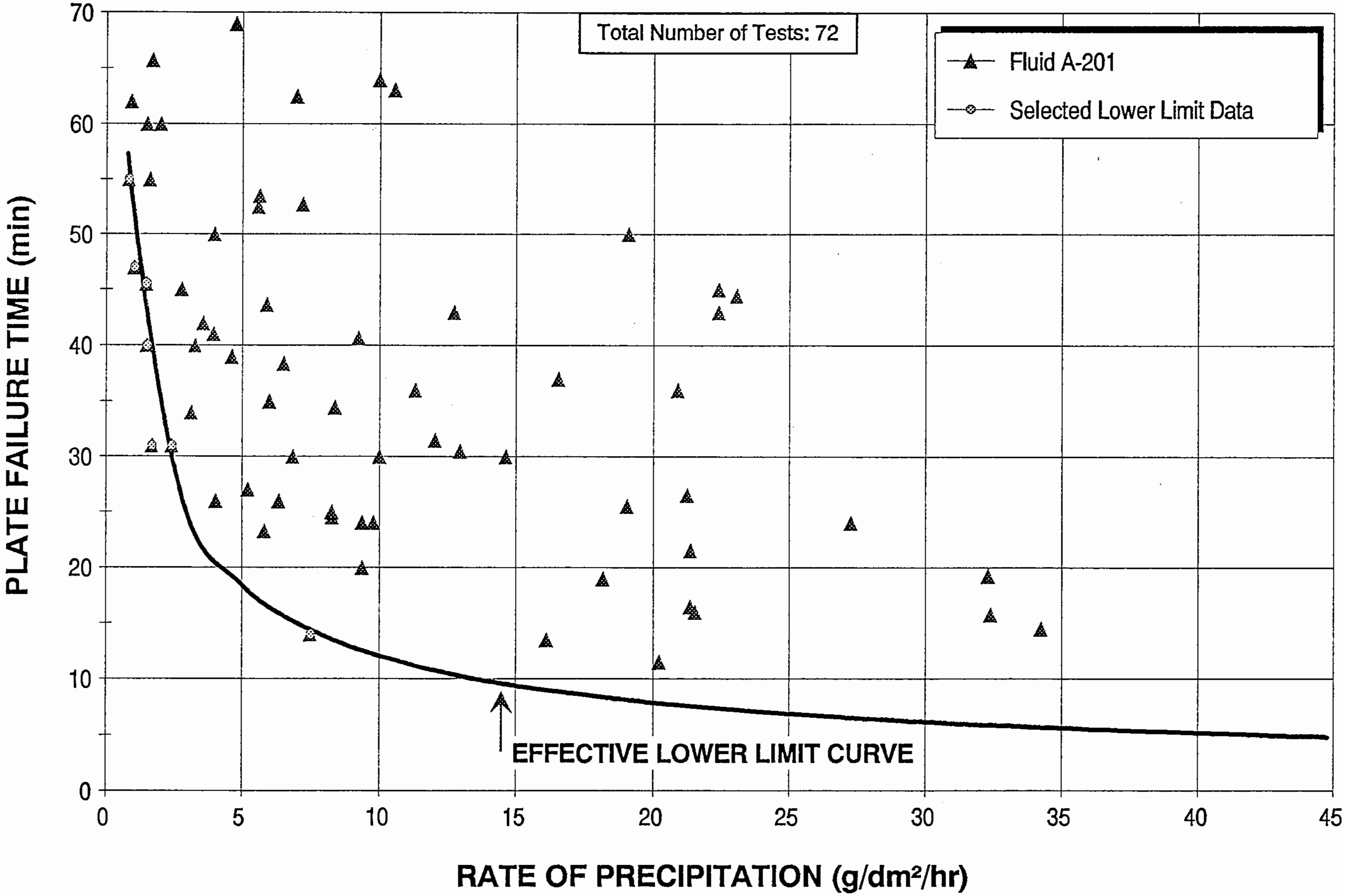
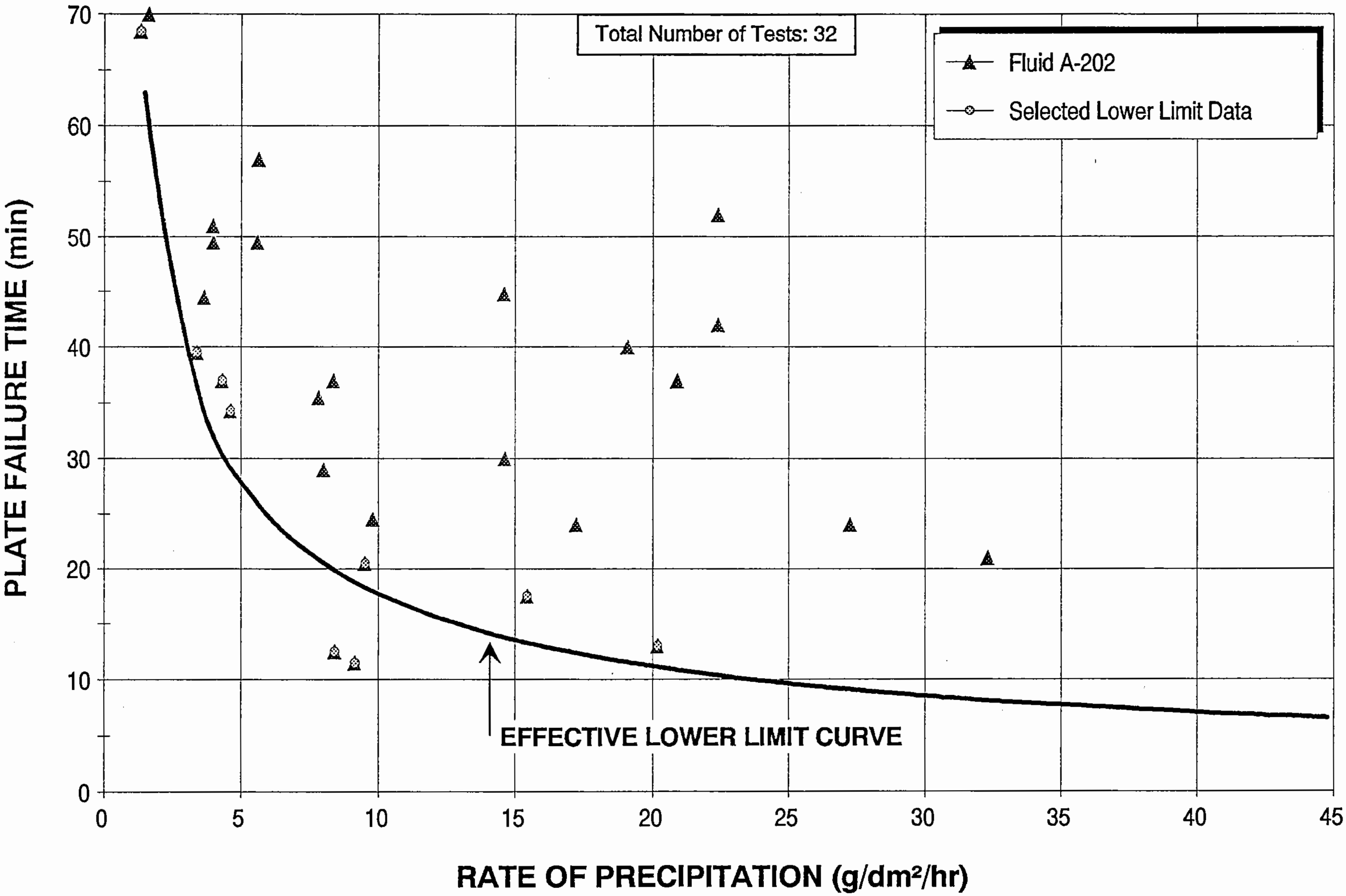


PLATE FAILURE TIMES
ALL DATA, SNOW CONDITIONS
FLUID A-202



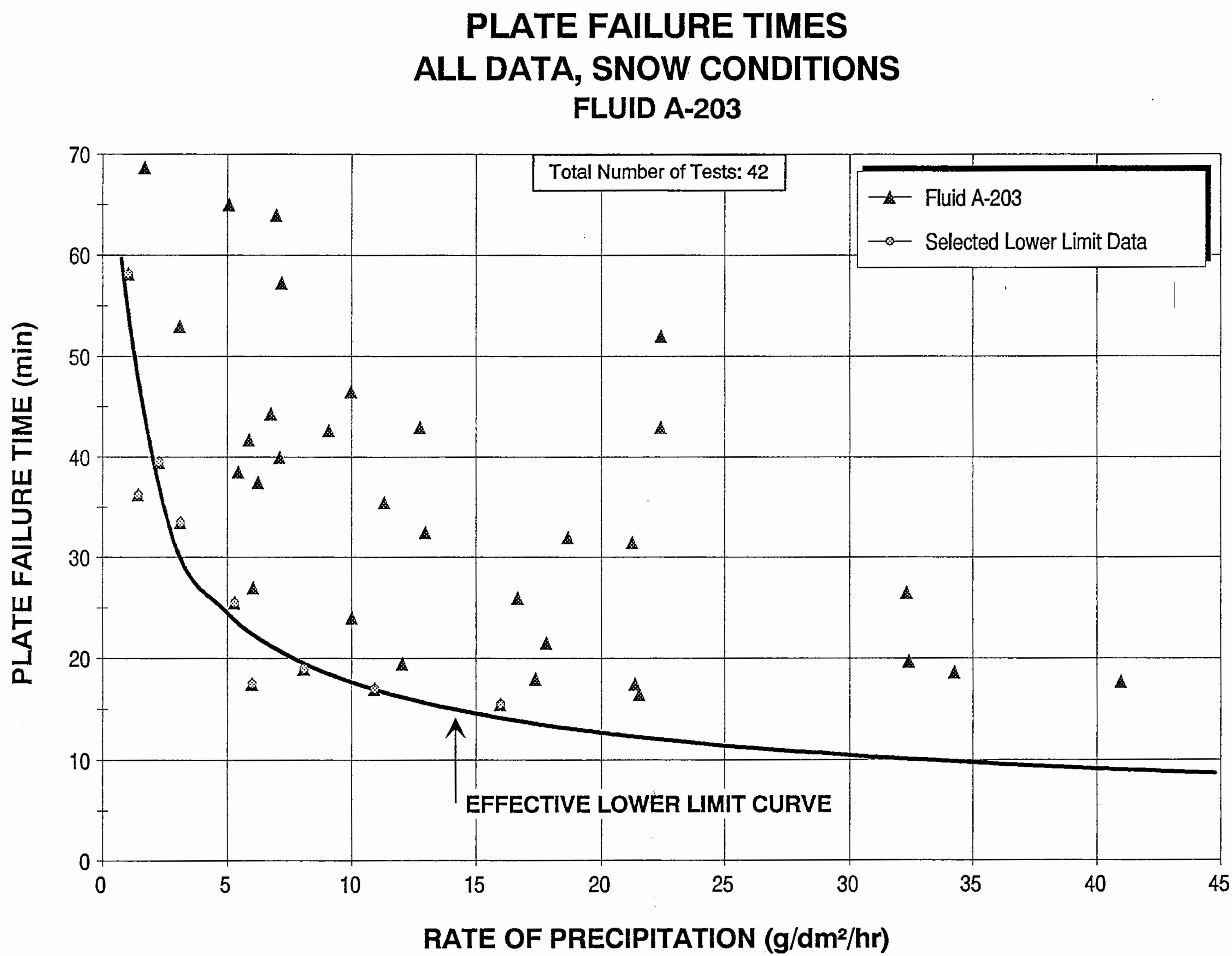
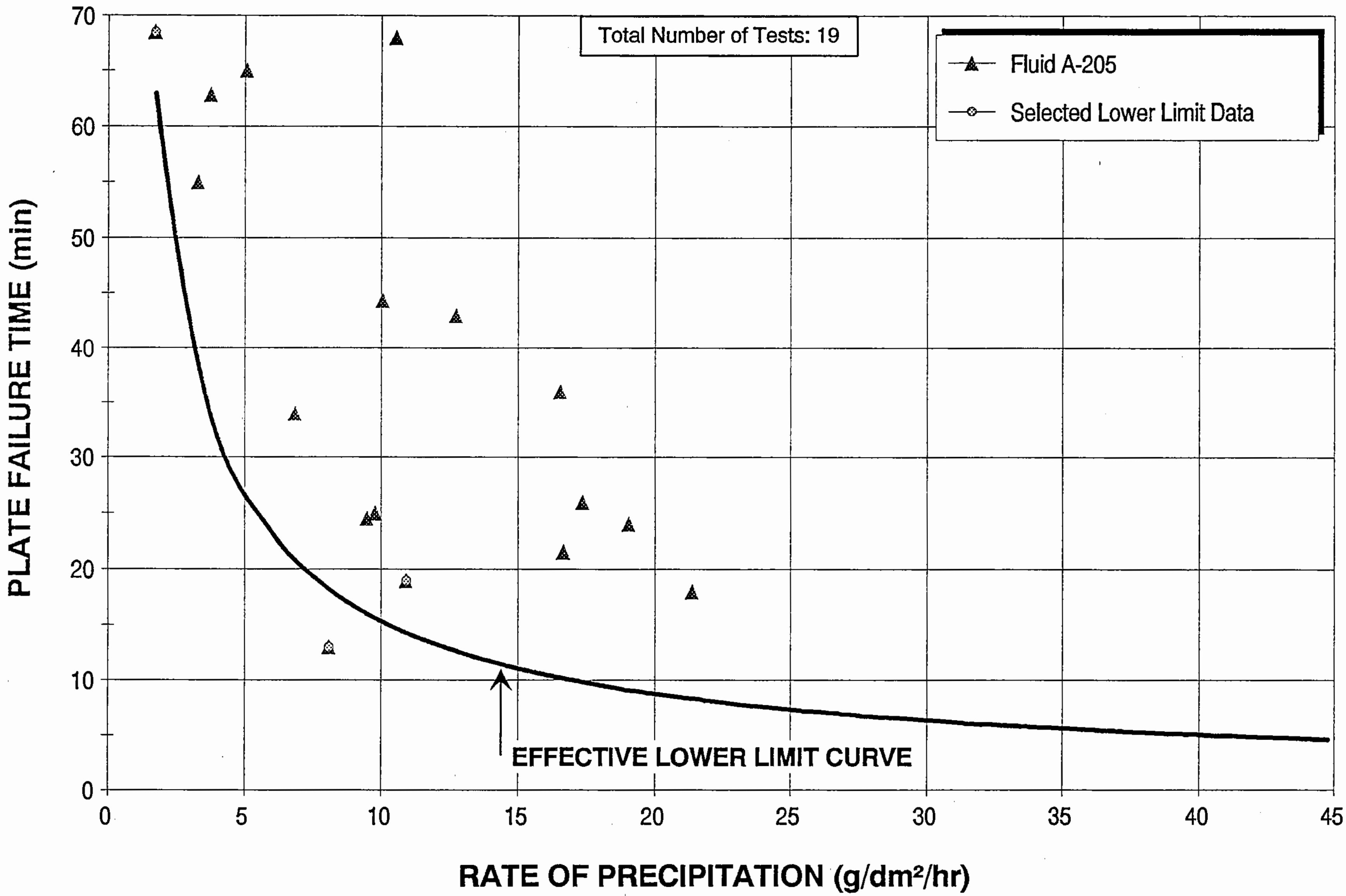
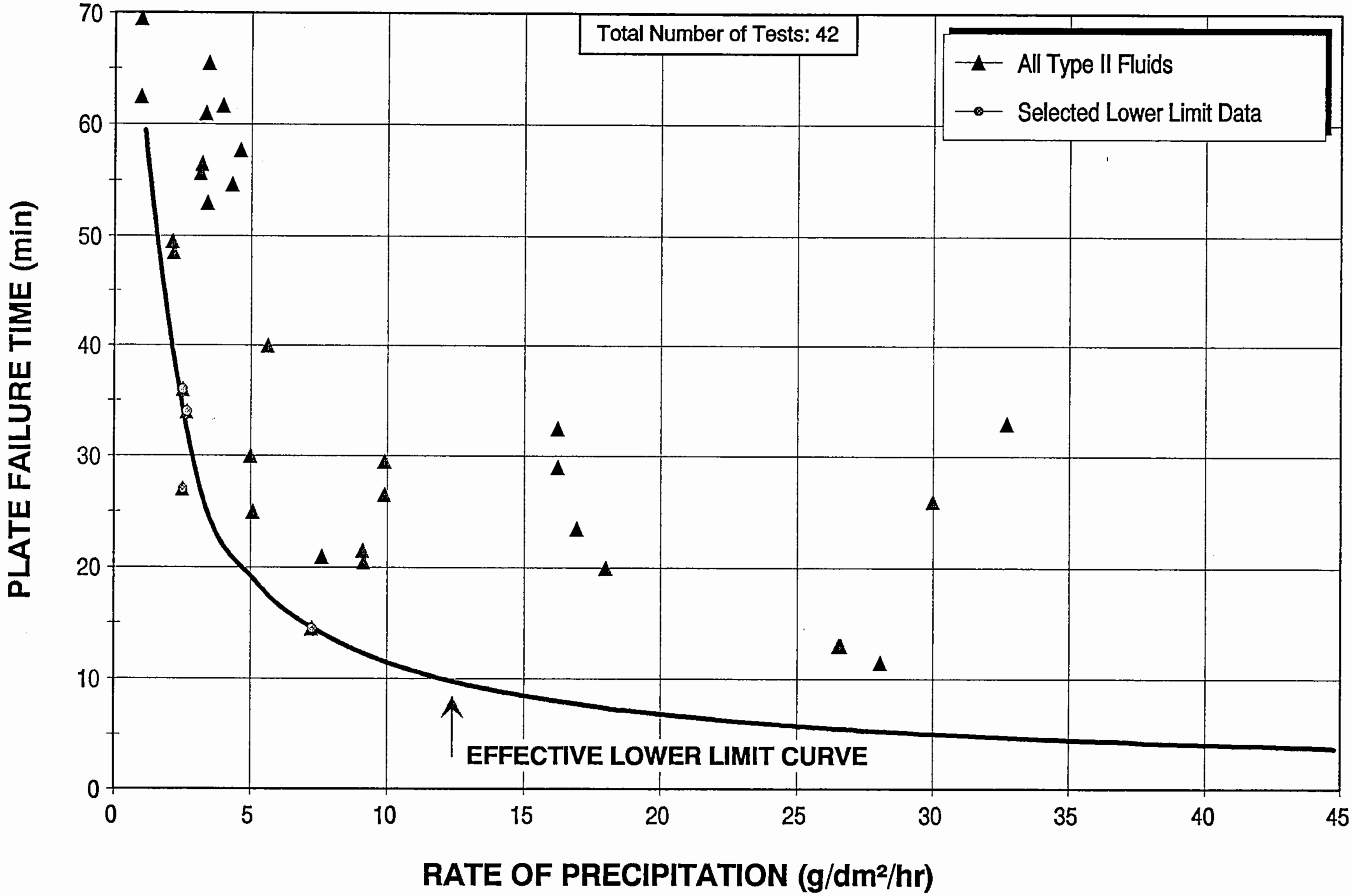


PLATE FAILURE TIMES
ALL DATA, SNOW CONDITIONS
FLUID A-203
Total Number of Tests: 42
Fluid A-203
Selected Lower Limit Data
EFFECTIVE LOWER LIMIT CURVE
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45

PLATE FAILURE TIMES
ALL DATA, SNOW CONDITIONS
FLUID A-205



FAILURE TIME vs RATE OF PRECIPITATION
ALL DATA, FREEZING RAIN/DRIZZLE
TYPE II FLUIDS



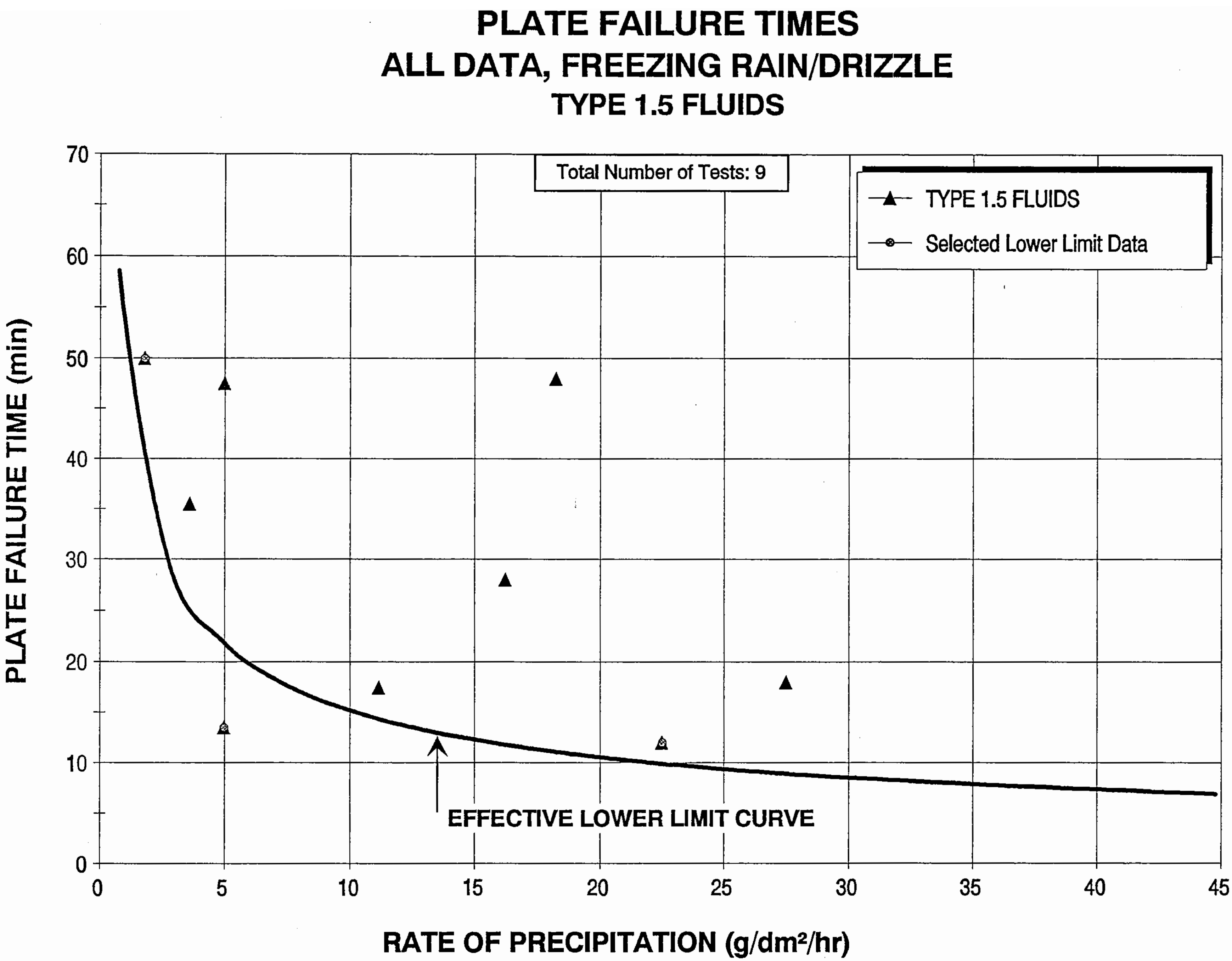


PLATE FAILURE TIMES
ALL DATA, FREEZING RAIN/DRIZZLE
TYPE 1.5 FLUIDS
Total Number of Tests: 9
TYPE 1.5 FLUIDS
Selected Lower Limit Data
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
EFFECTIVE LOWER LIMIT CURVE
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45

PLATE FAILURE TIMES
ALL DATA, FREEZING RAIN/DRIZZLE
FLUID A-199

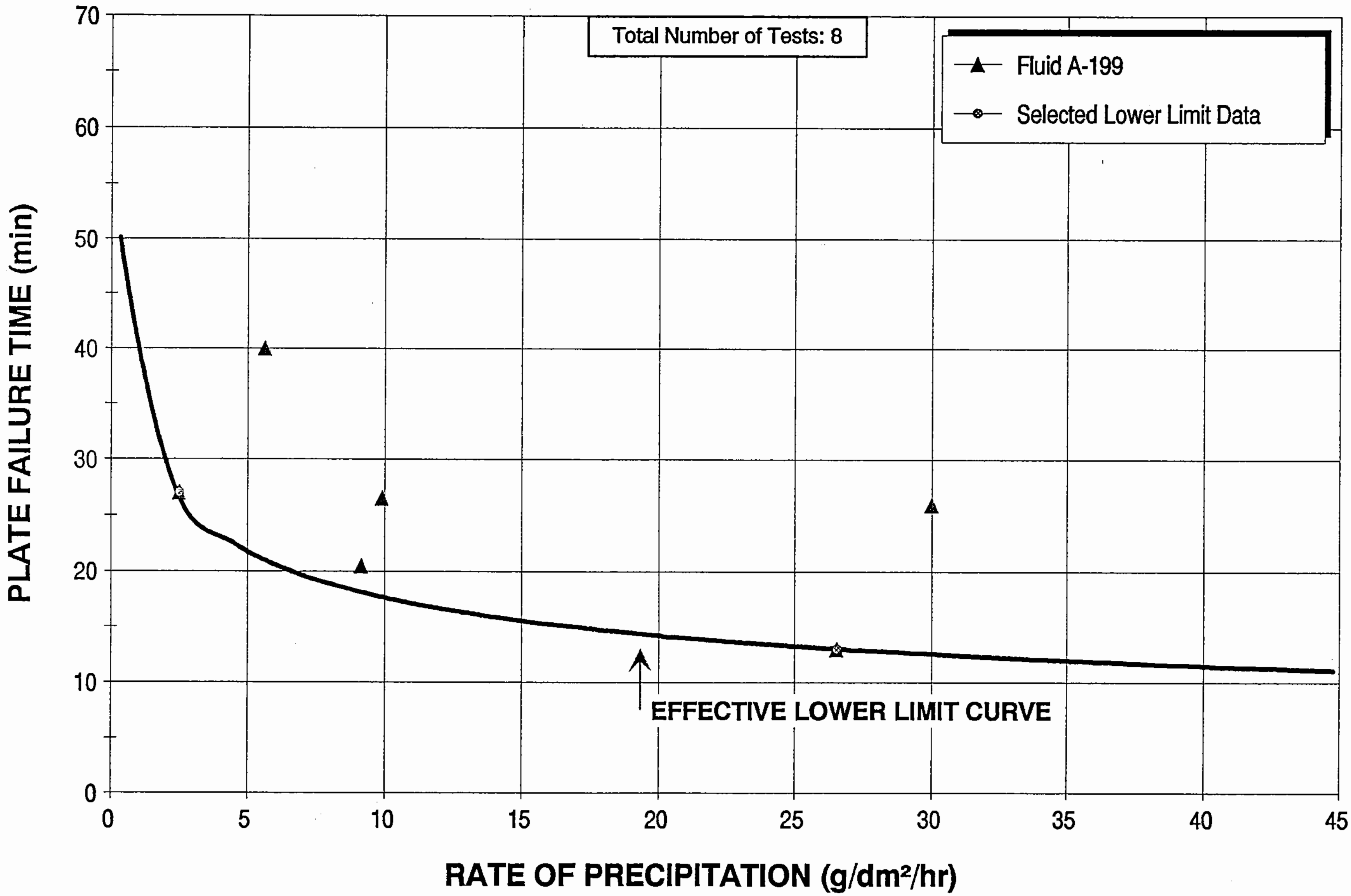


PLATE FAILURE TIMES
ALL DATA, FREEZING RAIN/DRIZZLE
FLUID A-201

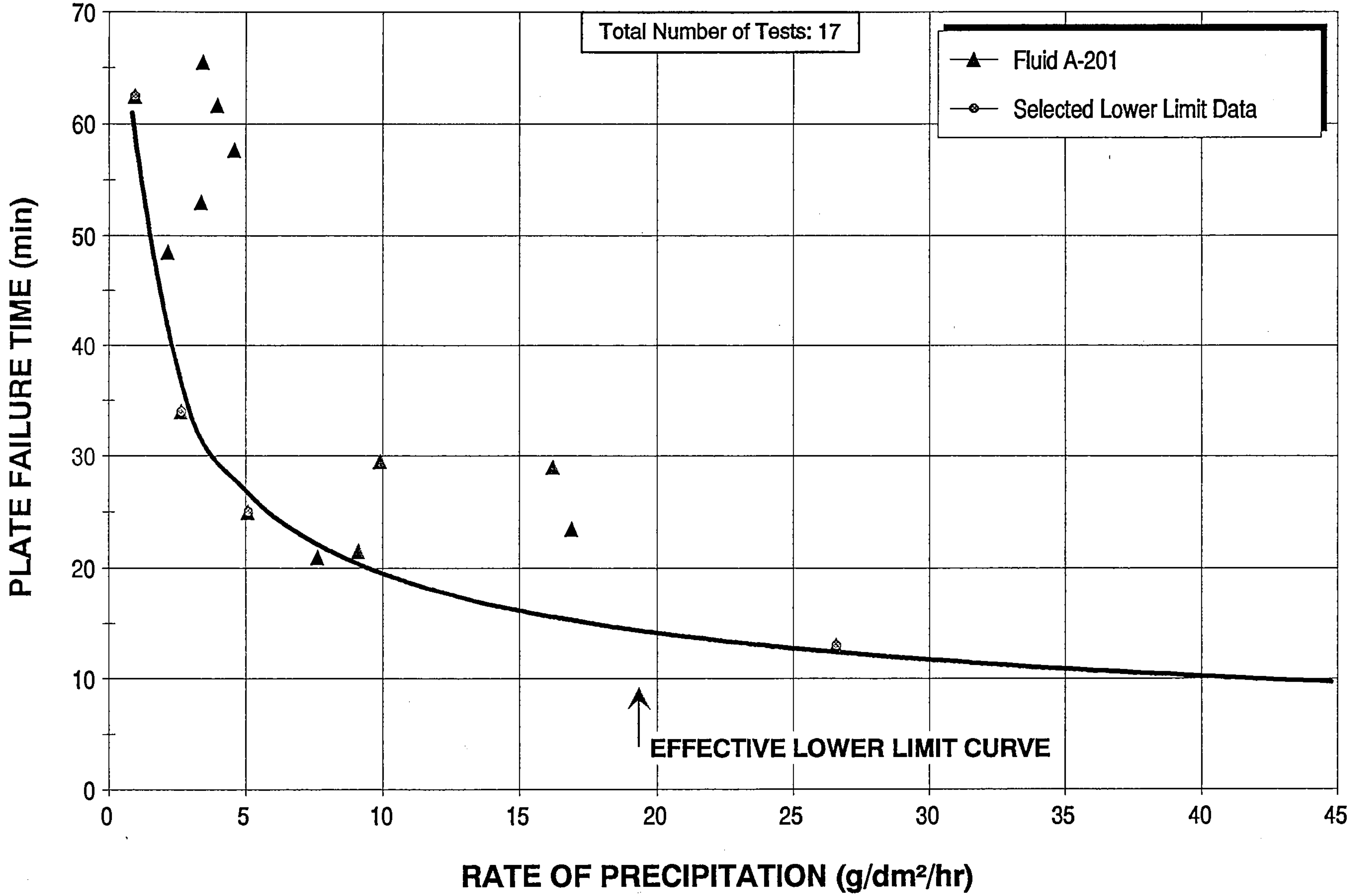
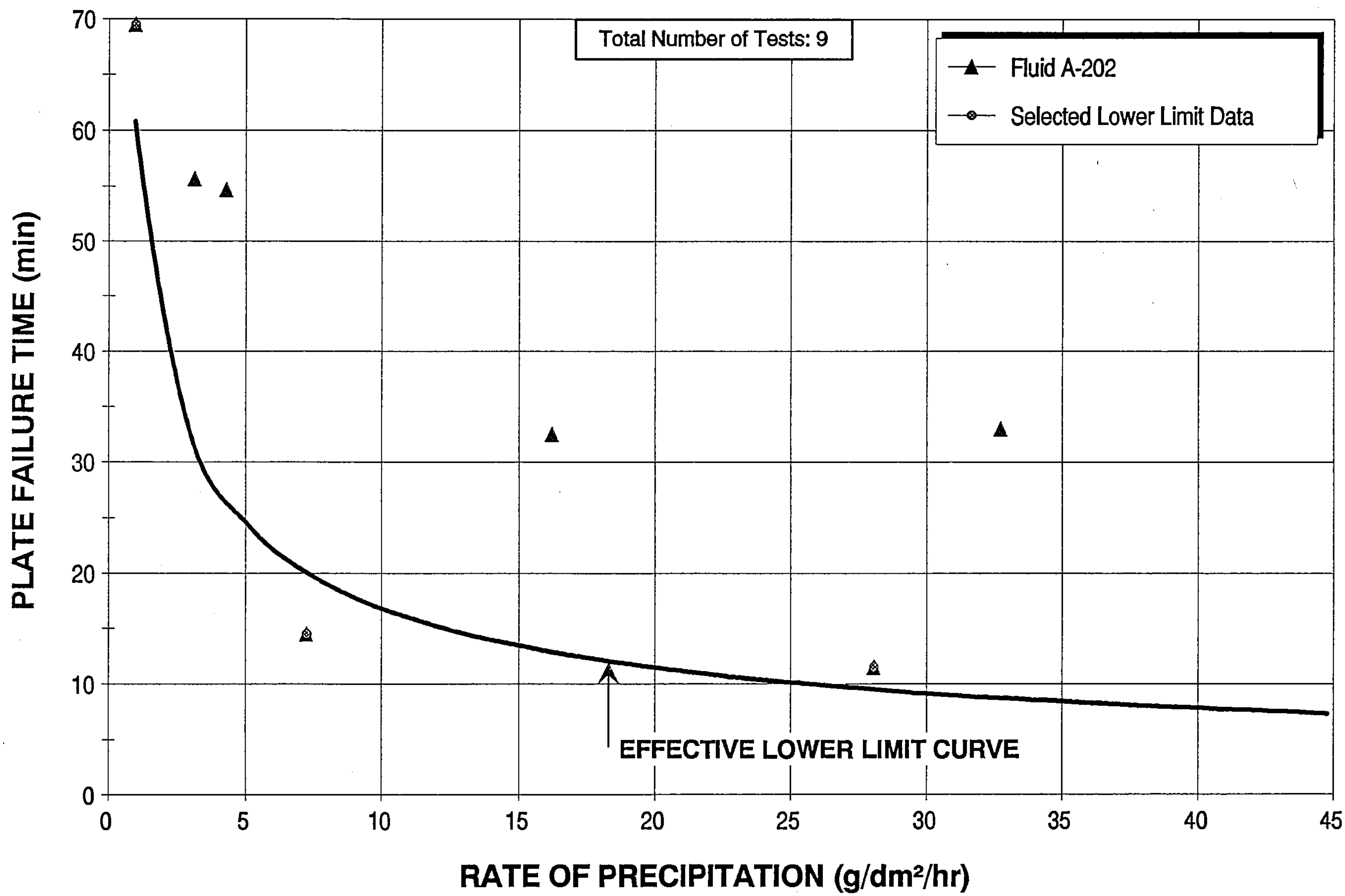
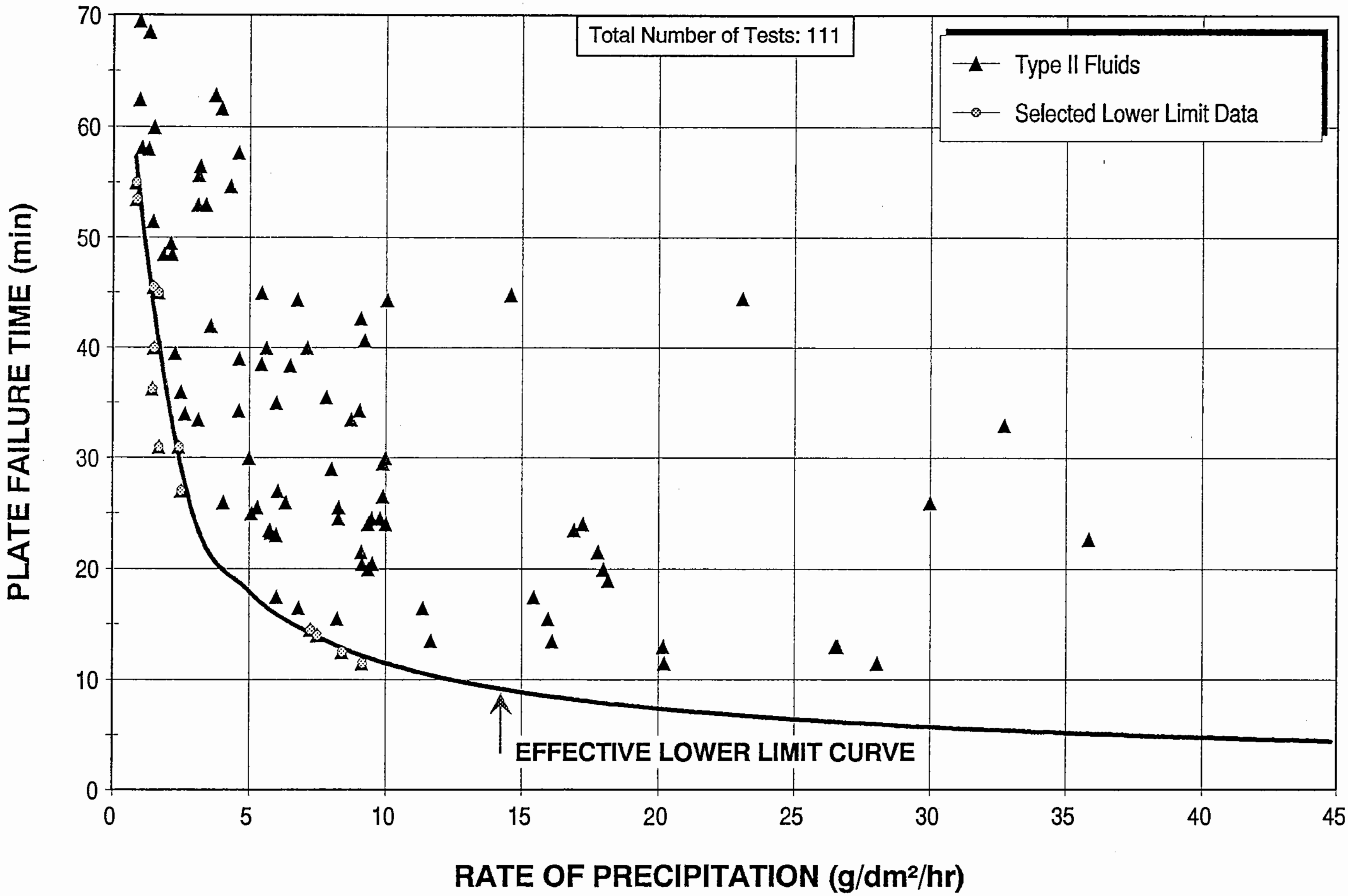


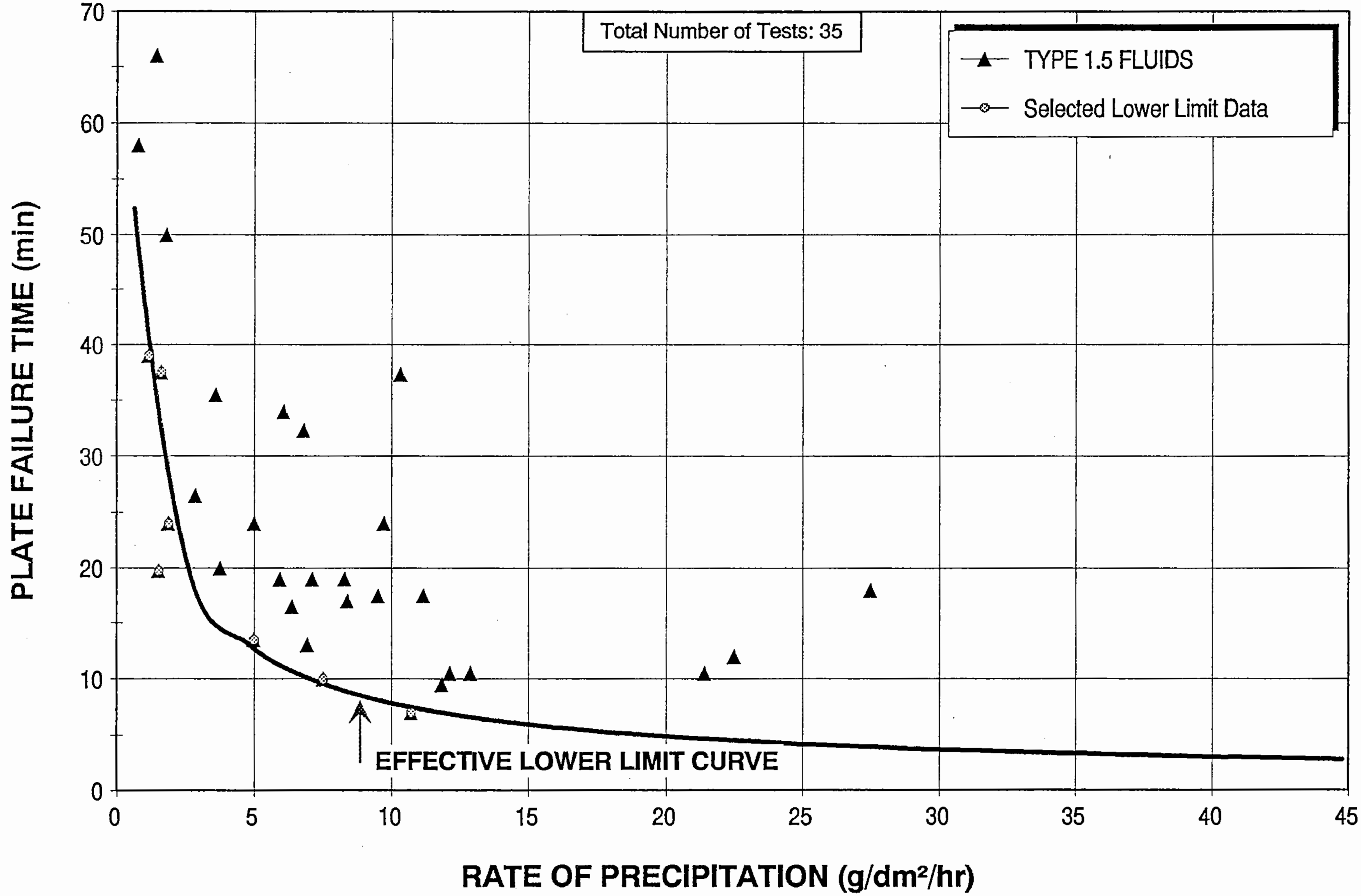
PLATE FAILURE TIMES
ALL DATA, FREEZING RAIN/DRIZZLE
FLUID A-202



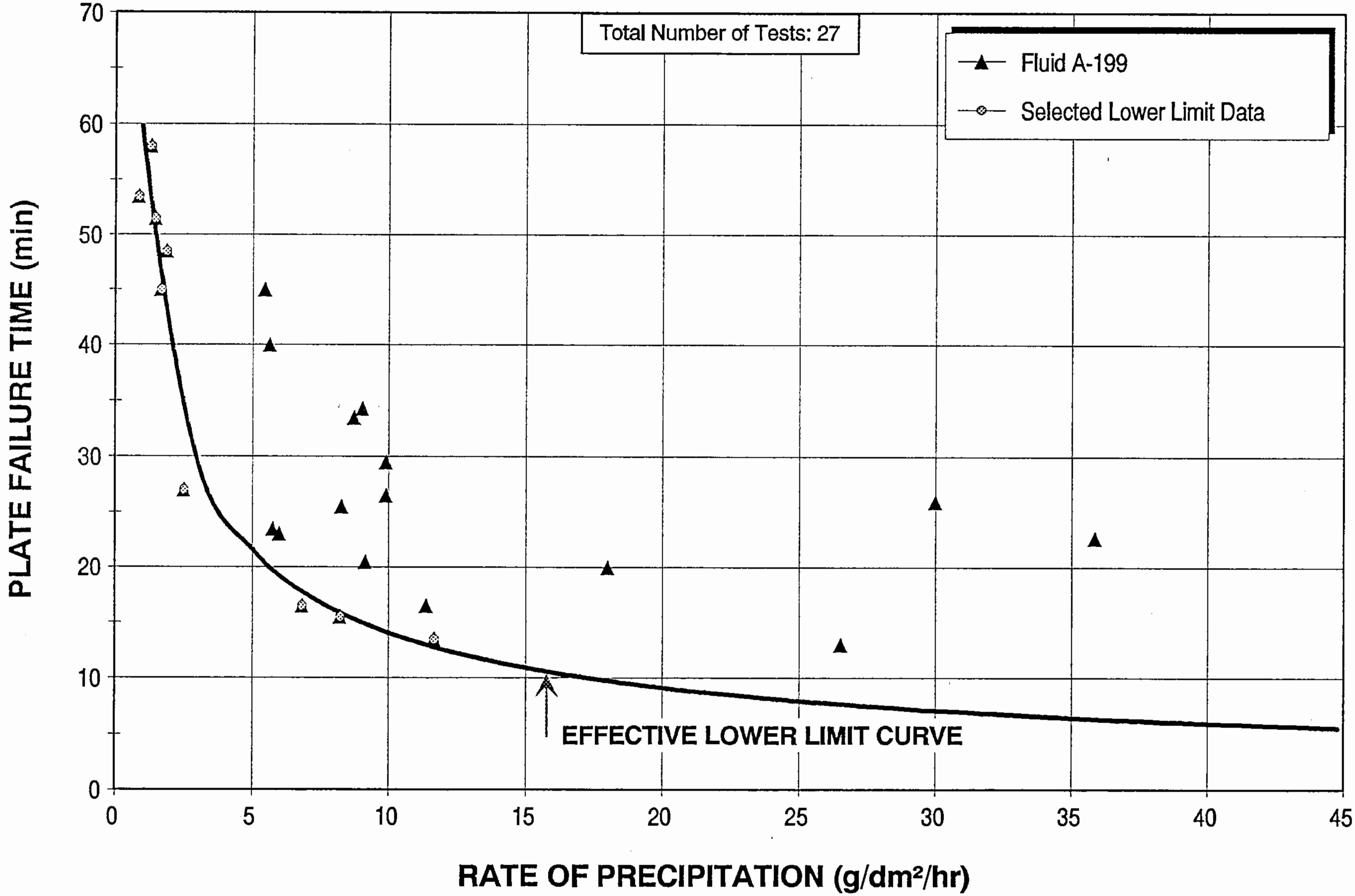
FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA, ALL WEATHER
TYPE II FLUIDS



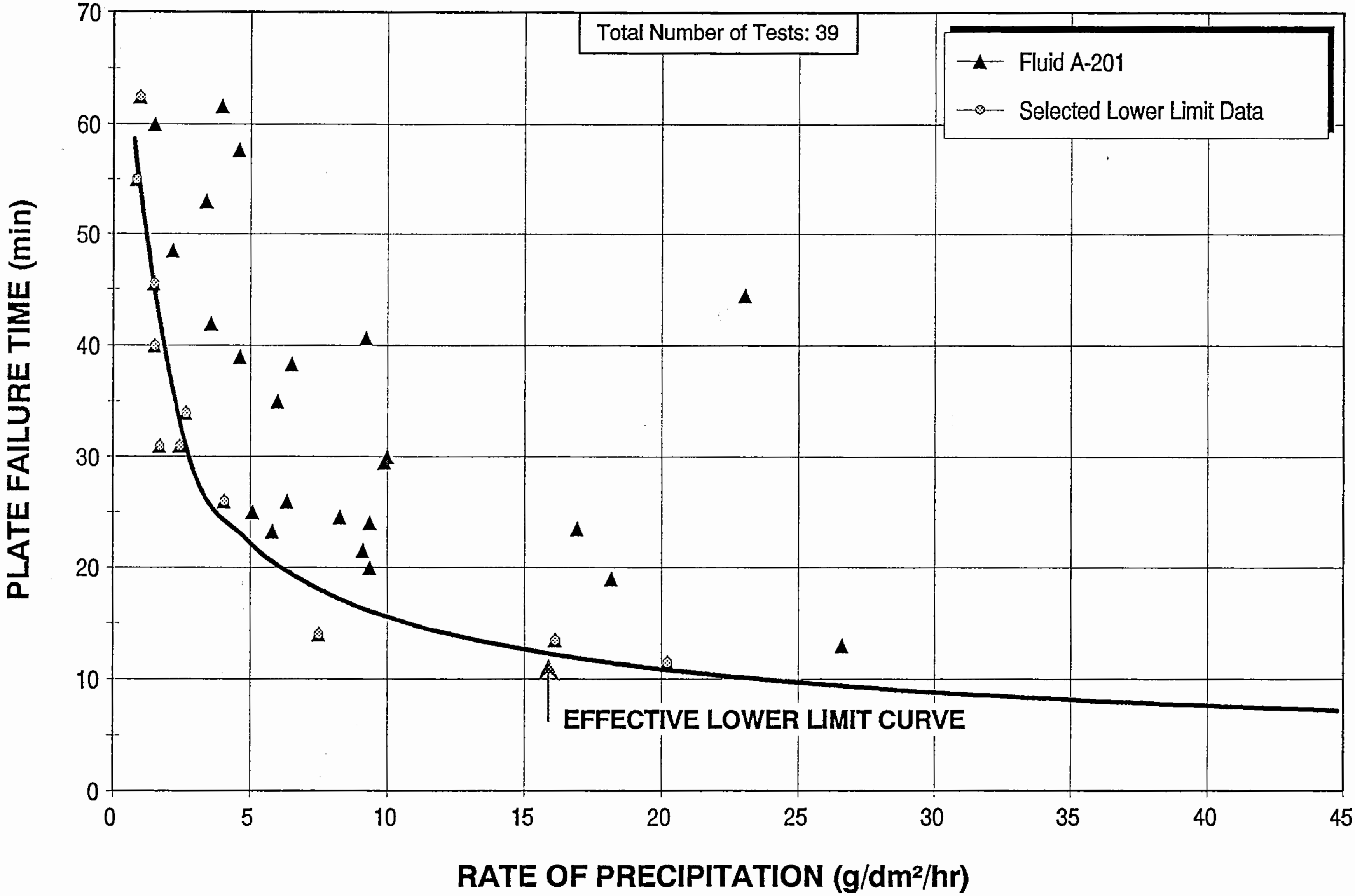
FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA, ALL WEATHER
TYPE 1.5 FLUIDS



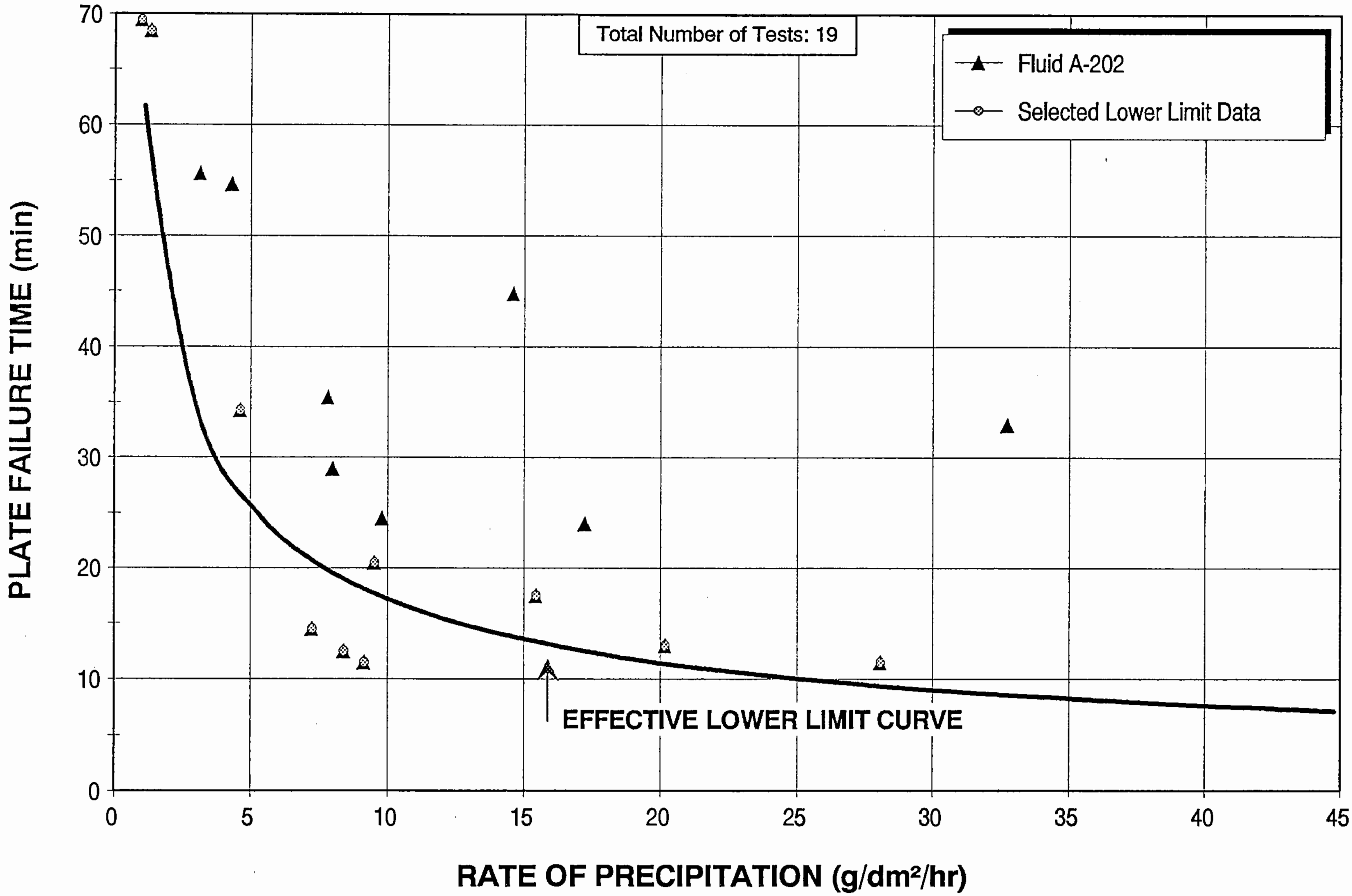
FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA, ALL WEATHER
FLUID A-199

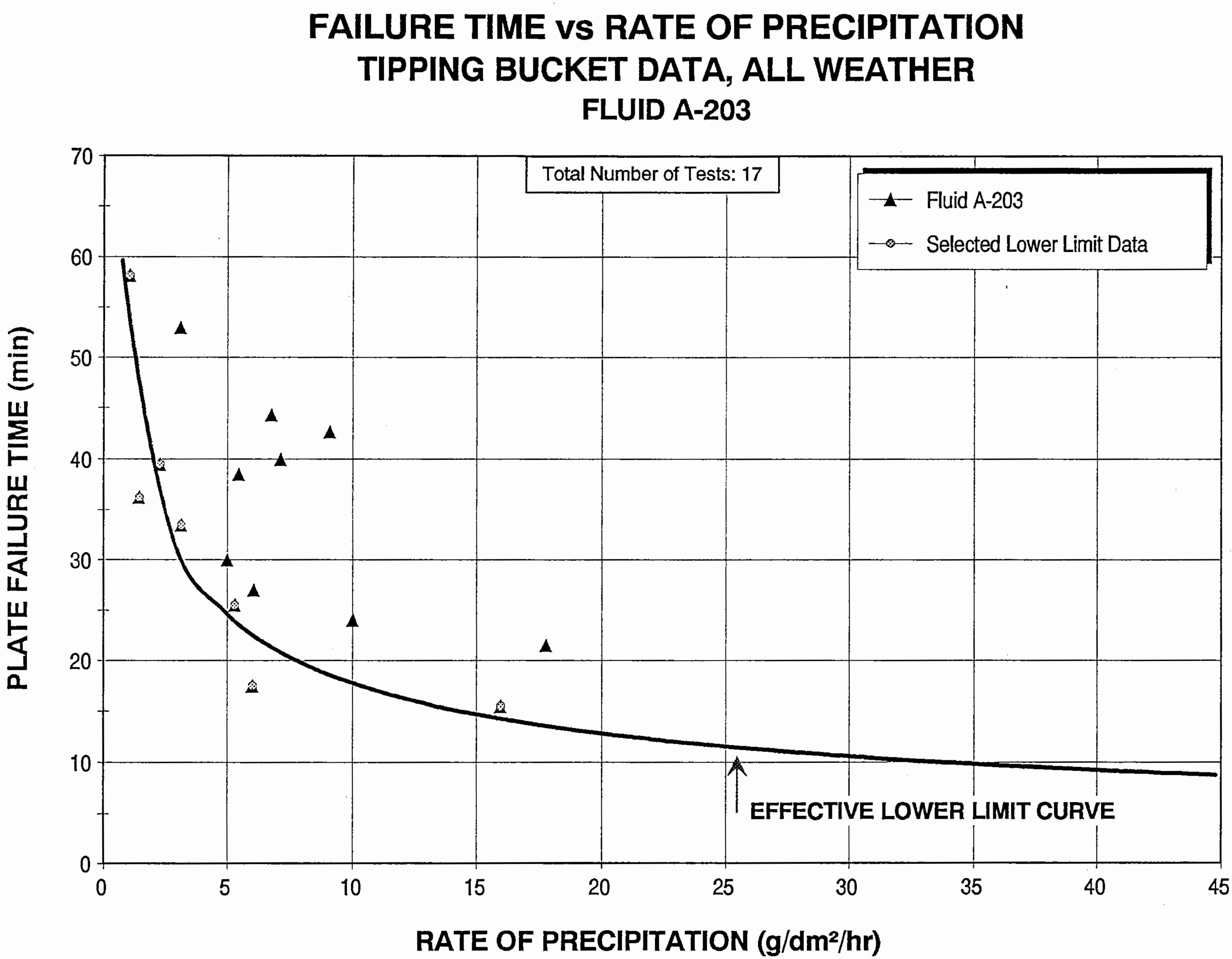


FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA, ALL WEATHER
FLUID A-201



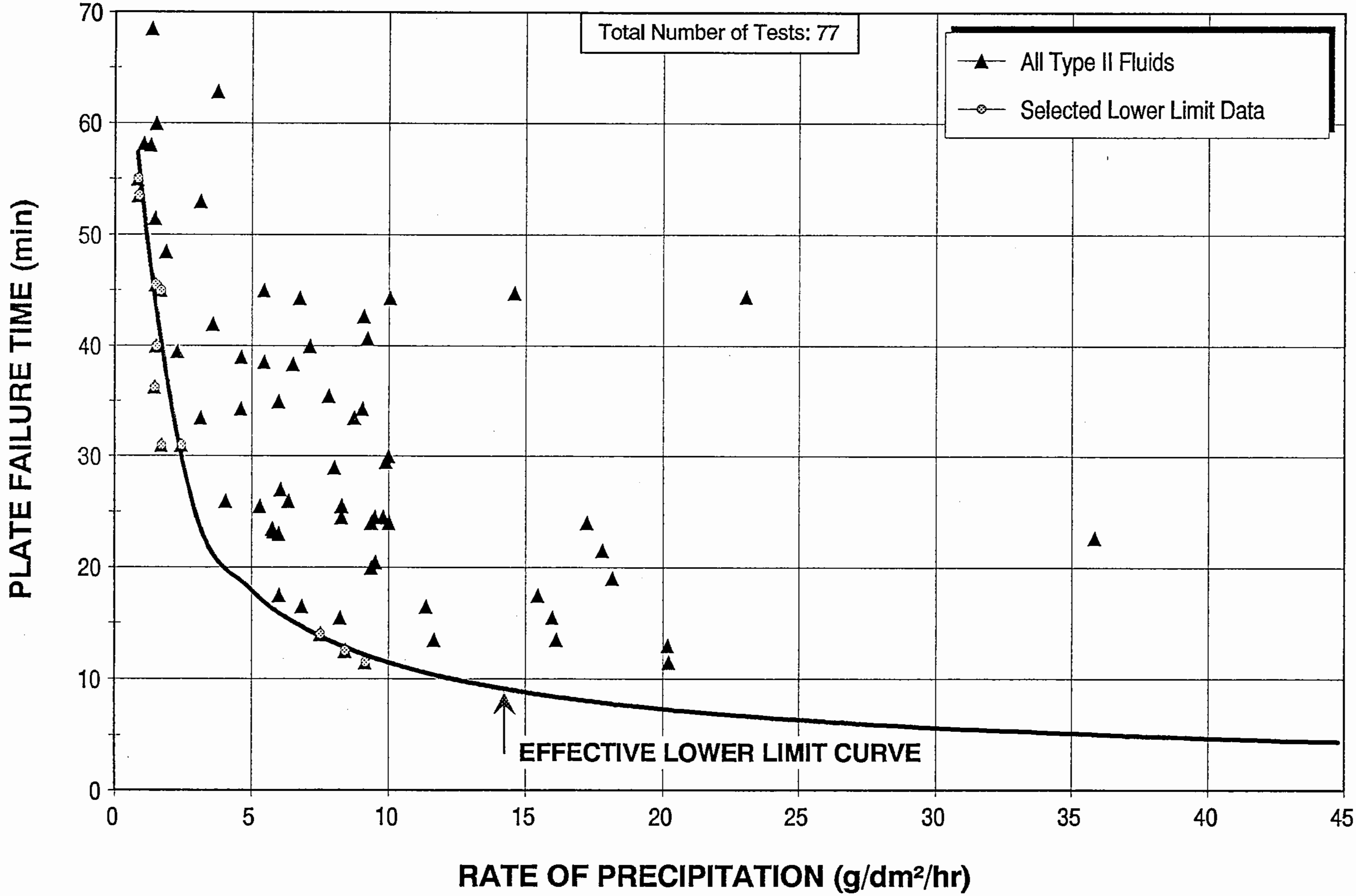
FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA, ALL WEATHER
FLUID A-202



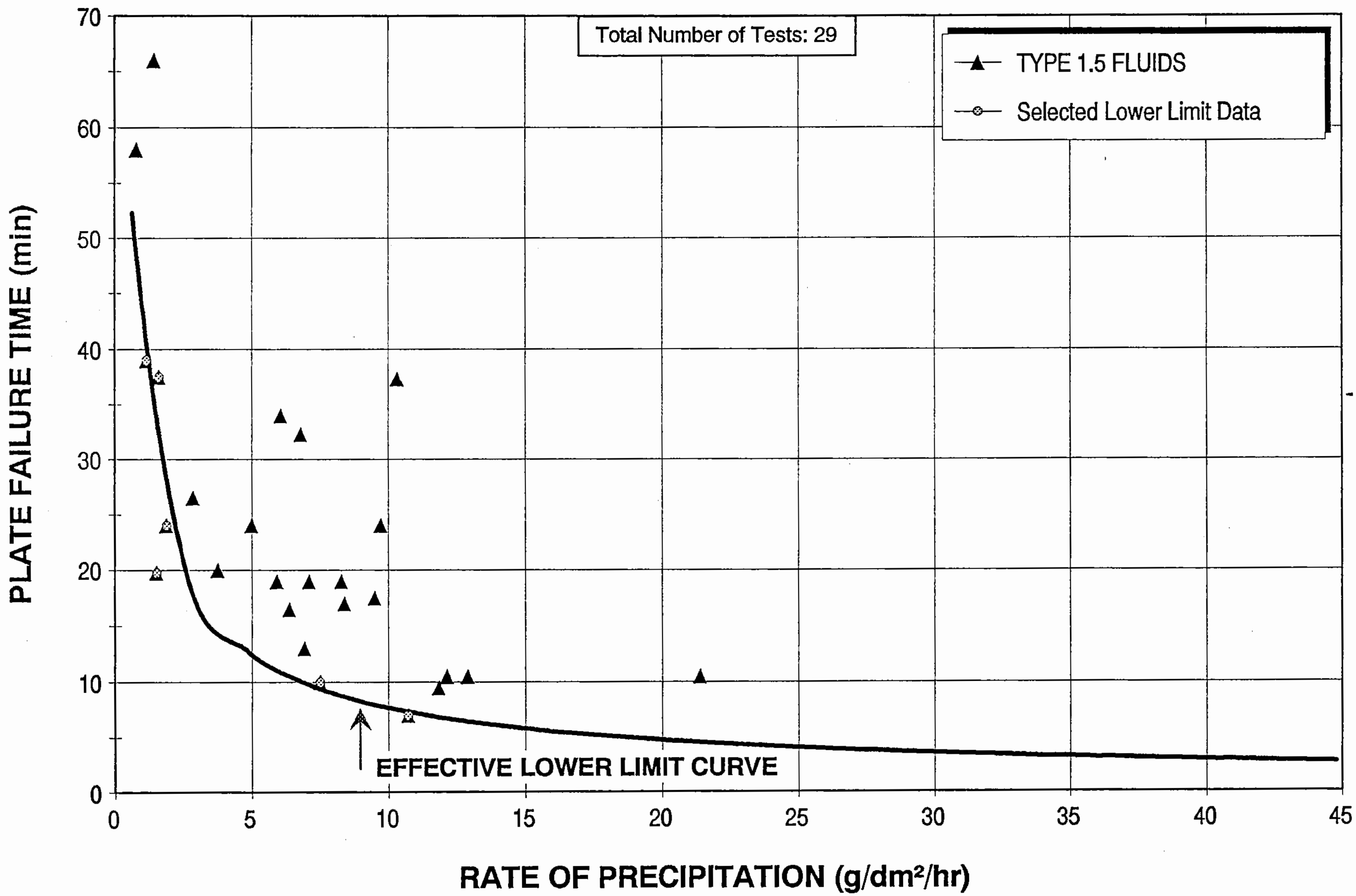


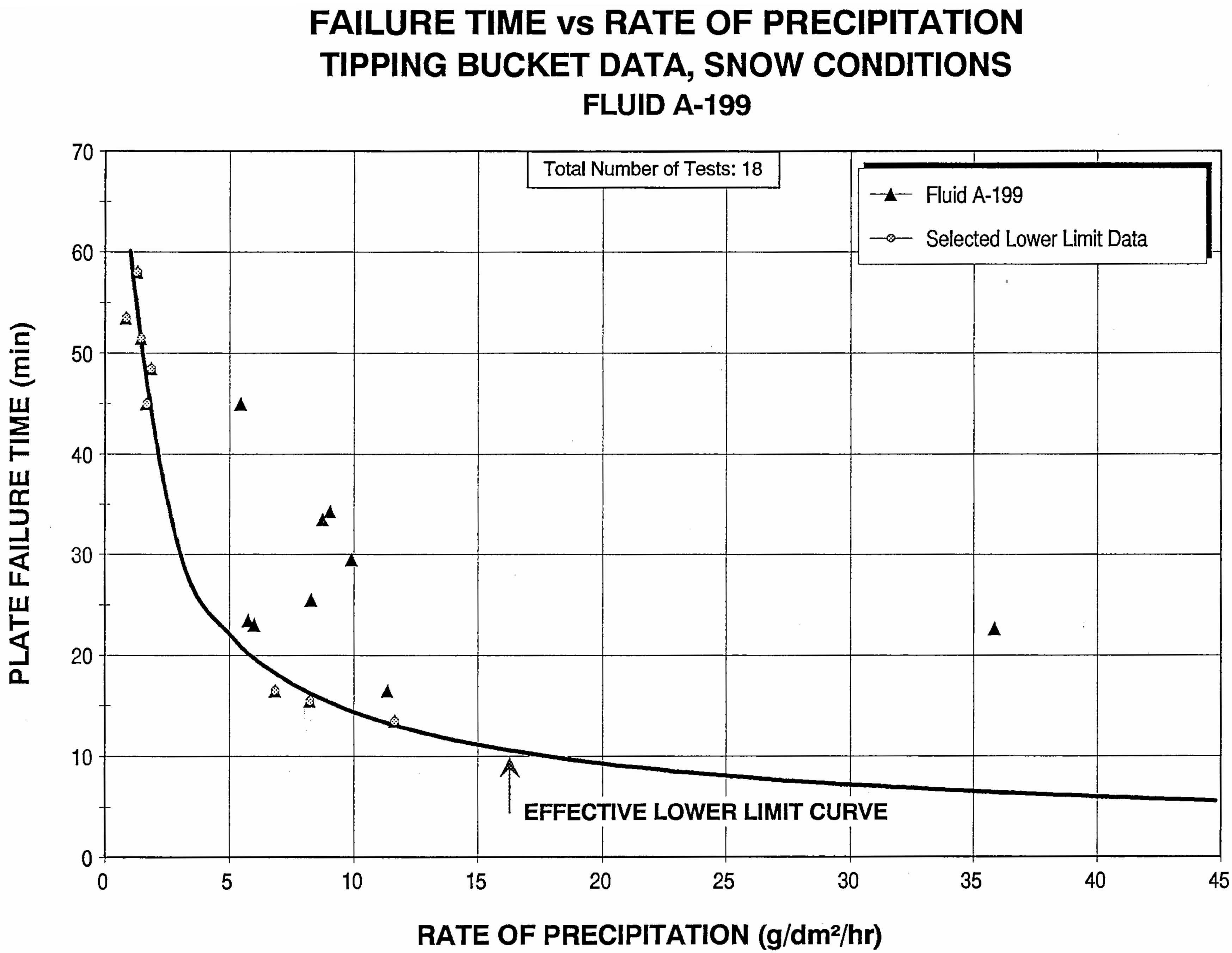
FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA, ALL WEATHER
FLUID A-203
Total Number of Tests: 17
Fluid A-203
Selected Lower Limit Data
EFFECTIVE LOWER LIMIT CURVE
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45

FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA, SNOW CONDITIONS
TYPE II FLUIDS

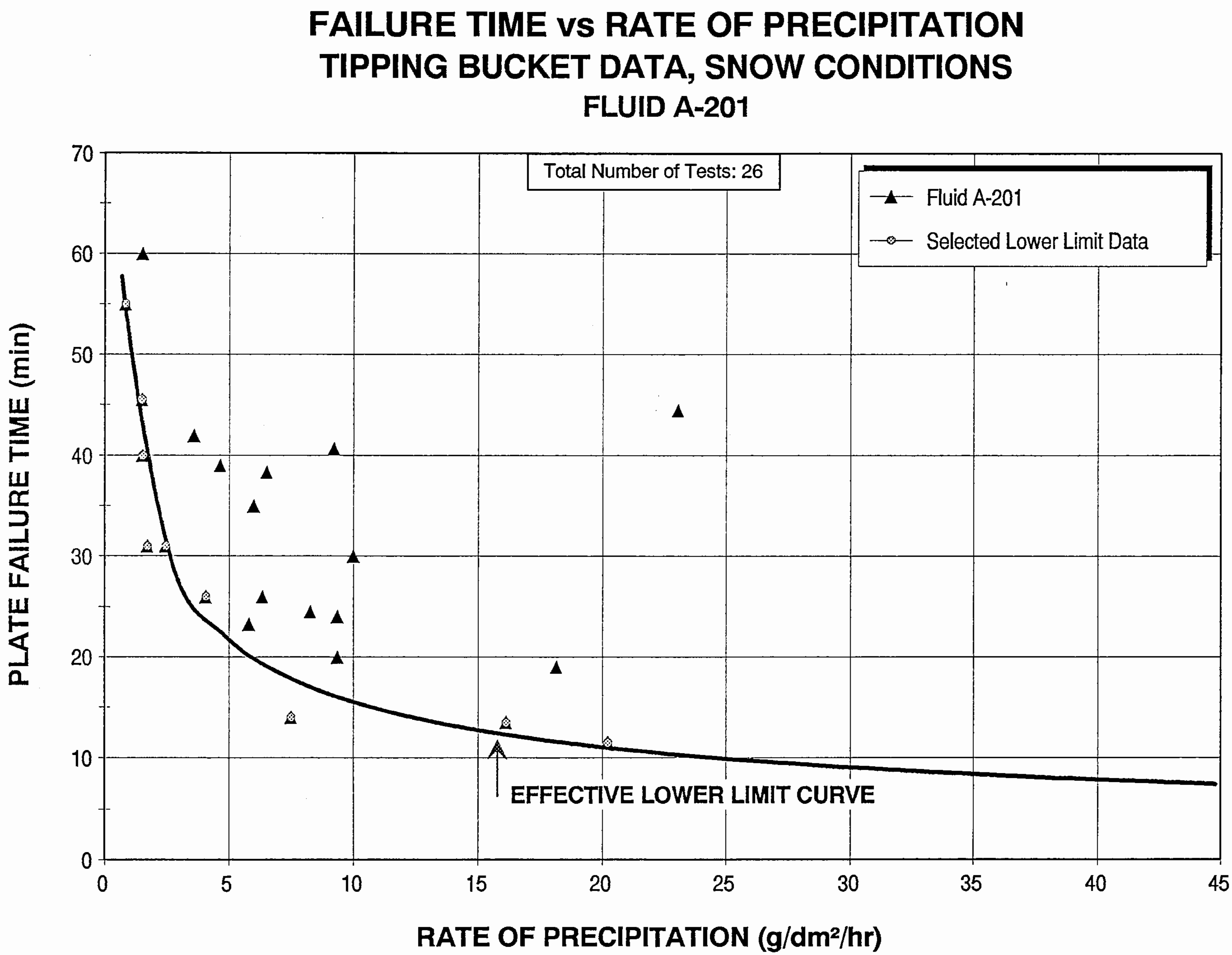


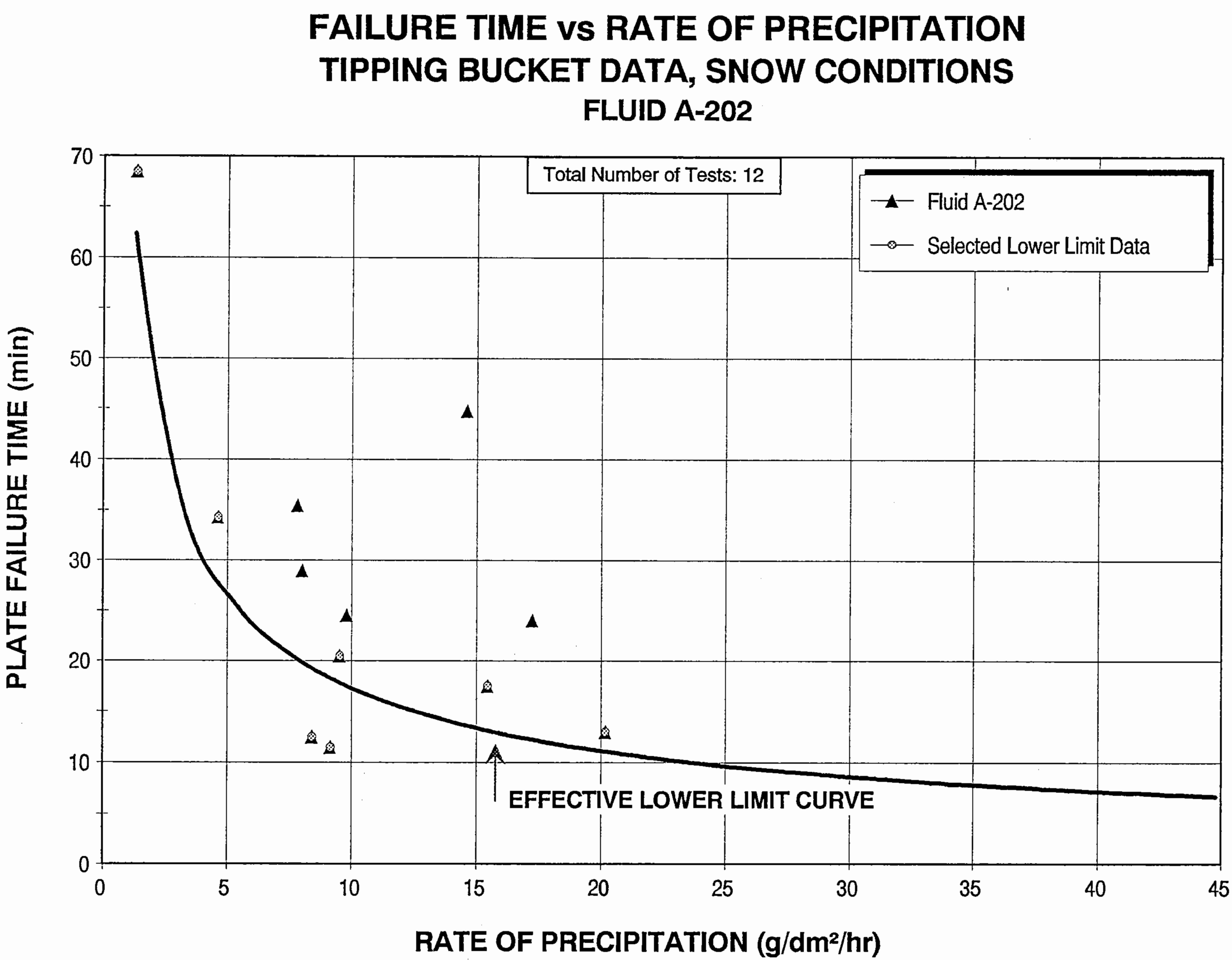
FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA, SNOW CONDITIONS
TYPE 1.5 FLUIDS



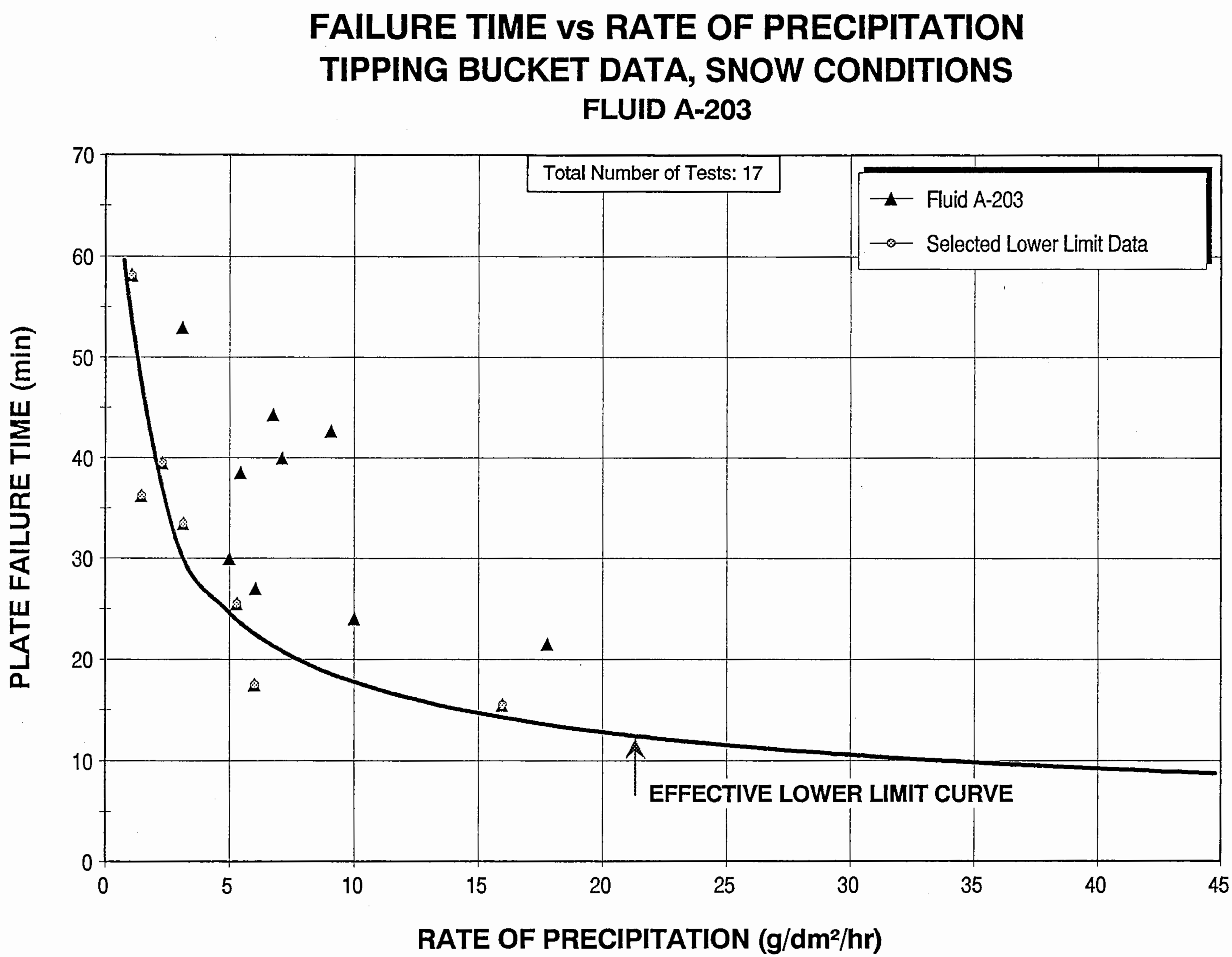


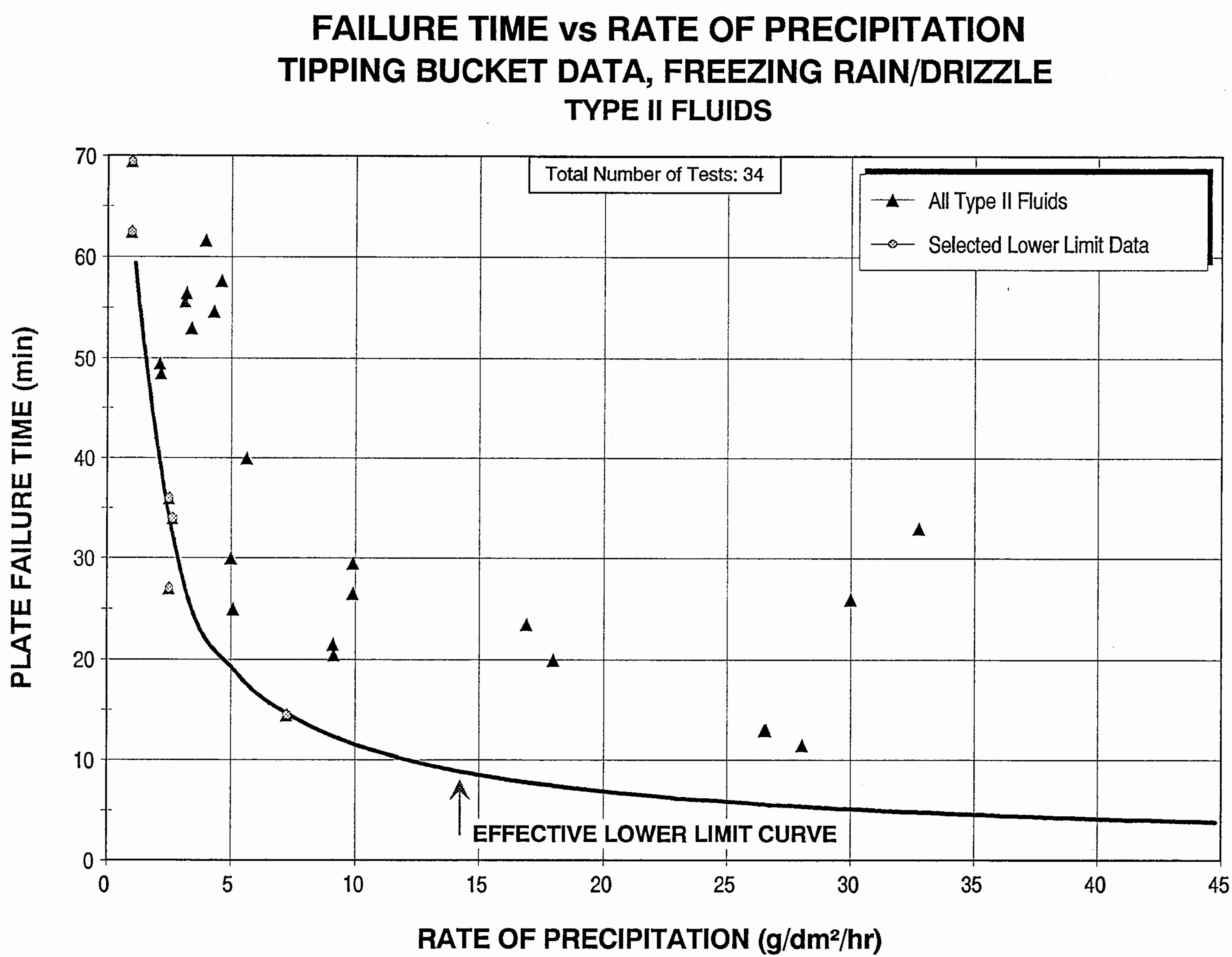
FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA, SNOW CONDITIONS
FLUID A-199
Total Number of Tests: 18
Fluid A-199
Selected Lower Limit Data
EFFECTIVE LOWER LIMIT CURVE
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45


FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA, SNOW CONDITIONS
FLUID A-201
Total Number of Tests: 26
Fluid A-201
Selected Lower Limit Data
EFFECTIVE LOWER LIMIT CURVE
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45

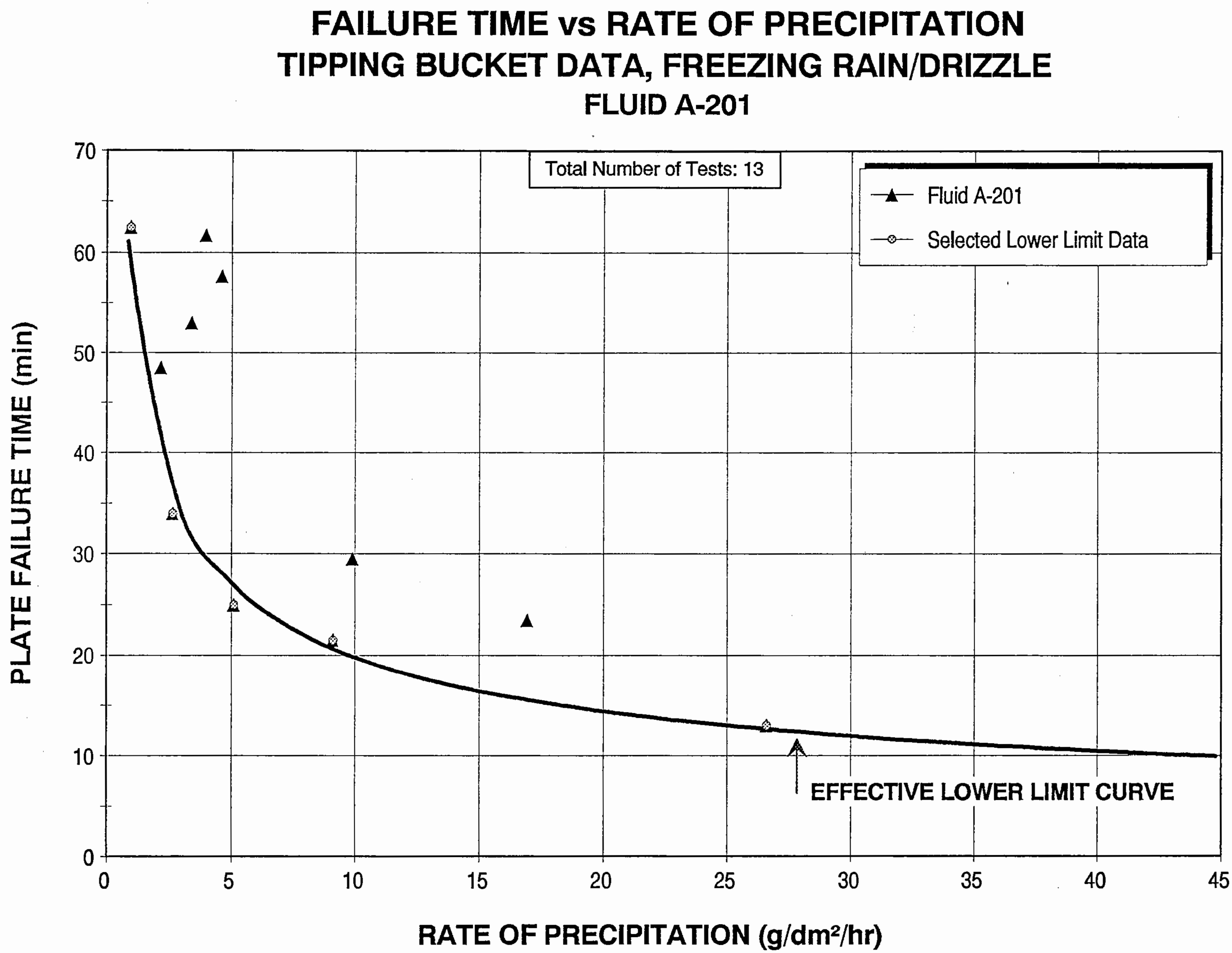


FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA, SNOW CONDITIONS
FLUID A-202
Total Number of Tests: 12
Fluid A-202
Selected Lower Limit Data
PLATE FAILURE TIME (min)
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
45
EFFECTIVE LOWER LIMIT CURVE
RATE OF PRECIPITATION (g/dm²/hr)


FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA, SNOW CONDITIONS
FLUID A-203
Total Number of Tests: 17
Fluid A-203
Selected Lower Limit Data
EFFECTIVE LOWER LIMIT CURVE
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45

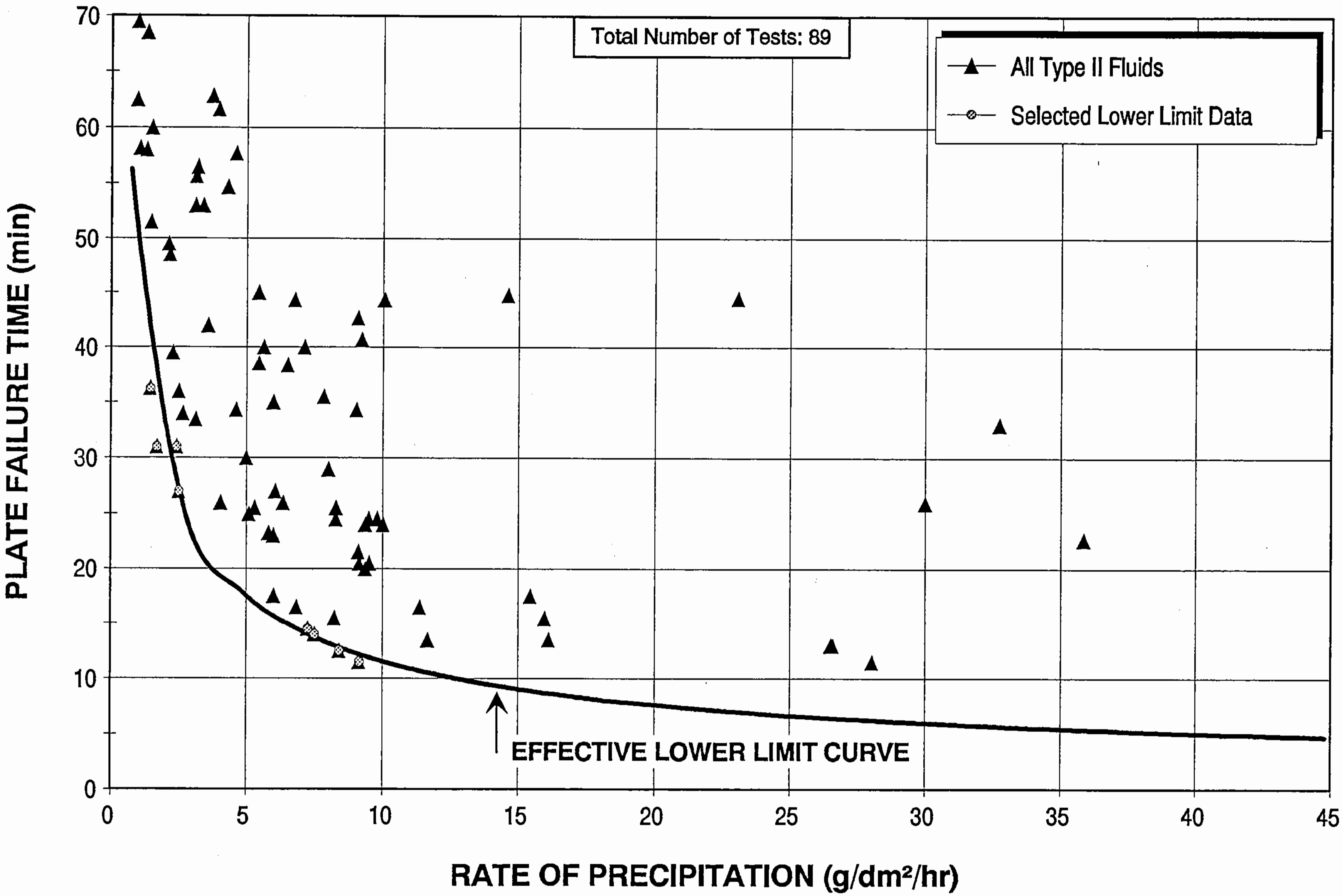


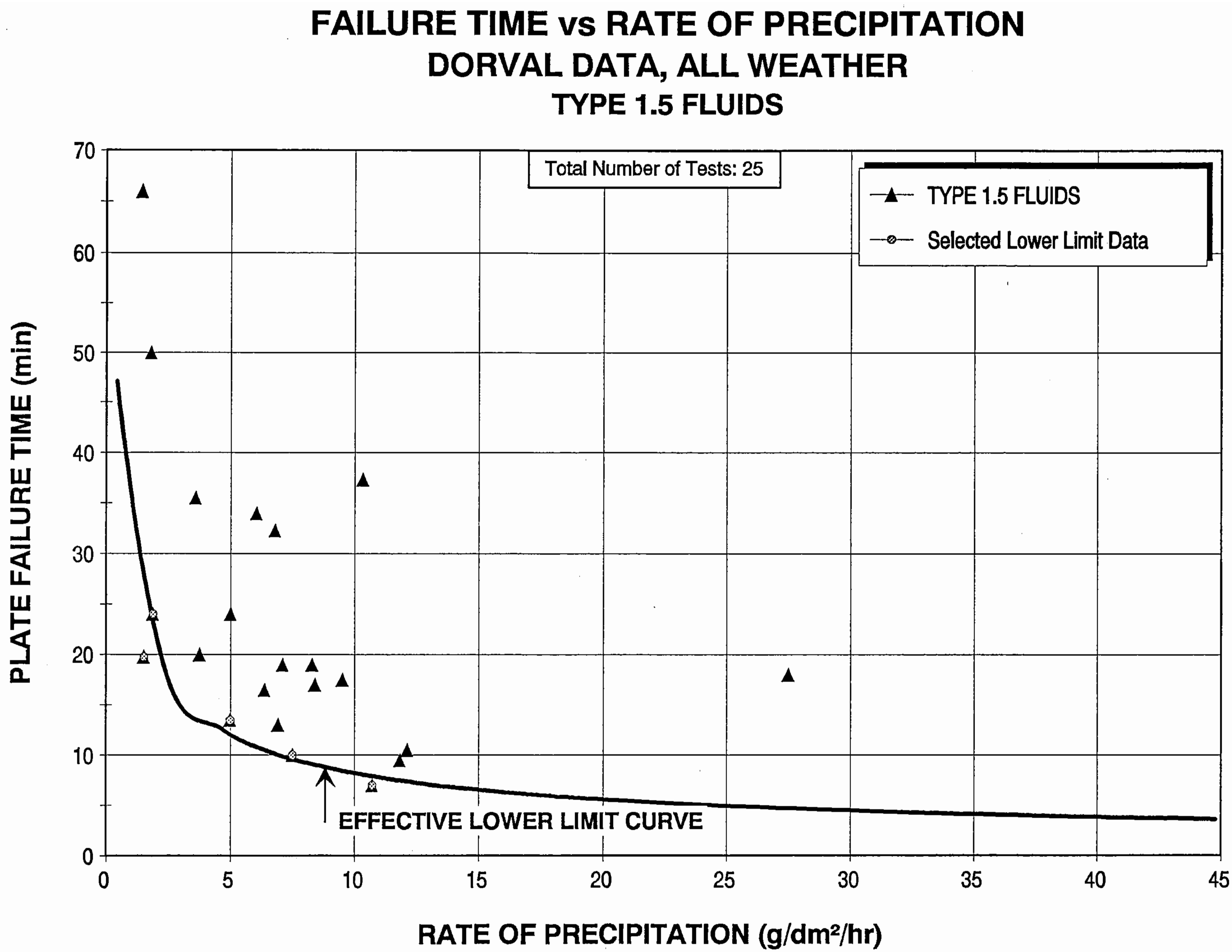
FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA, FREEZING RAIN/DRIZZLE
TYPE II FLUIDS
Total Number of Tests: 34
All Type II Fluids
Selected Lower Limit Data
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
EFFECTIVE LOWER LIMIT CURVE
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45



FAILURE TIME vs RATE OF PRECIPITATION
TIPPING BUCKET DATA, FREEZING RAIN/DRIZZLE
FLUID A-201
Total Number of Tests: 13
Fluid A-201
Selected Lower Limit Data
EFFECTIVE LOWER LIMIT CURVE
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45

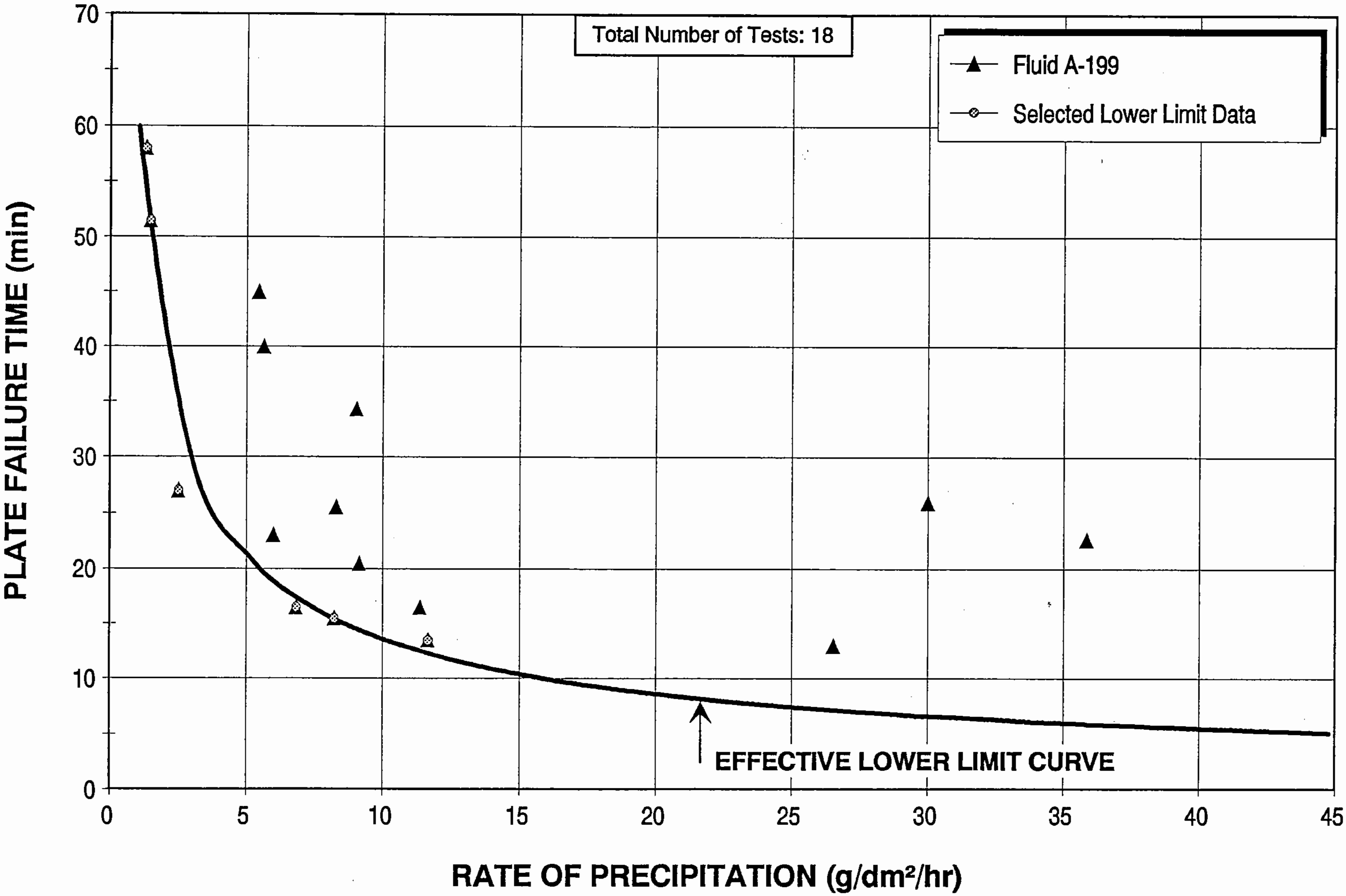
FAILURE TIME vs RATE OF PRECIPITATION
DORVAL DATA, ALL WEATHER
TYPE II FLUIDS

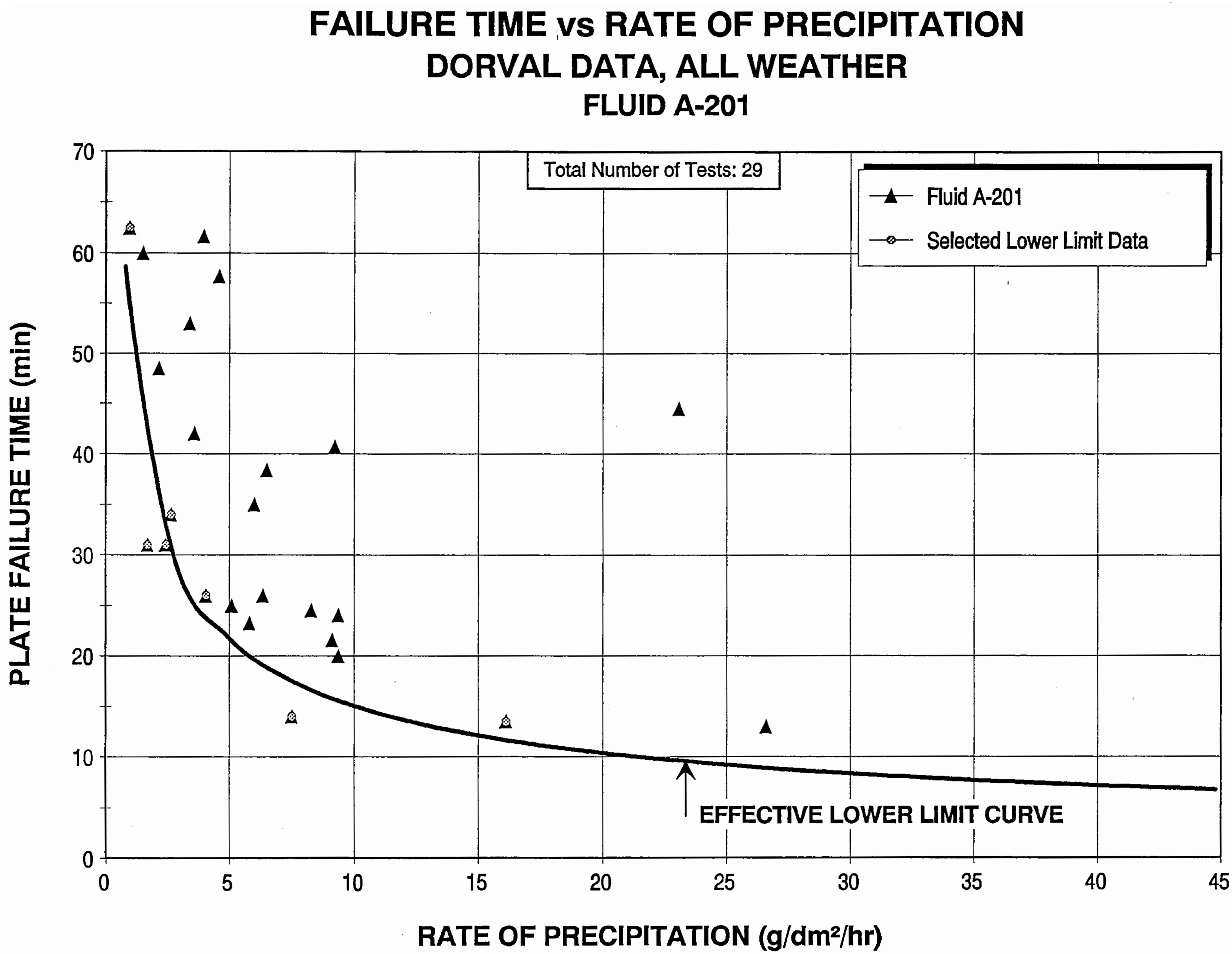




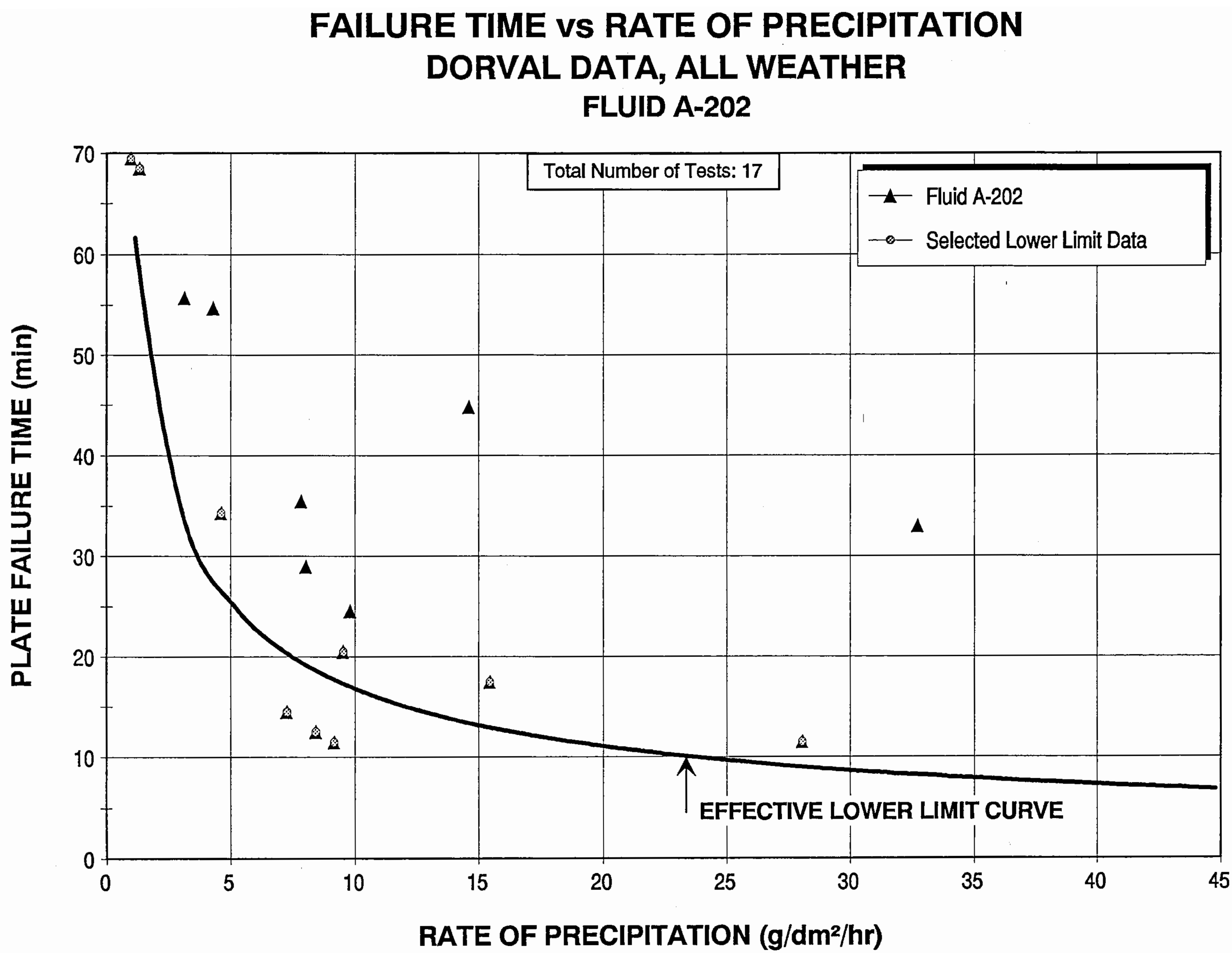
FAILURE TIME vs RATE OF PRECIPITATION
DORVAL DATA, ALL WEATHER
TYPE 1.5 FLUIDS
Total Number of Tests: 25
TYPE 1.5 FLUIDS
Selected Lower Limit Data
EFFECTIVE LOWER LIMIT CURVE
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45

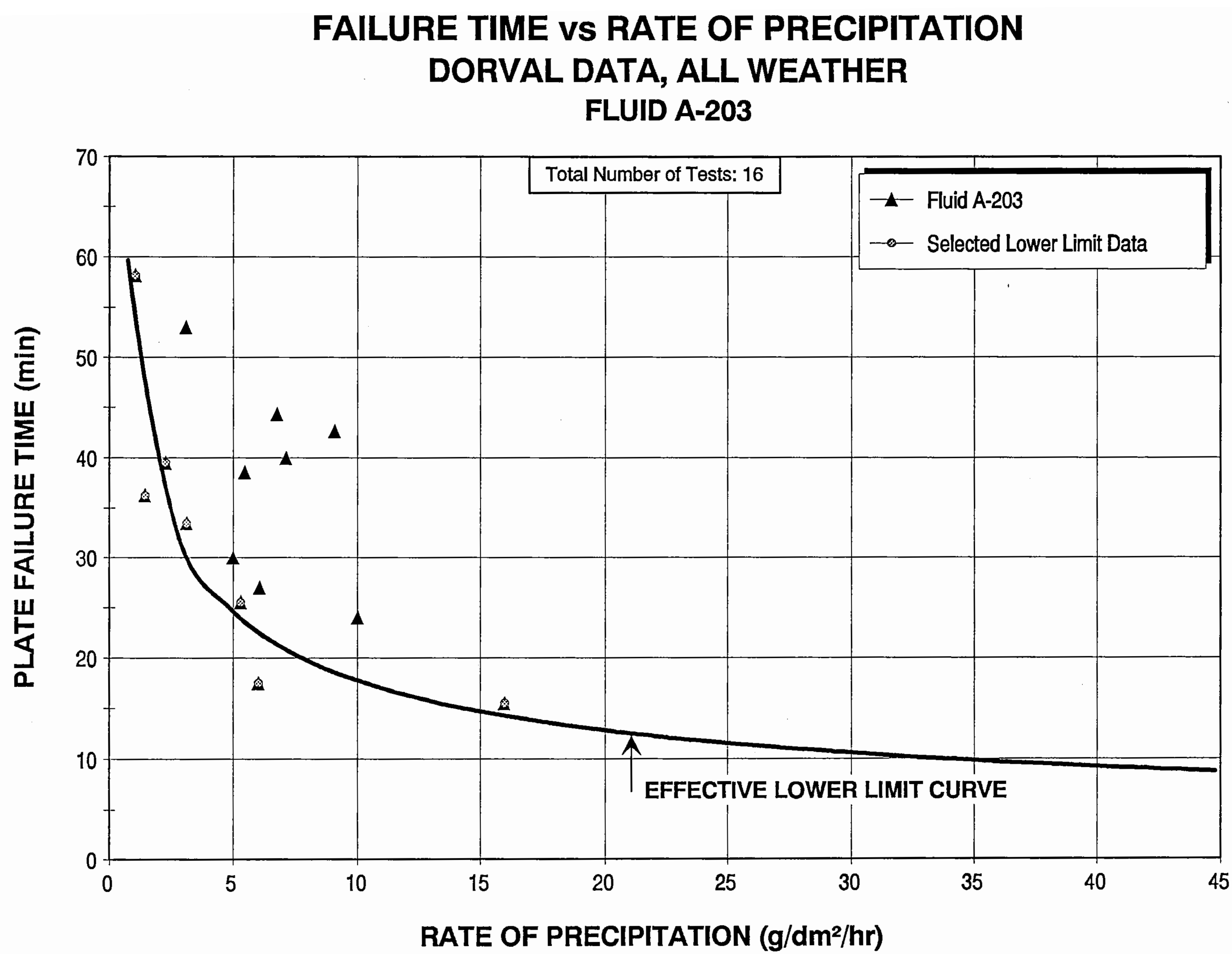
FAILURE TIME vs RATE OF PRECIPITATION
DORVAL DATA, ALL WEATHER
FLUID A-199

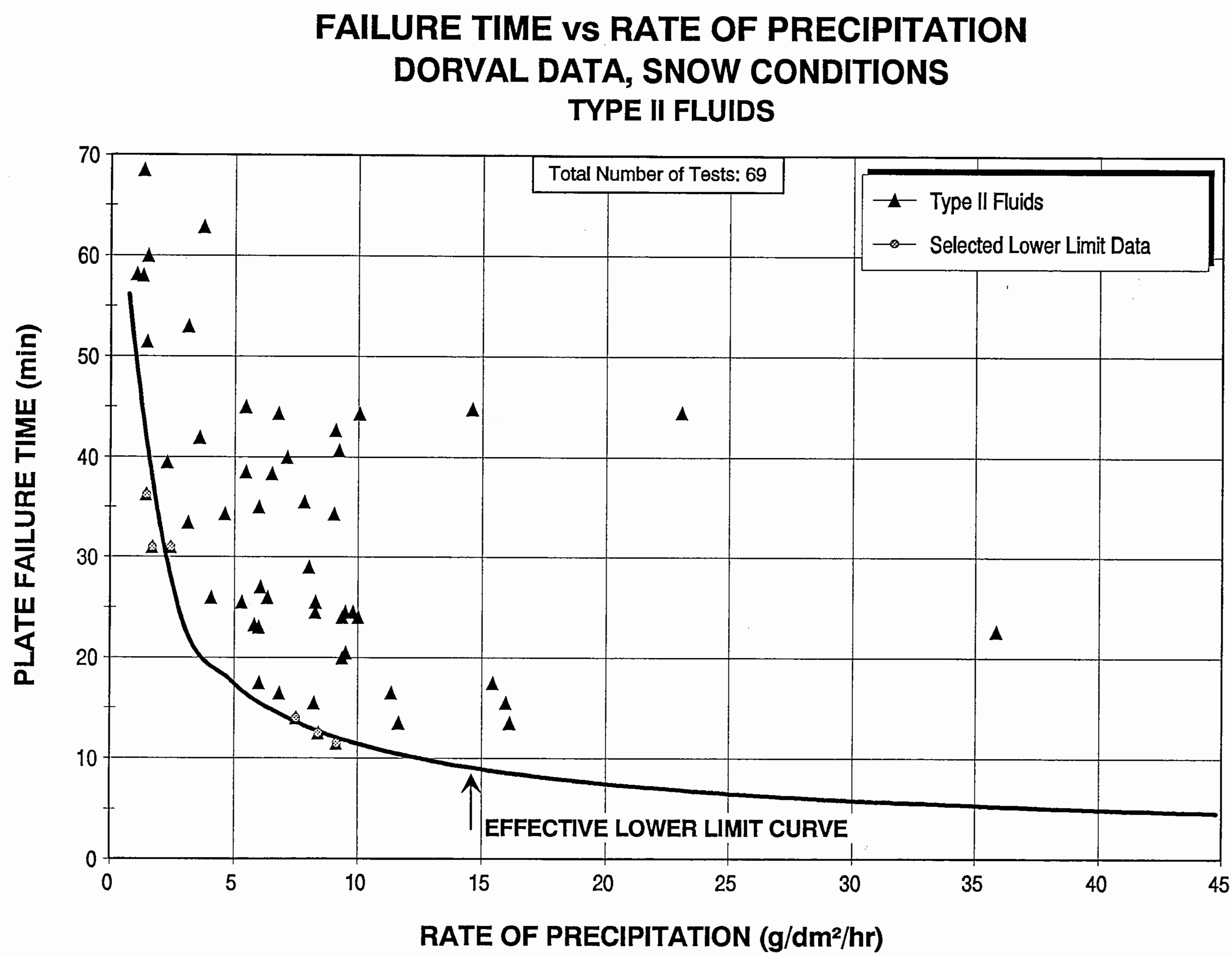


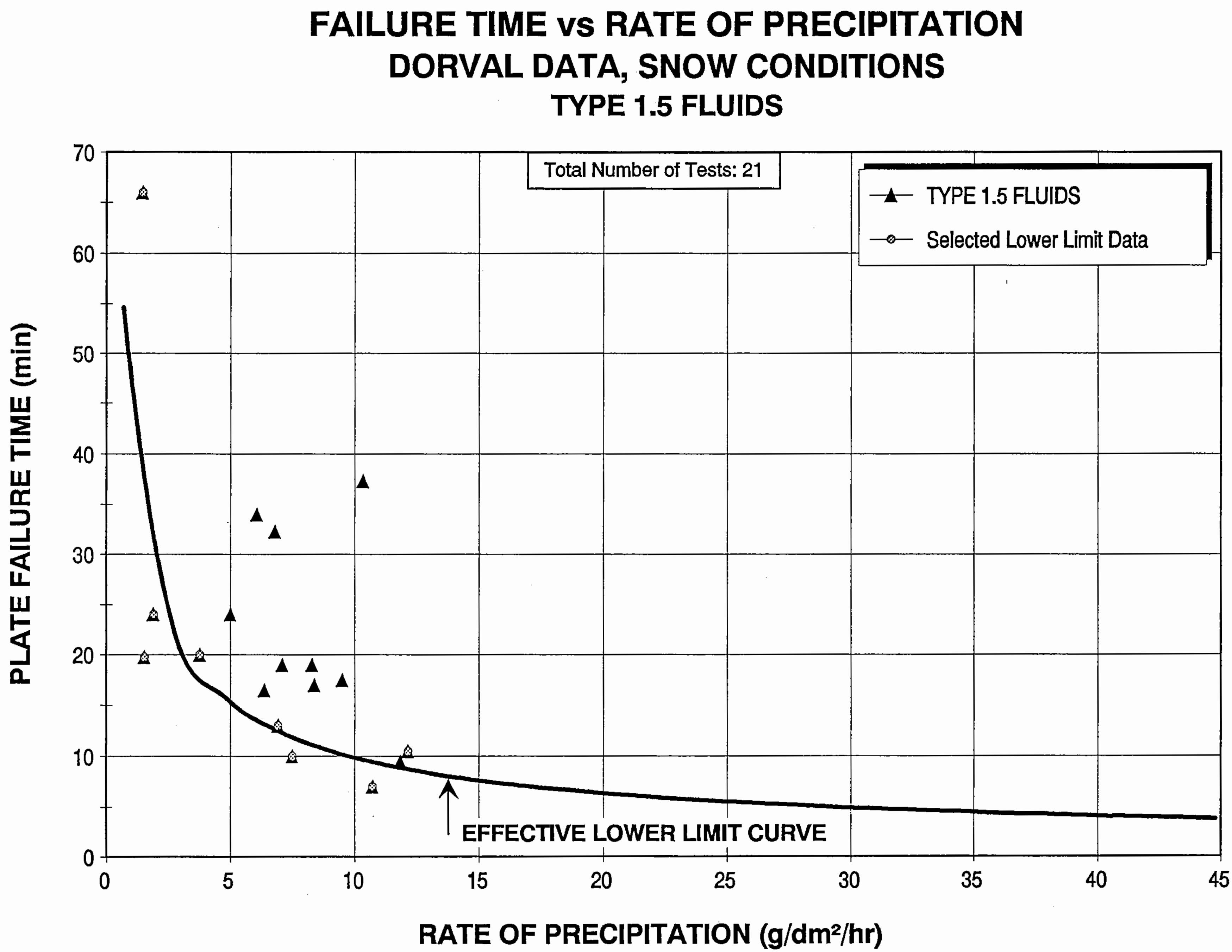


FAILURE TIME vs RATE OF PRECIPITATION
DORVAL DATA, ALL WEATHER
FLUID A-201
Total Number of Tests: 29
Fluid A-201
Selected Lower Limit Data
PLATE FAILURE TIME (min)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45
EFFECTIVE LOWER LIMIT CURVE
RATE OF PRECIPITATION (g/dm²/hr)

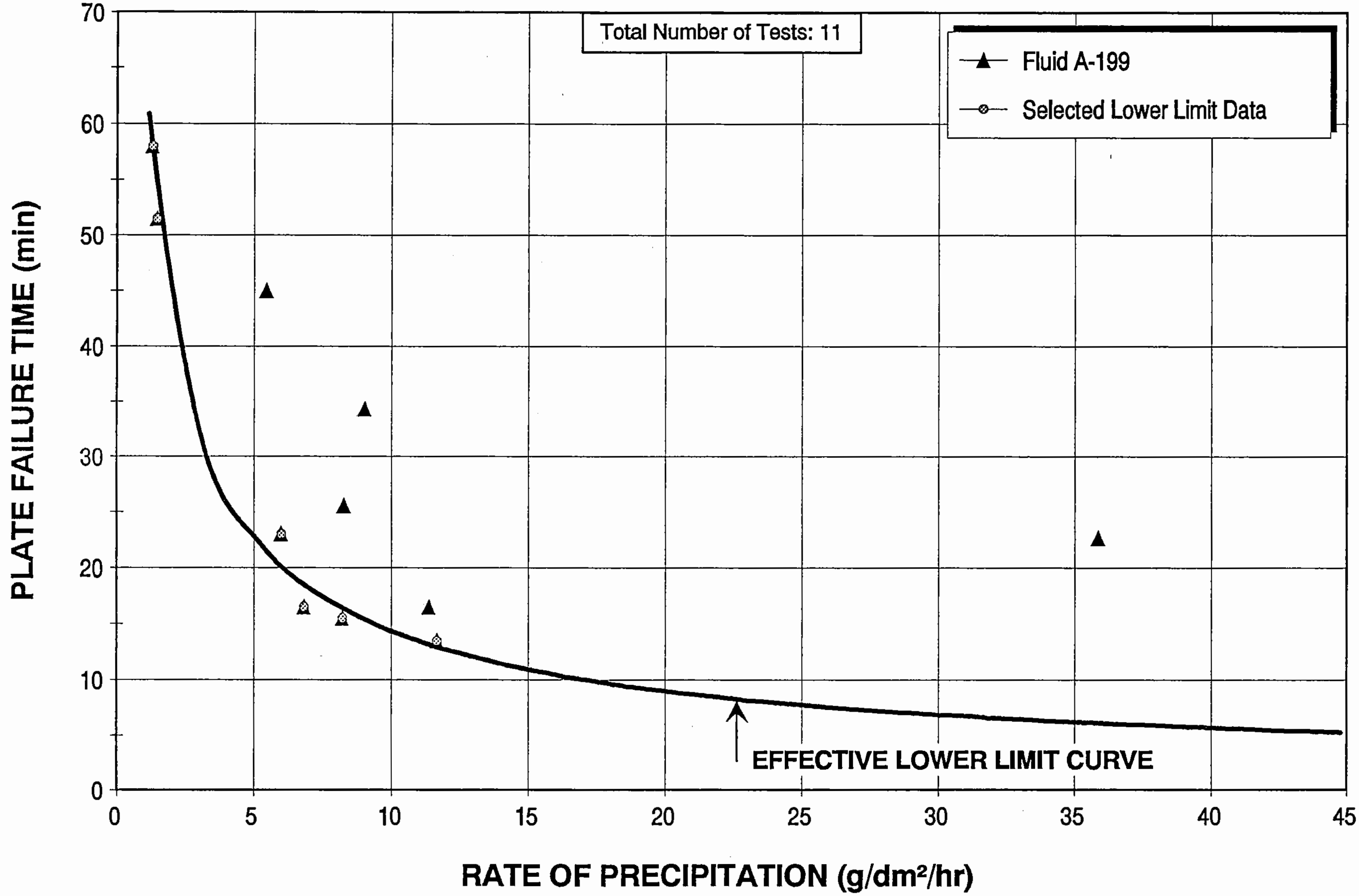

FAILURE TIME vs RATE OF PRECIPITATION
DORVAL DATA, ALL WEATHER
FLUID A-202
Total Number of Tests: 17
Fluid A-202
Selected Lower Limit Data
PLATE FAILURE TIME (min)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45
EFFECTIVE LOWER LIMIT CURVE
RATE OF PRECIPITATION (g/dm²/hr)

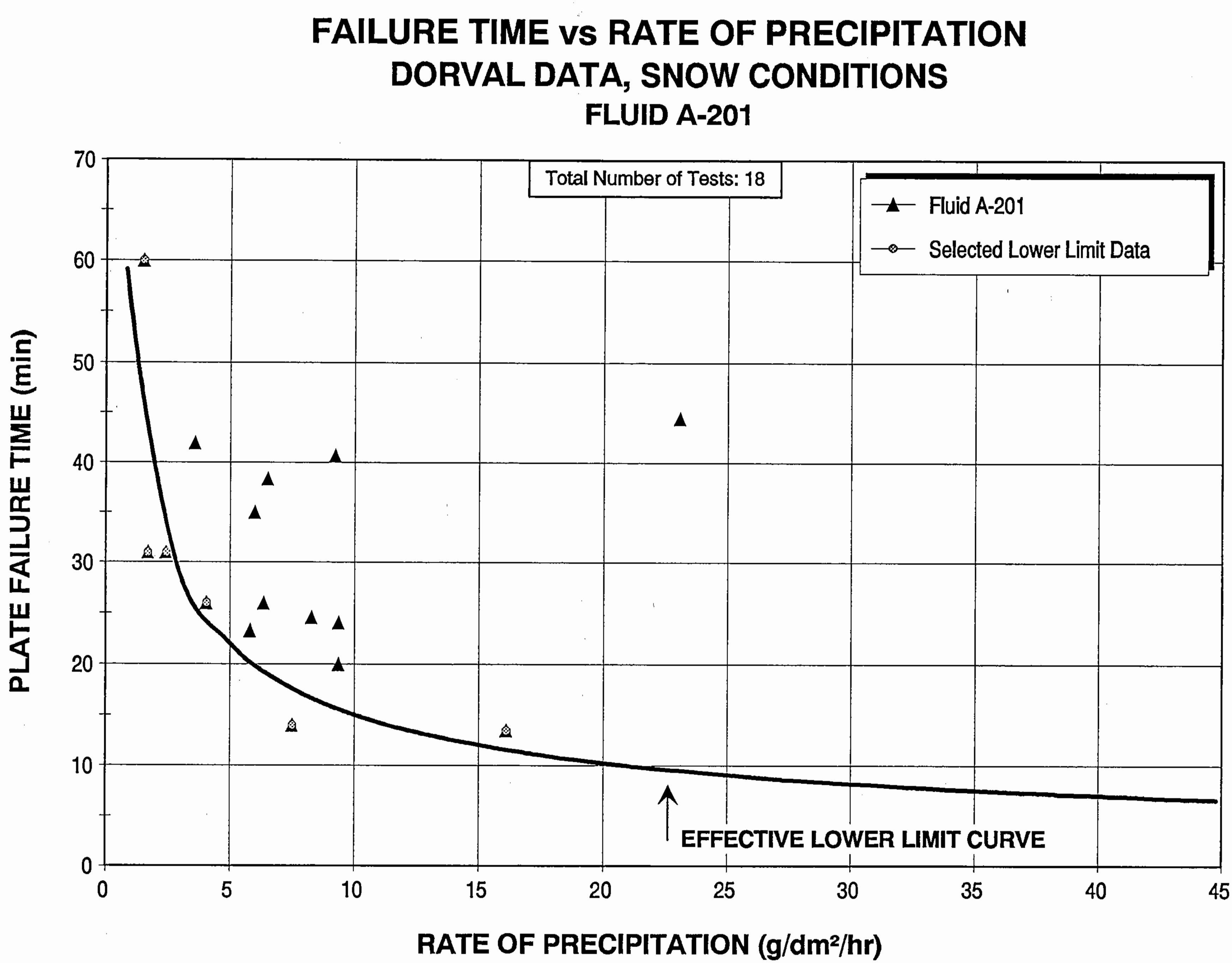

FAILURE TIME vs RATE OF PRECIPITATION
DORVAL DATA, ALL WEATHER
FLUID A-203
Total Number of Tests: 16
Fluid A-203
Selected Lower Limit Data
EFFECTIVE LOWER LIMIT CURVE
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45

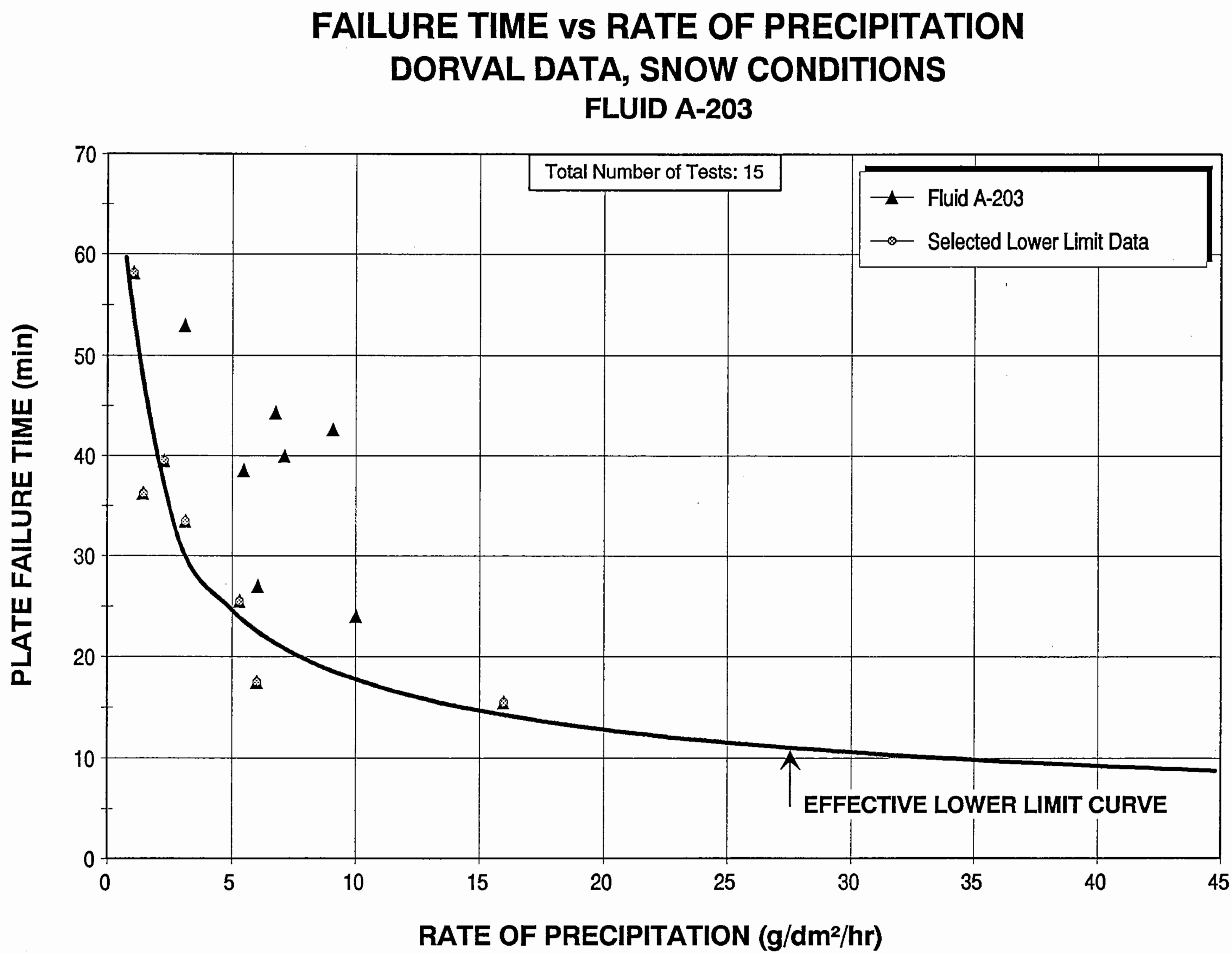

FAILURE TIME vs RATE OF PRECIPITATION
DORVAL DATA, SNOW CONDITIONS
TYPE II FLUIDS
Total Number of Tests: 69
Type II Fluids
Selected Lower Limit Data
EFFECTIVE LOWER LIMIT CURVE
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45

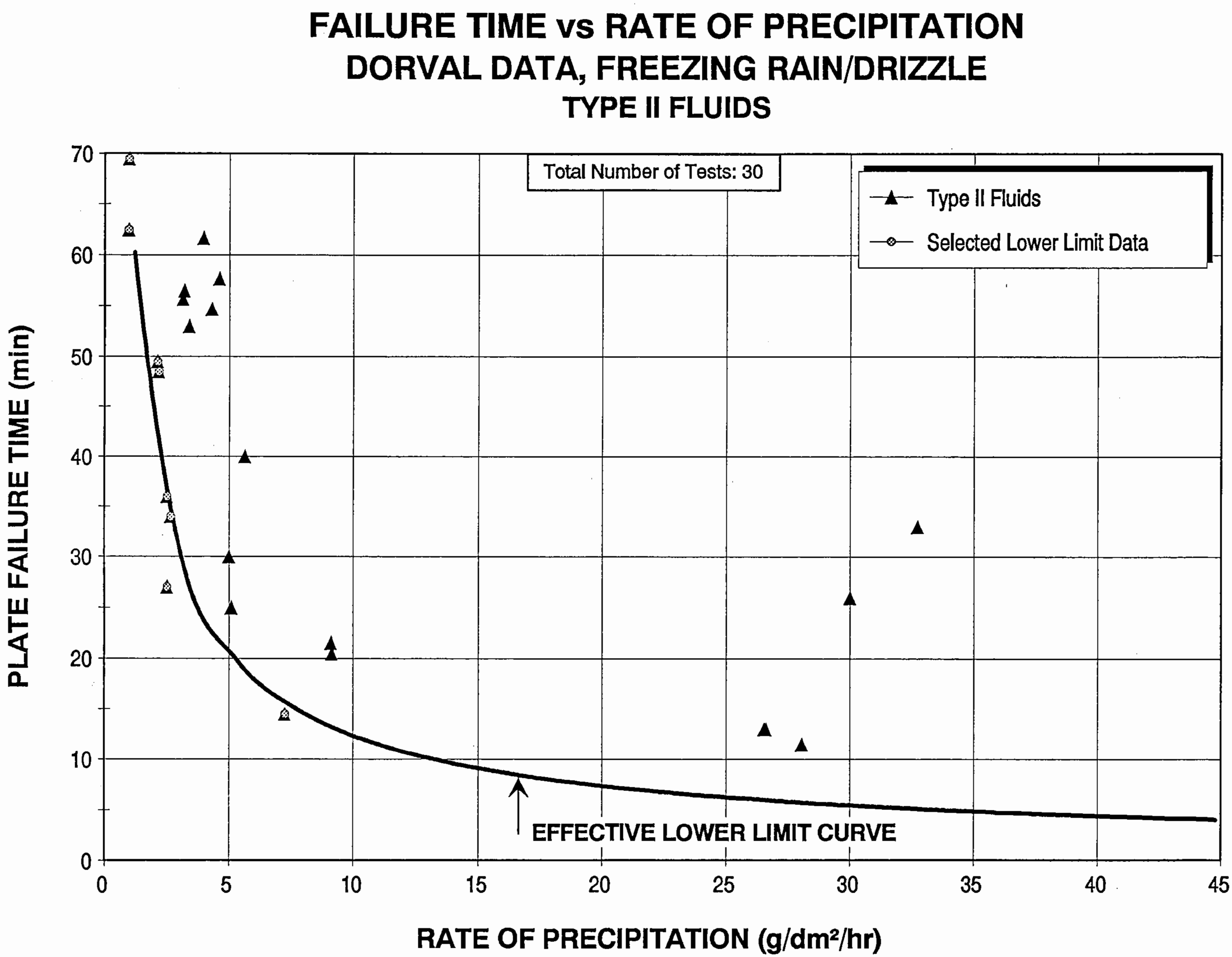

FAILURE TIME vs RATE OF PRECIPITATION
DORVAL DATA, SNOW CONDITIONS
TYPE 1.5 FLUIDS
Total Number of Tests: 21
TYPE 1.5 FLUIDS
Selected Lower Limit Data
PLATE FAILURE TIME (min)
EFFECTIVE LOWER LIMIT CURVE
RATE OF PRECIPITATION (g/dm²/hr)
0
5
10
15
20
25
30
35
40
45
0
10
20
30
40
50
60
70

FAILURE TIME vs RATE OF PRECIPITATION
DORVAL DATA, SNOW CONDITIONS
FLUID A-199

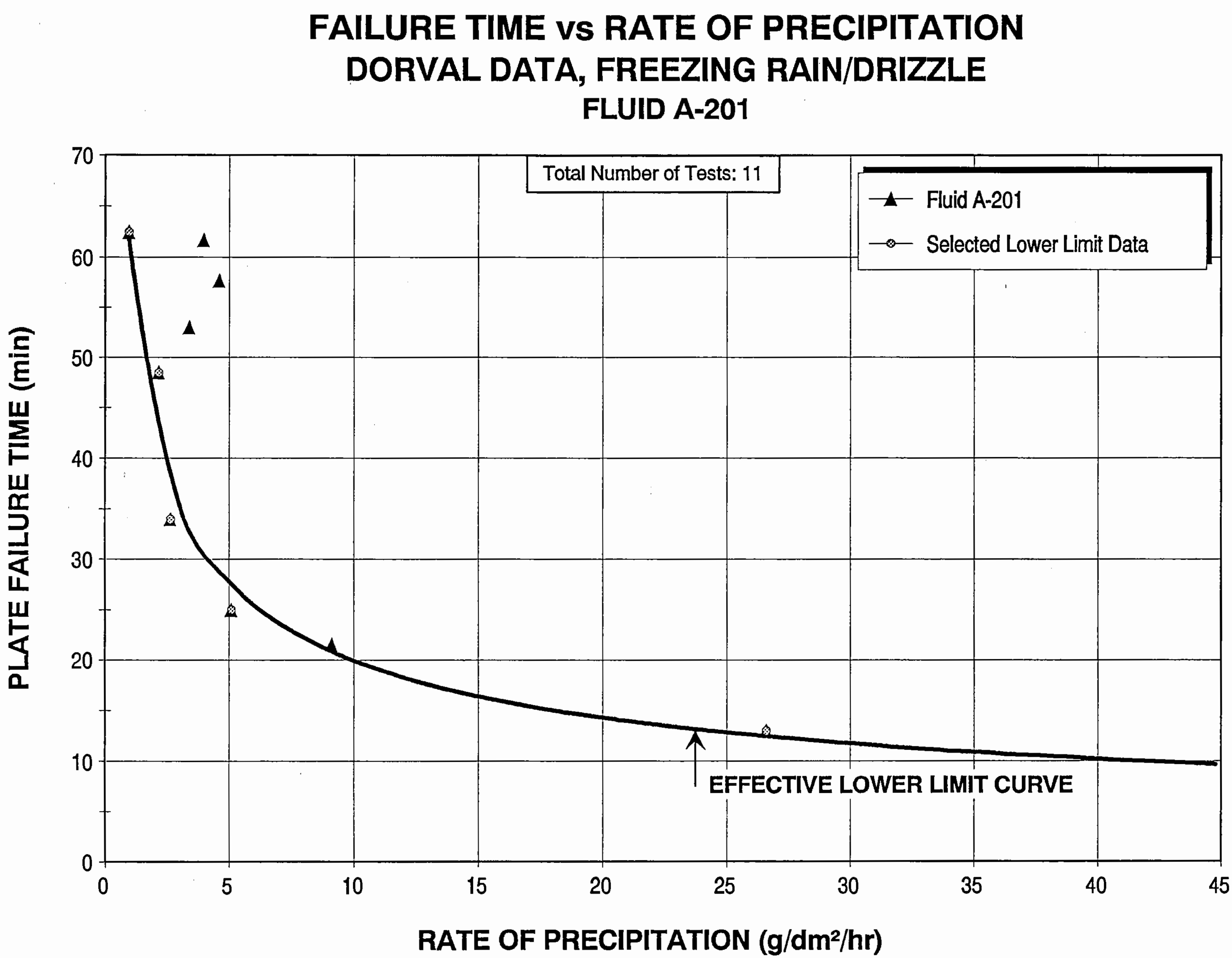



FAILURE TIME vs RATE OF PRECIPITATION
DORVAL DATA, SNOW CONDITIONS
FLUID A-201
Total Number of Tests: 18
Fluid A-201
Selected Lower Limit Data
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
EFFECTIVE LOWER LIMIT CURVE
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45

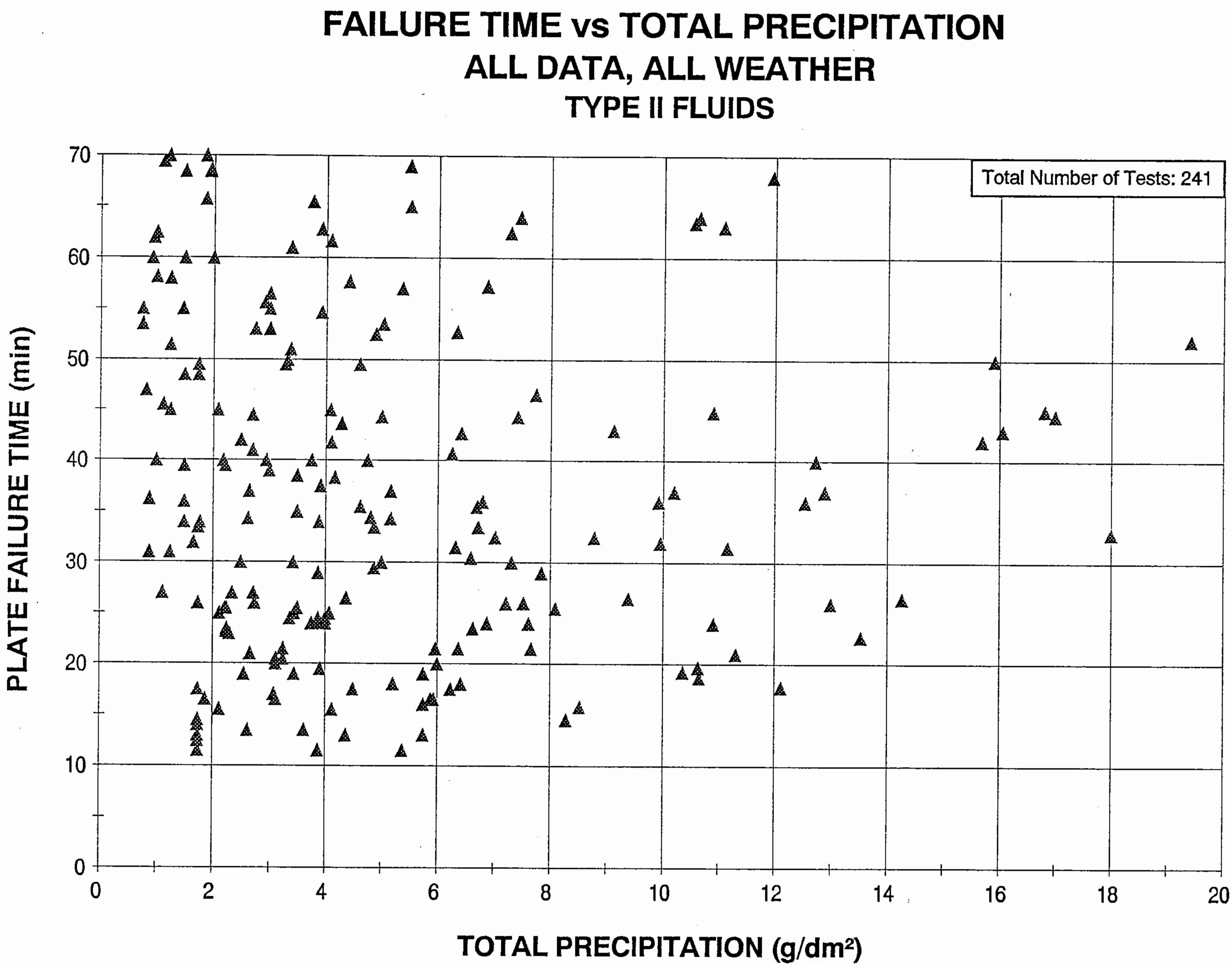

FAILURE TIME vs RATE OF PRECIPITATION
DORVAL DATA, SNOW CONDITIONS
FLUID A-203
Total Number of Tests: 15
Fluid A-203
Selected Lower Limit Data
EFFECTIVE LOWER LIMIT CURVE
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45



FAILURE TIME vs RATE OF PRECIPITATION
DORVAL DATA, FREEZING RAIN/DRIZZLE
TYPE II FLUIDS
Total Number of Tests: 30
Type II Fluids
Selected Lower Limit Data
EFFECTIVE LOWER LIMIT CURVE
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
0
10
20
30
40
50
60
70
5
15
25
35
45

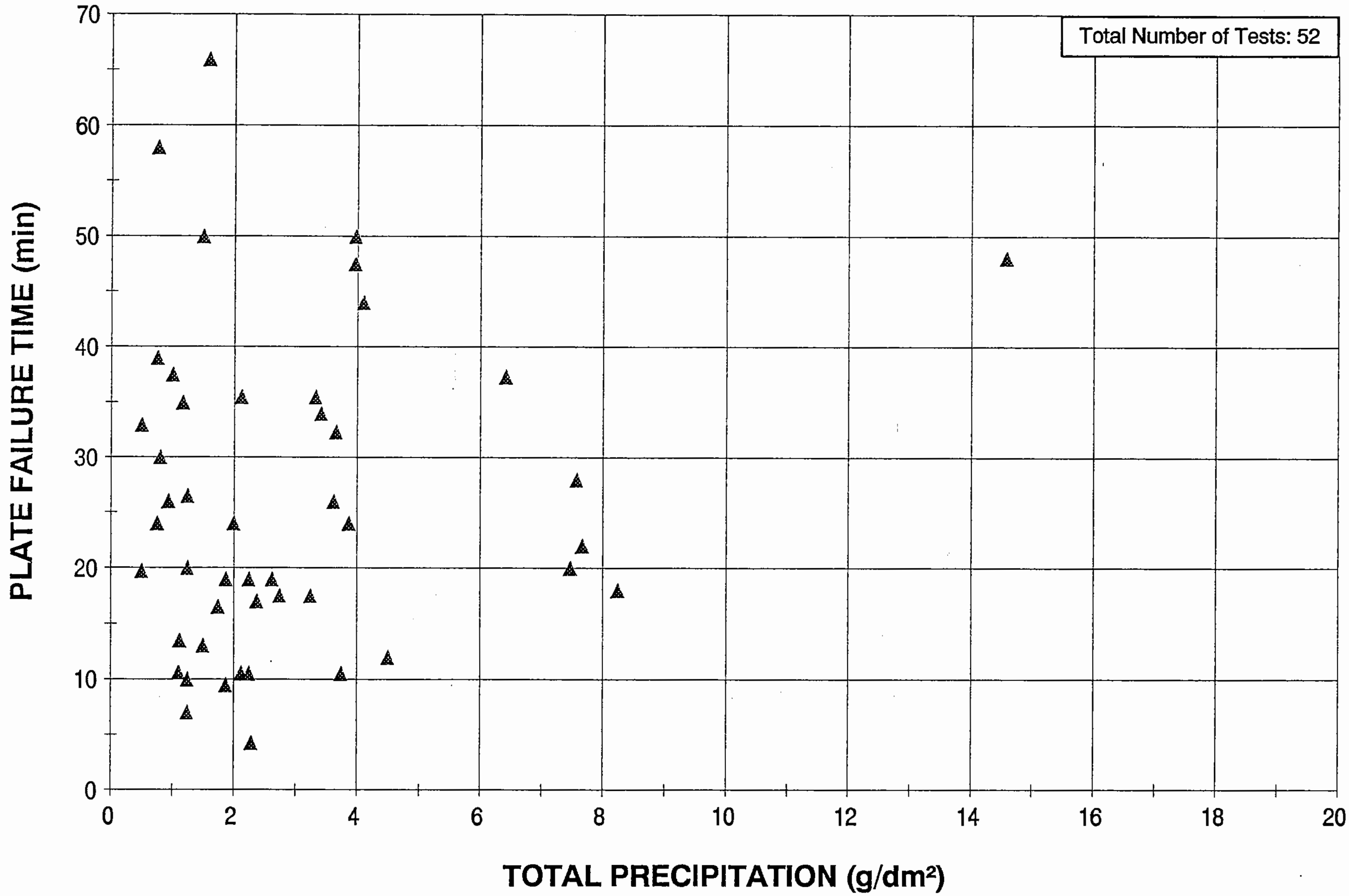


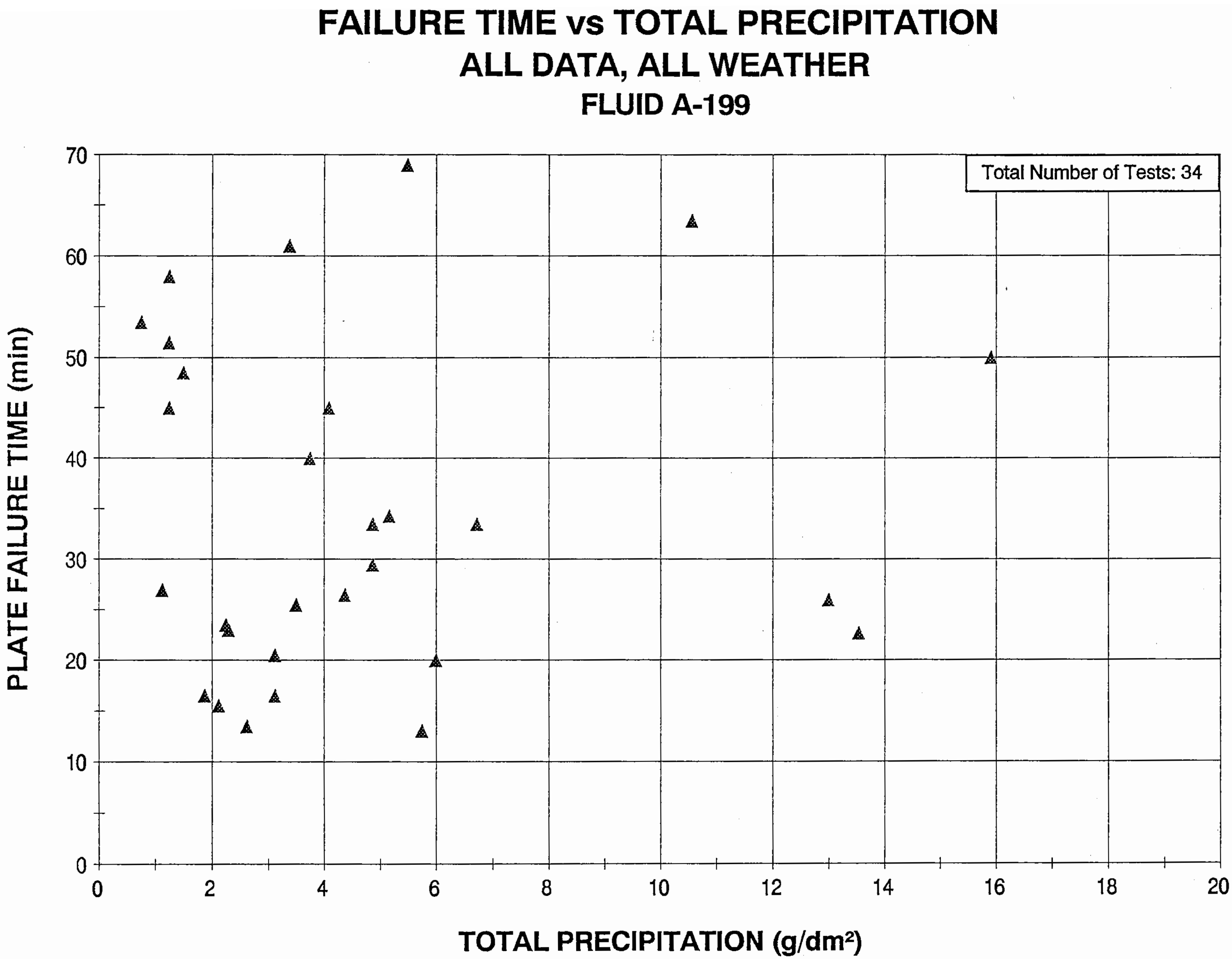
FAILURE TIME vs RATE OF PRECIPITATION
DORVAL DATA, FREEZING RAIN/DRIZZLE
FLUID A-201
Total Number of Tests: 11
Fluid A-201
Selected Lower Limit Data
PLATE FAILURE TIME (min)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45
EFFECTIVE LOWER LIMIT CURVE
RATE OF PRECIPITATION (g/dm²/hr)

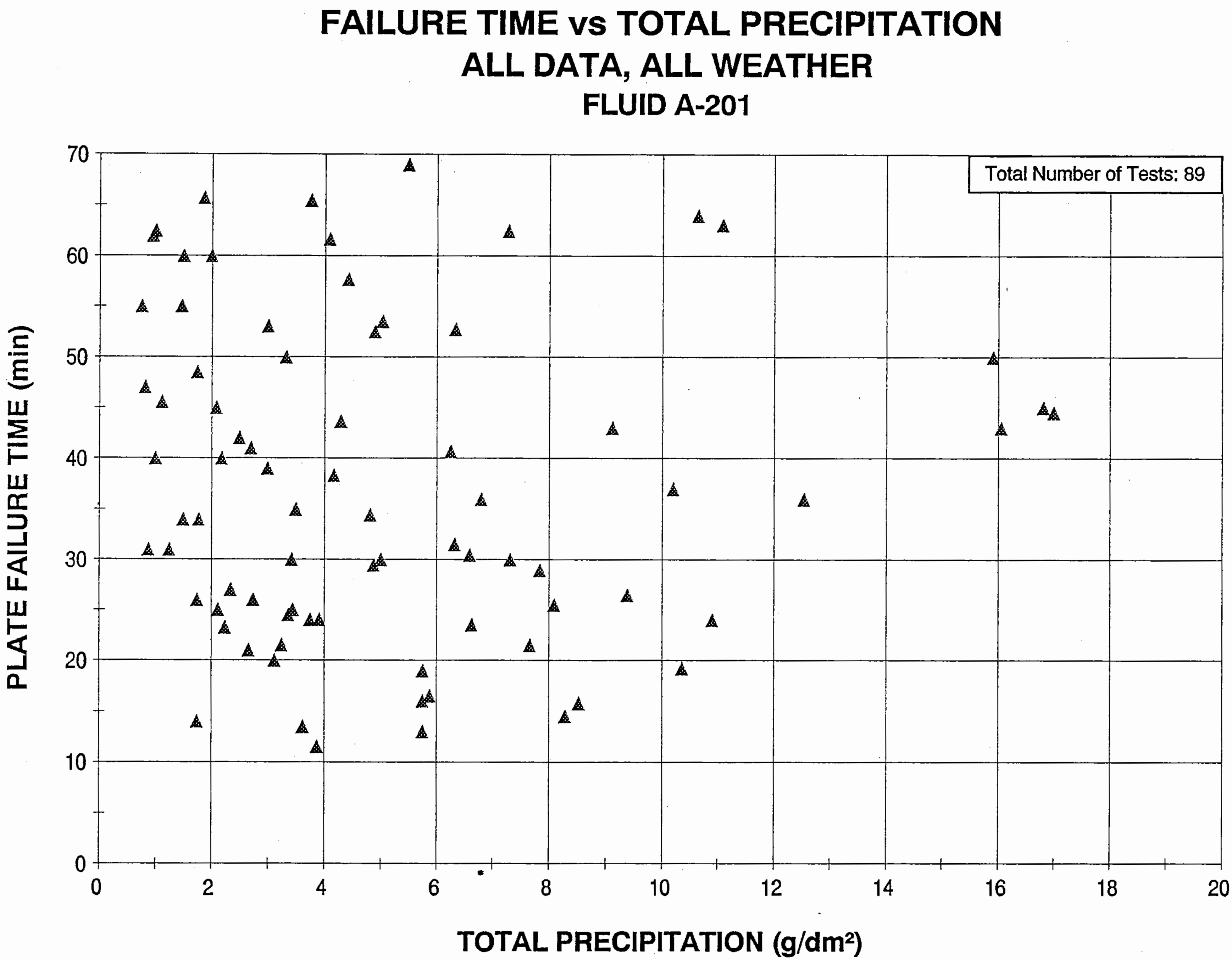


FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, ALL WEATHER
TYPE II FLUIDS
Total Number of Tests: 241
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20

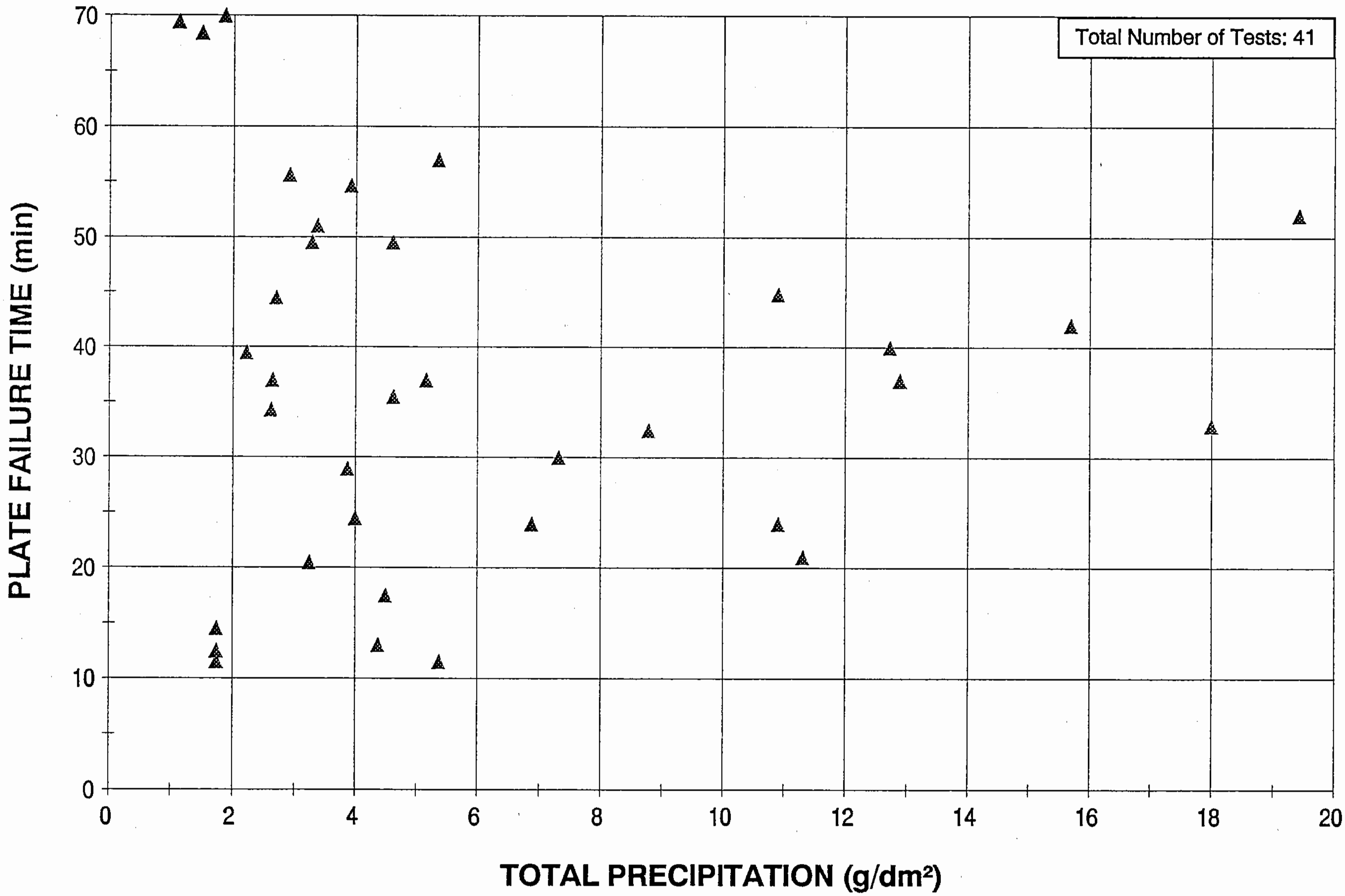
FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, ALL WEATHER
TYPE 1.5 FLUIDS

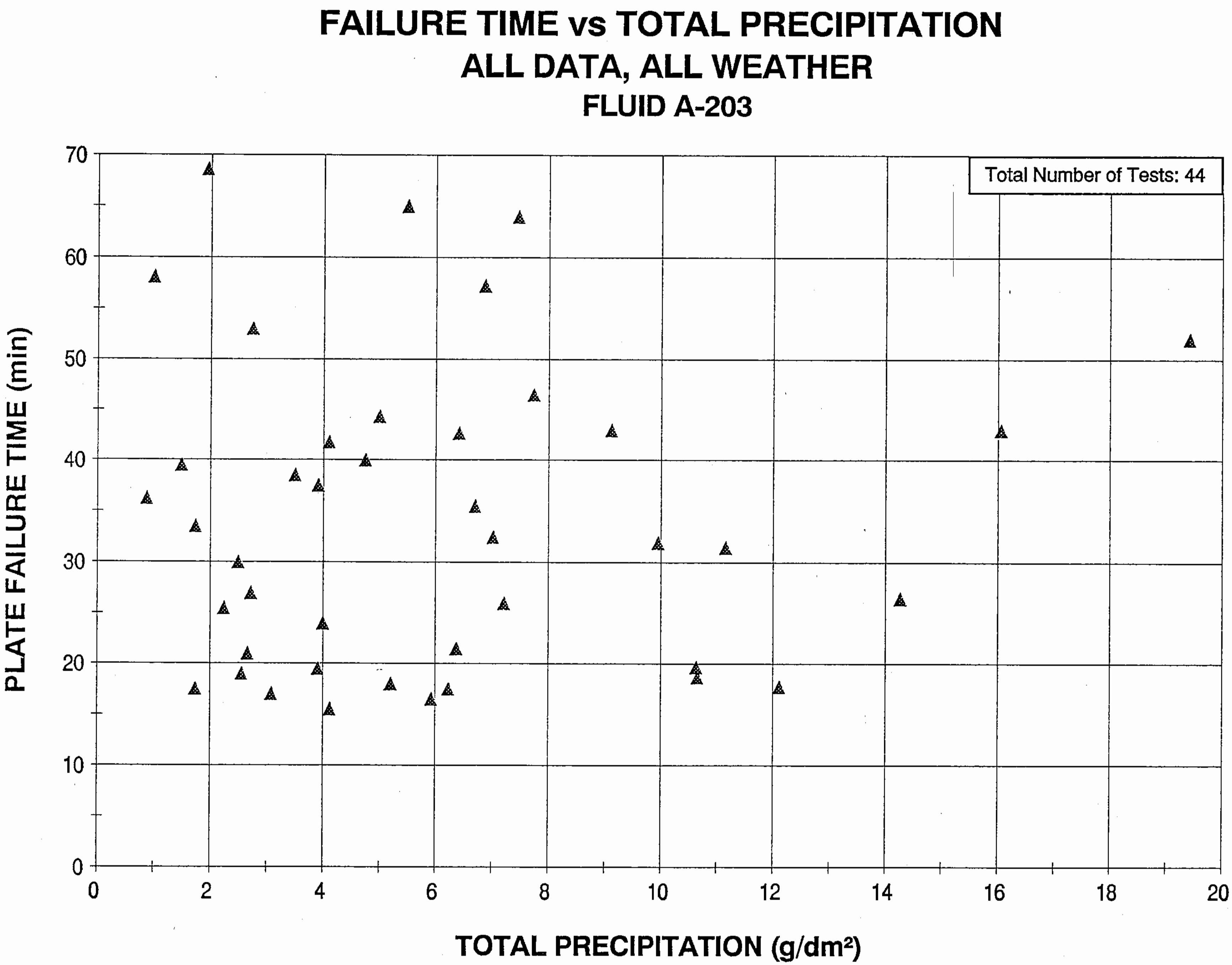


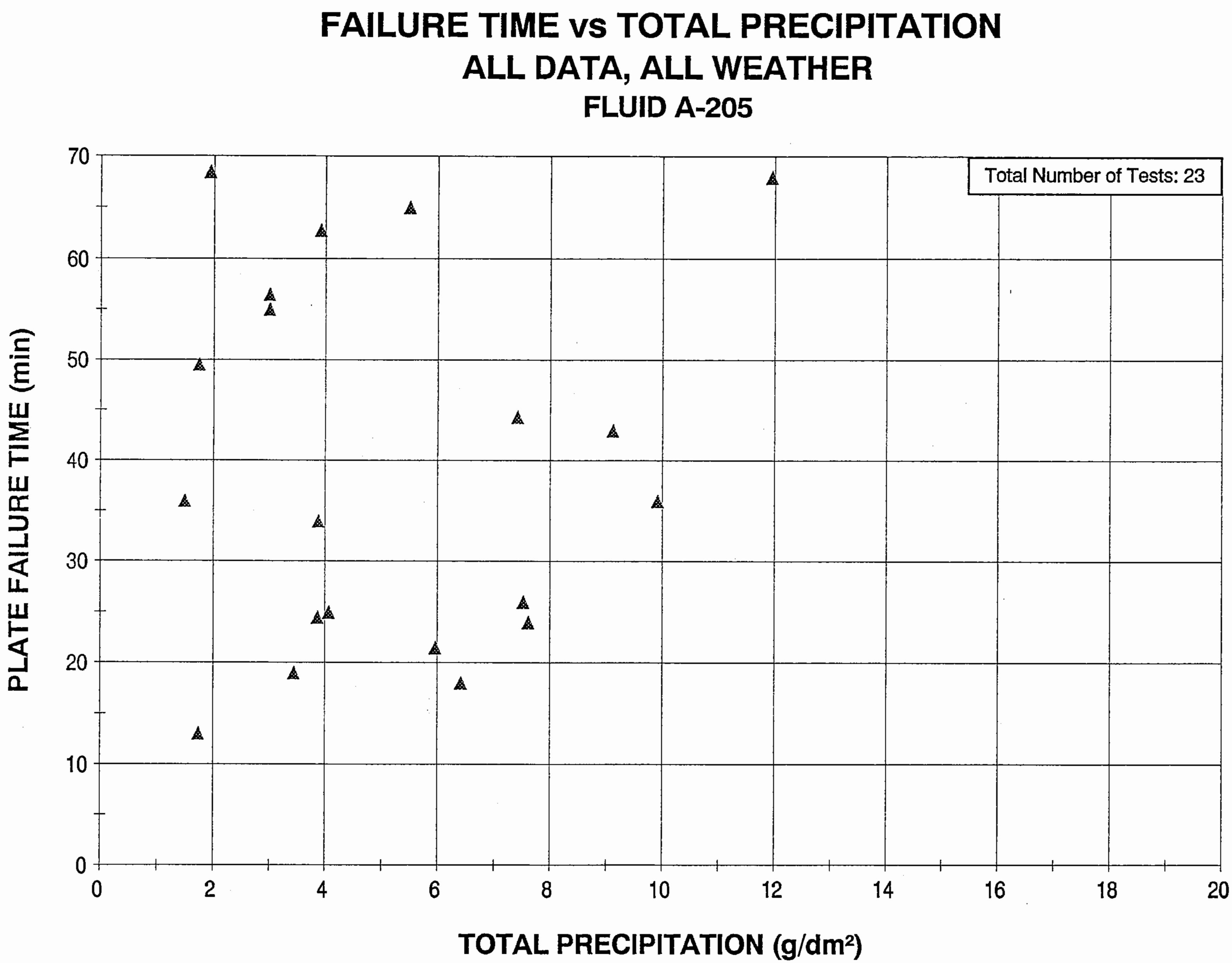

FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, ALL WEATHER
FLUID A-199
Total Number of Tests: 34
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20


FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, ALL WEATHER
FLUID A-201
Total Number of Tests: 89
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20

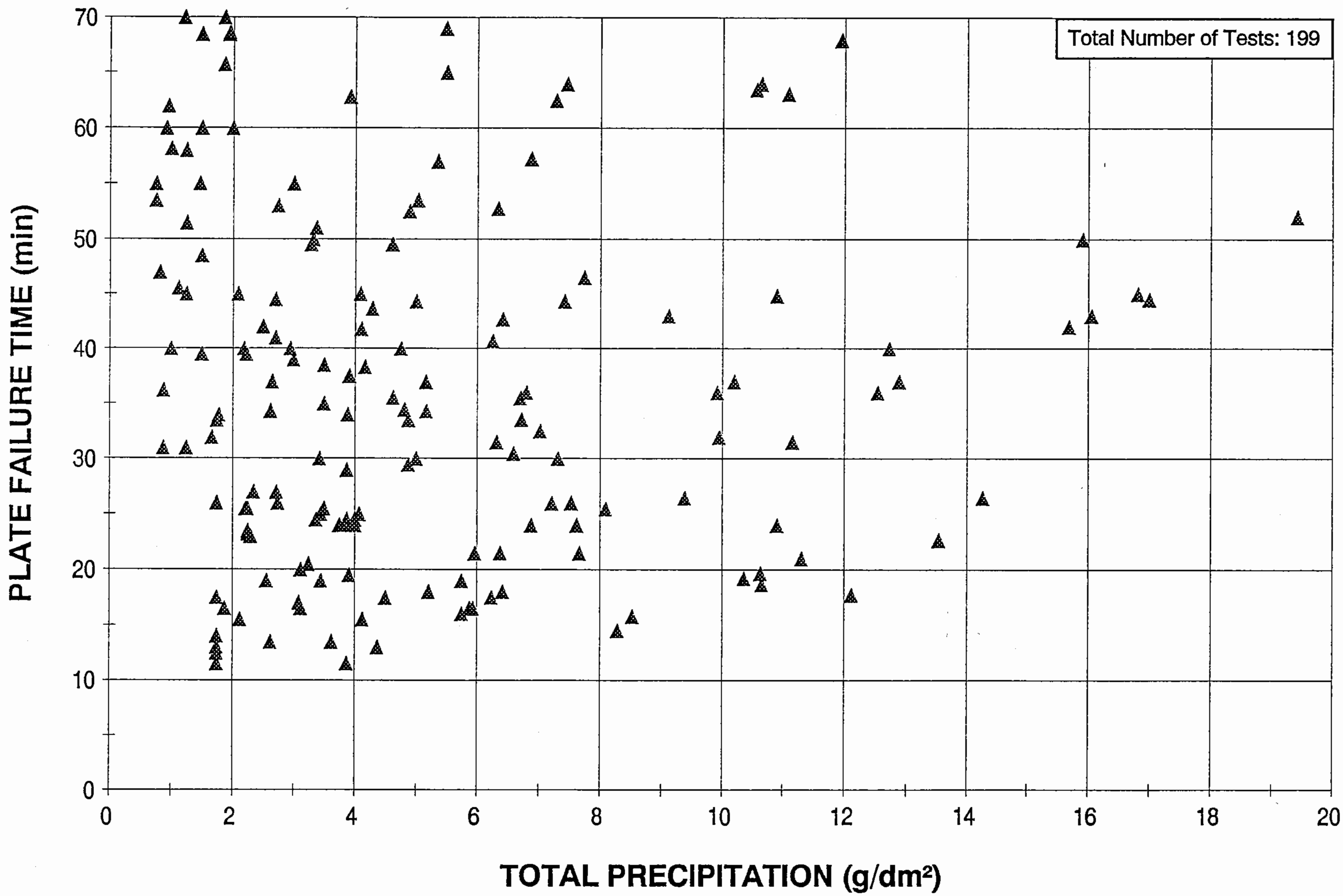
FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, ALL WEATHER
FLUID A-202



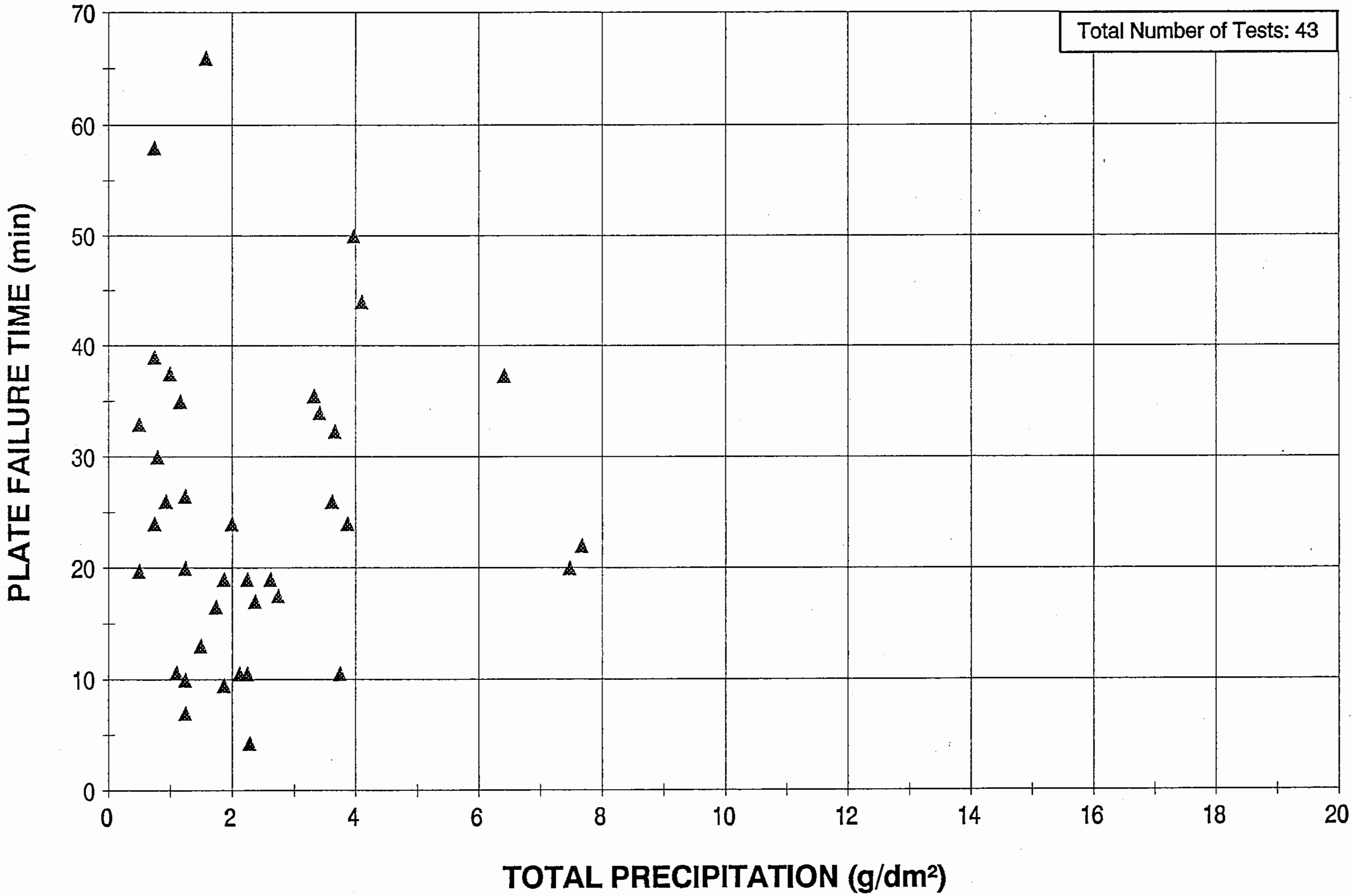

FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, ALL WEATHER
FLUID A-203
Total Number of Tests: 44
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20


FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, ALL WEATHER
FLUID A-205
Total Number of Tests: 23
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20

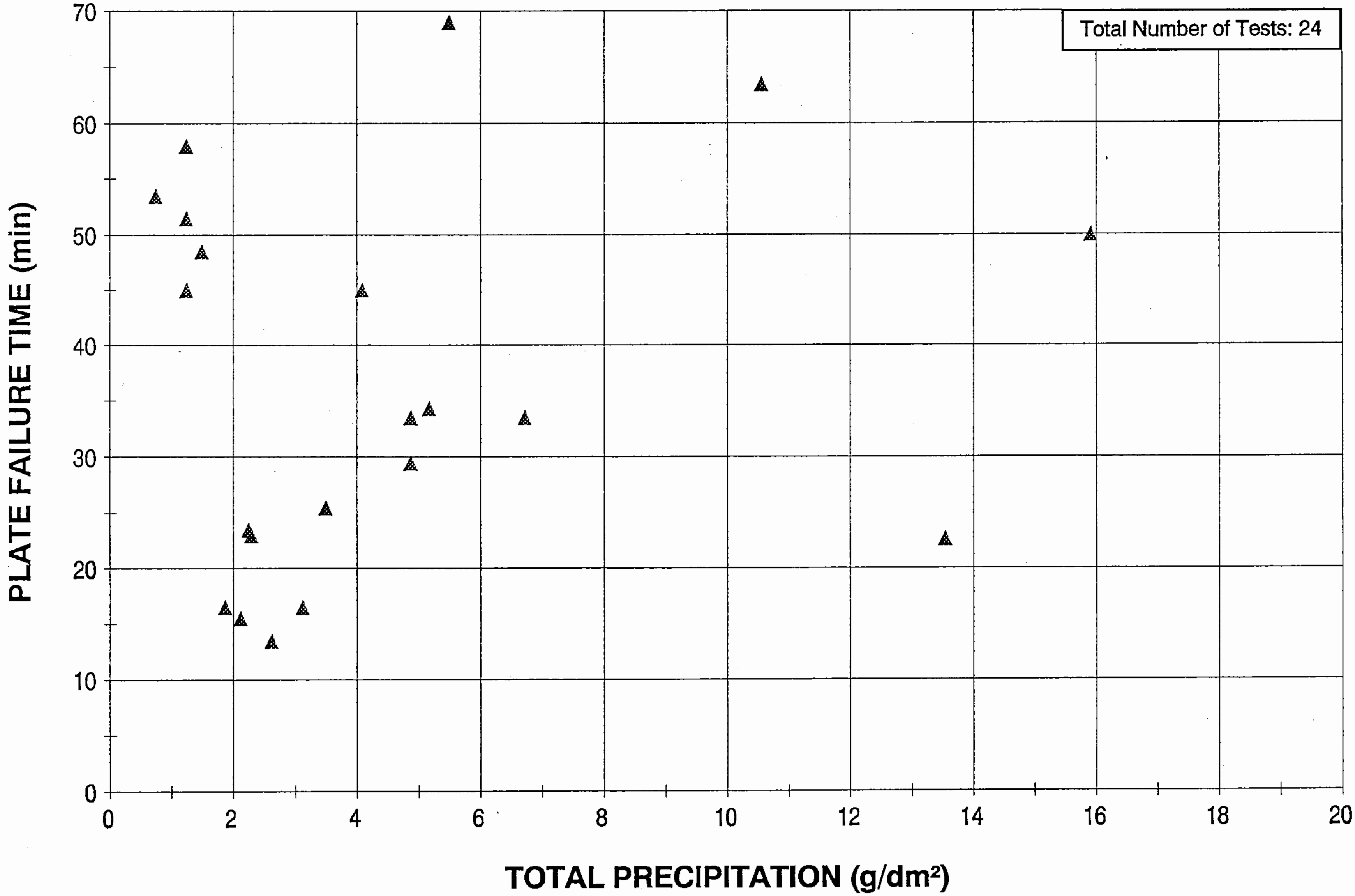
FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, SNOW CONDITIONS
ALL TYPE II FLUIDS



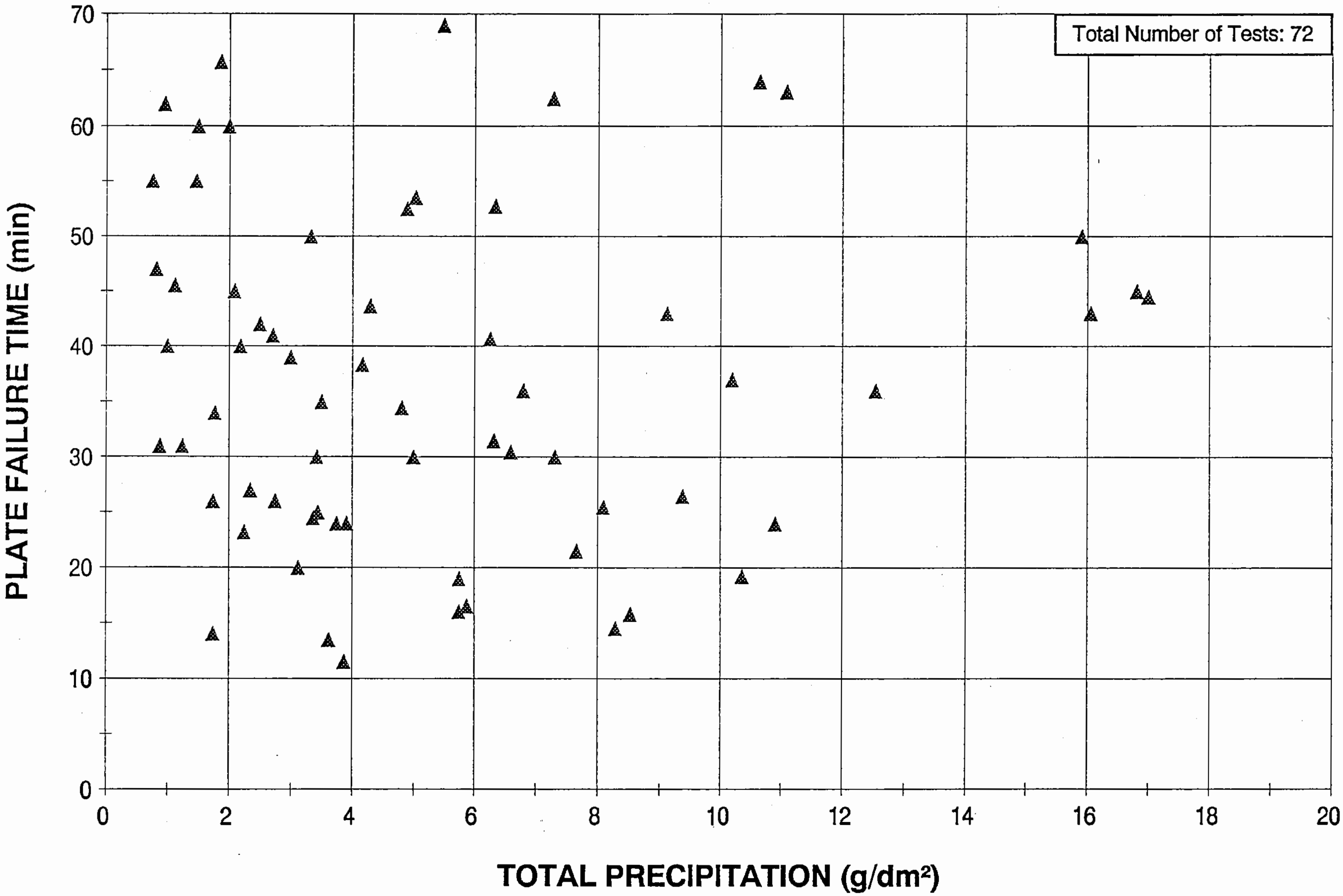
FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, SNOW CONDITIONS
ALL TYPE 1.5 FLUIDS



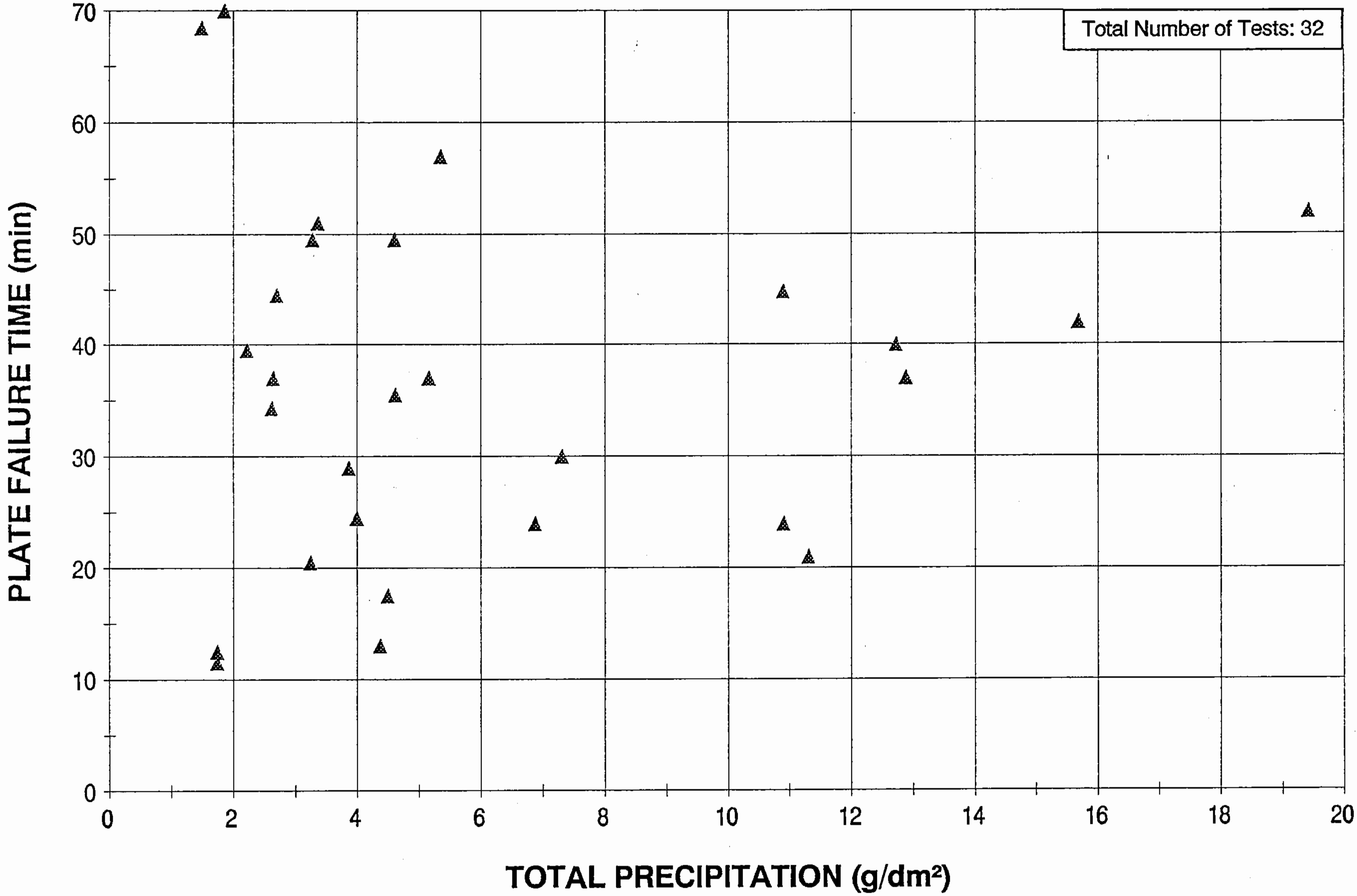
FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, SNOW CONDITIONS
FLUID A-199



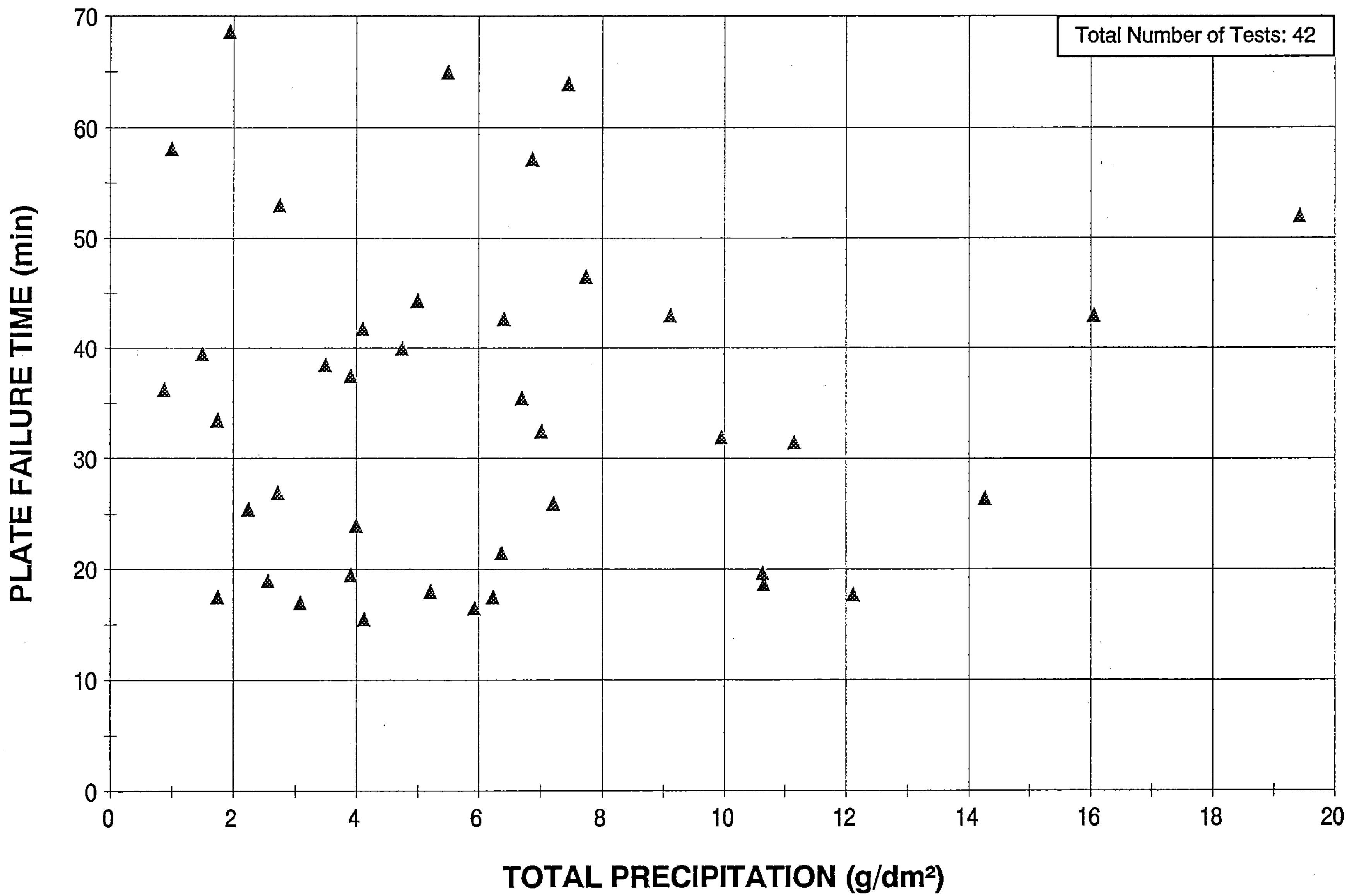
FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, SNOW CONDITIONS
FLUID A-201



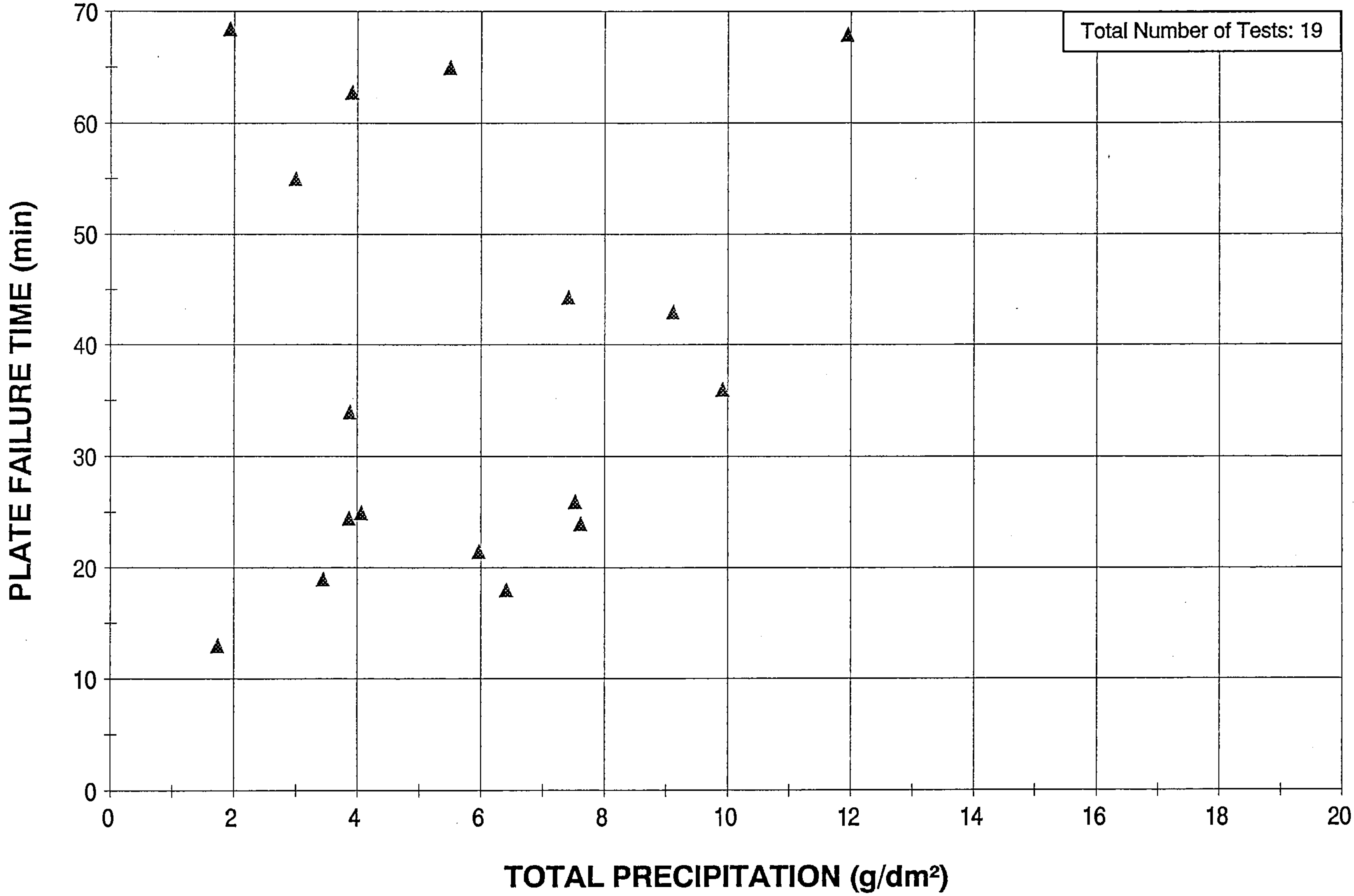
FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, SNOW CONDITIONS
FLUID A-202

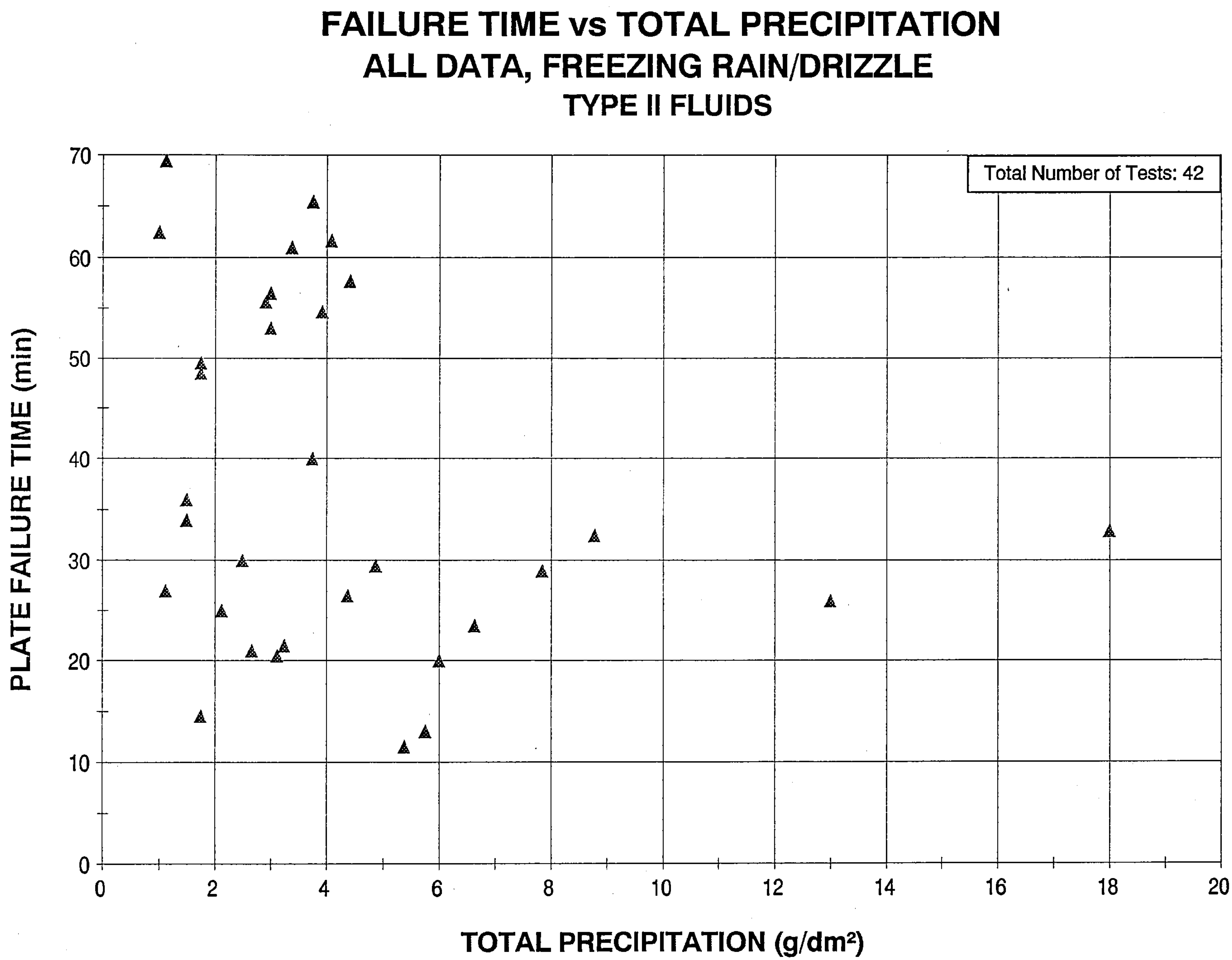


FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, SNOW CONDITIONS
FLUID A-203

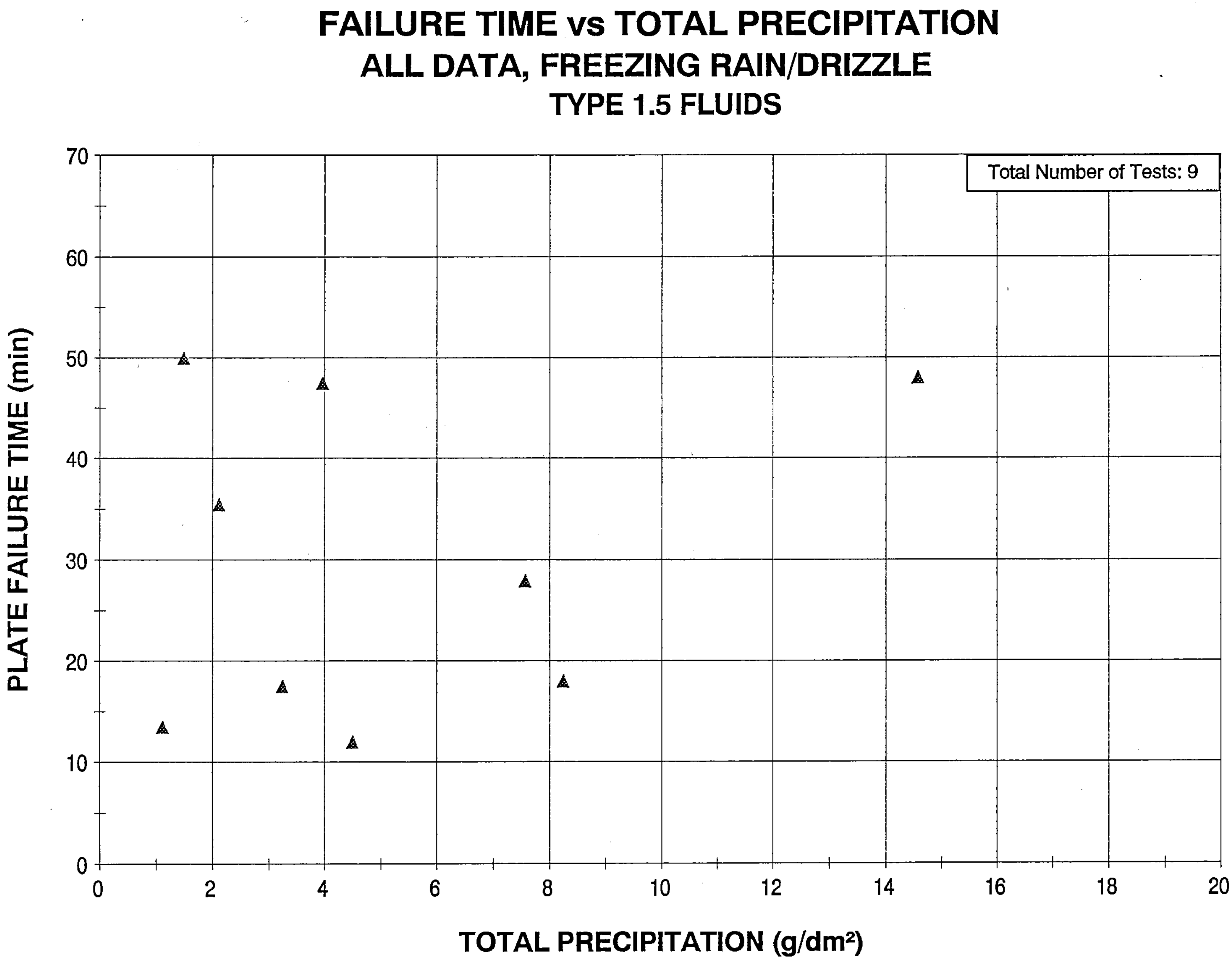


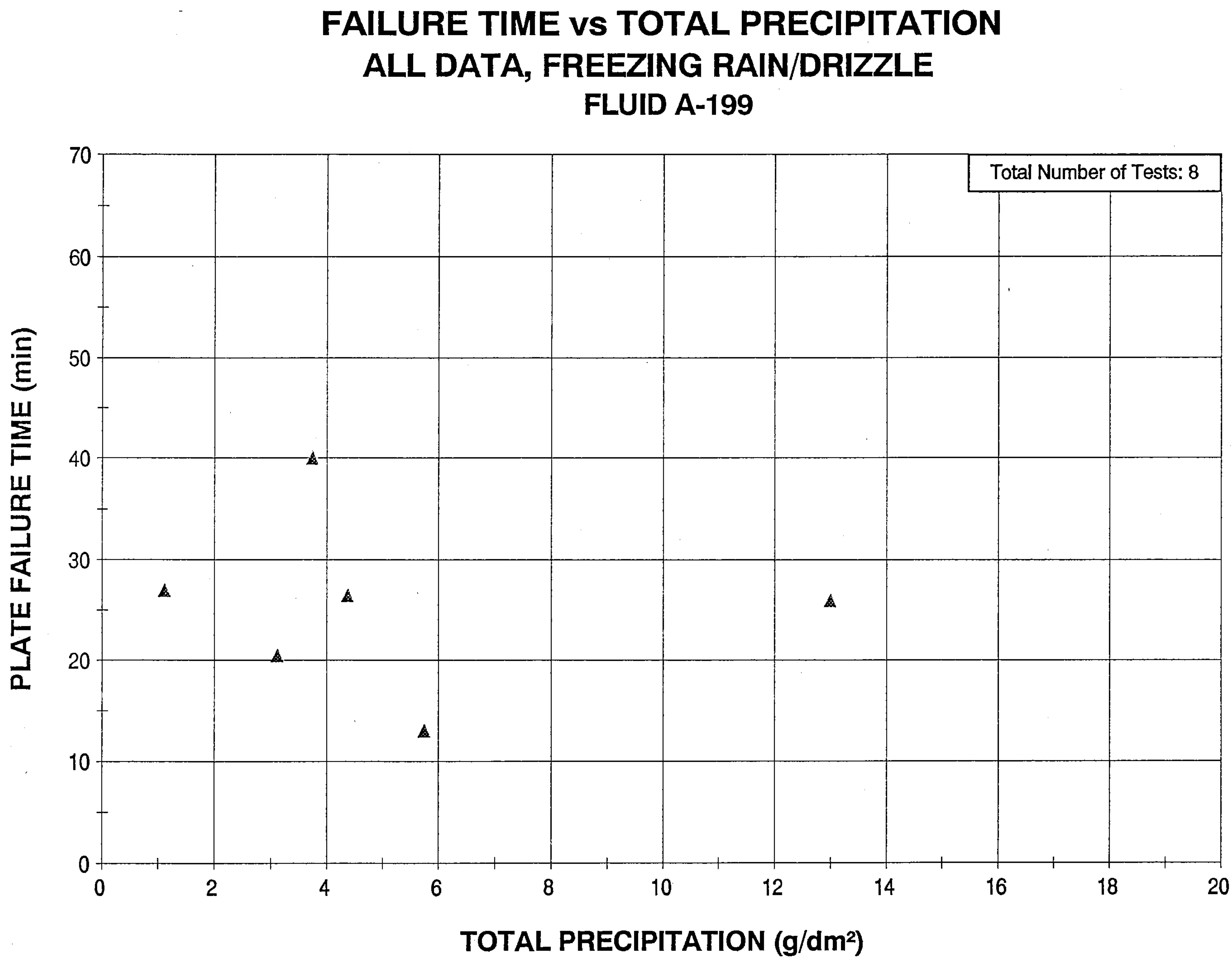
FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, SNOW CONDITIONS
FLUID A-205



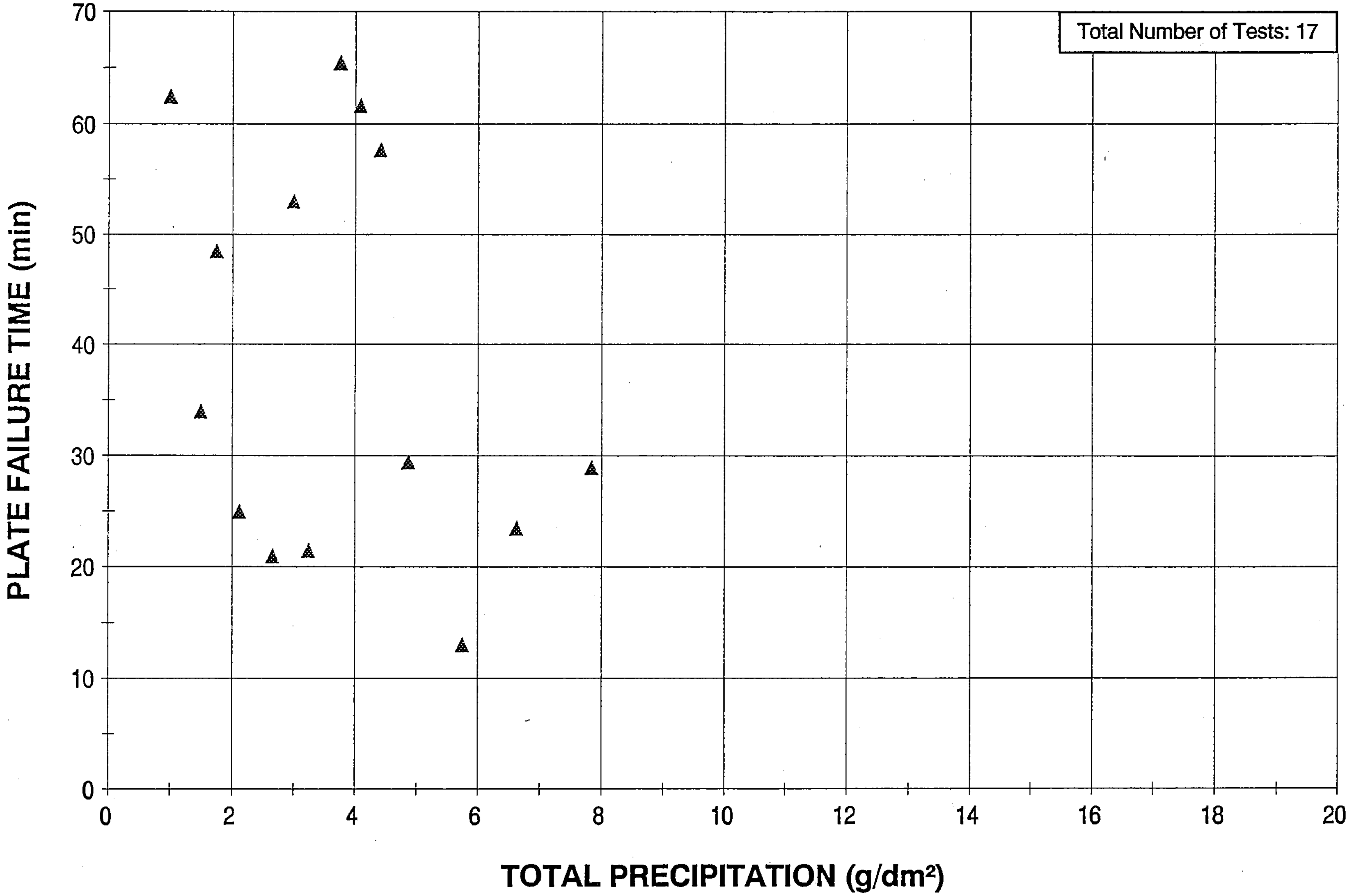


FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, FREEZING RAIN/DRIZZLE
TYPE II FLUIDS
Total Number of Tests: 42
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20

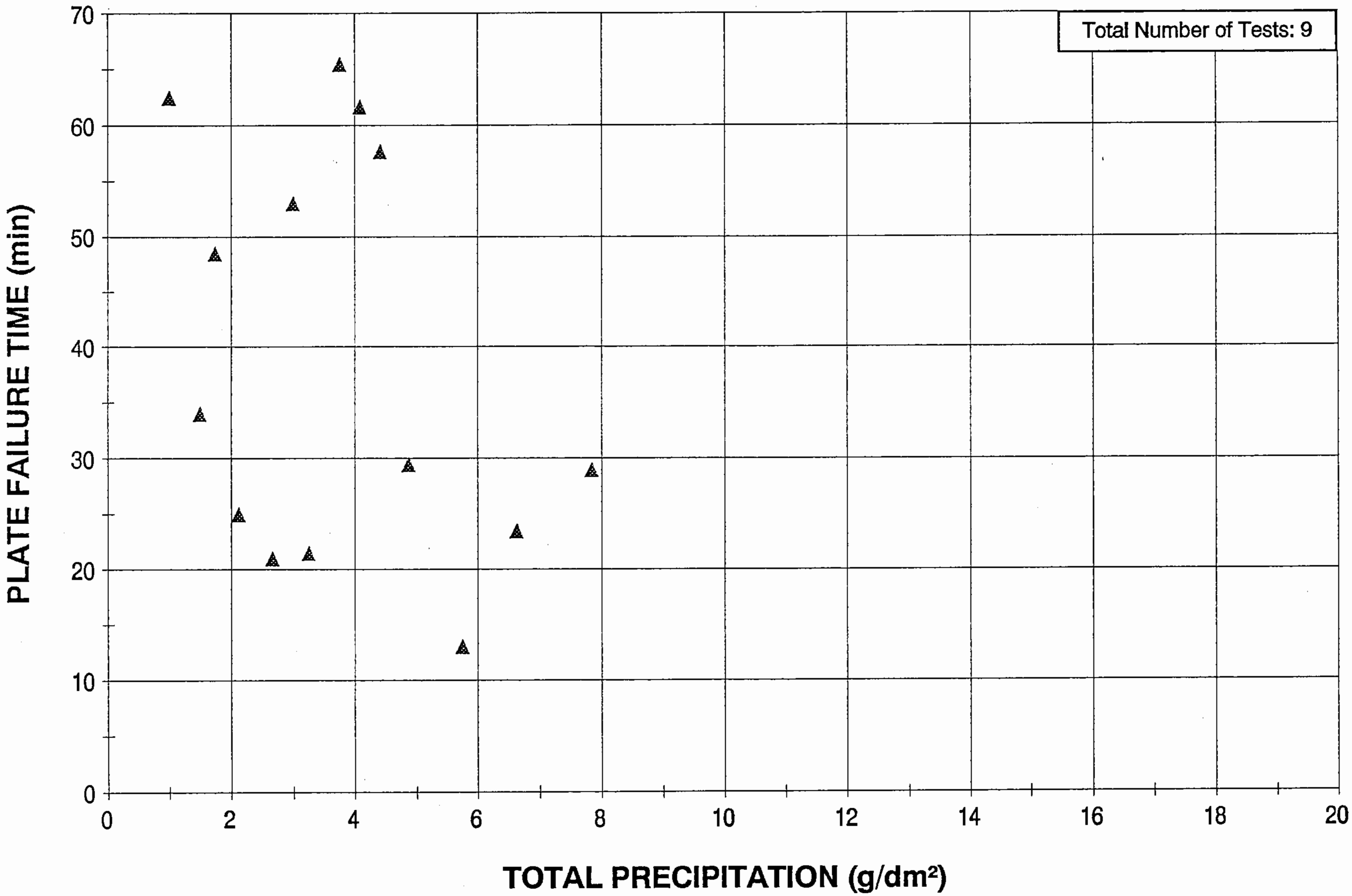

FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, FREEZING RAIN/DRIZZLE
TYPE 1.5 FLUIDS
Total Number of Tests: 9
PLATE FAILURE TIME (min)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20
TOTAL PRECIPITATION (g/dm²)


FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, FREEZING RAIN/DRIZZLE
FLUID A-199
Total Number of Tests: 8
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
2
4
6
8
10
12
14
16
18
20

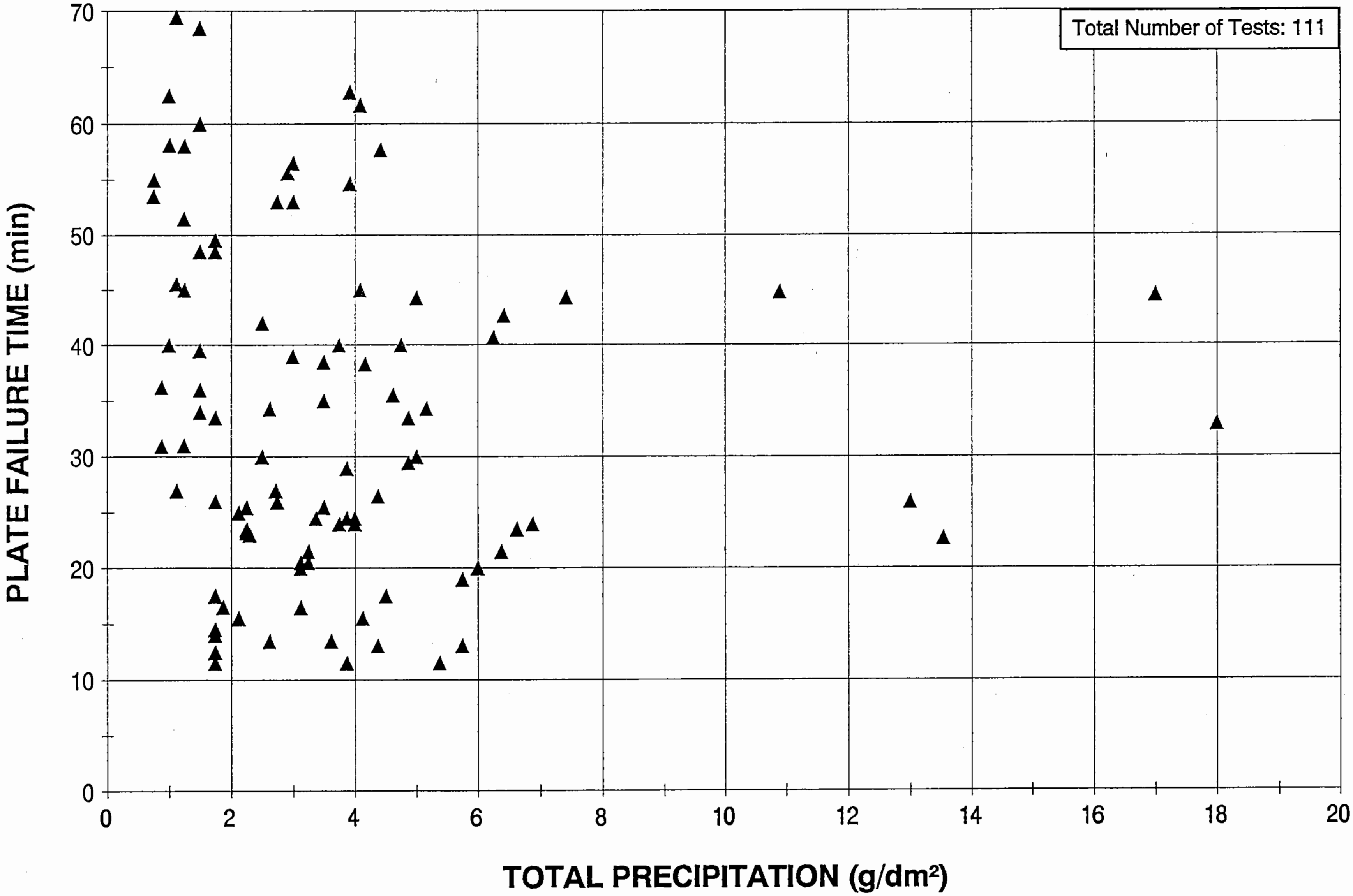
FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, FREEZING RAIN/DRIZZLE
FLUID A-201

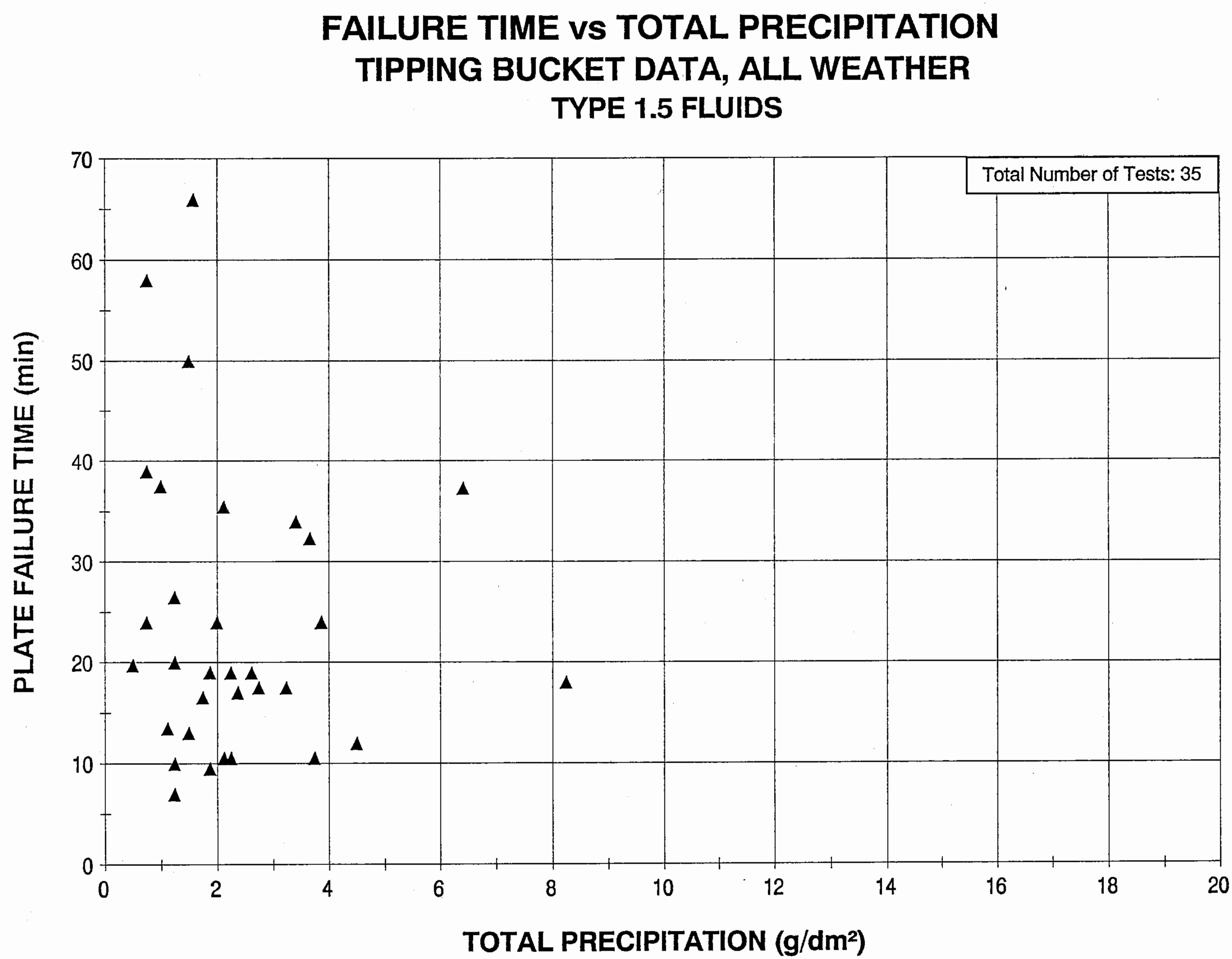


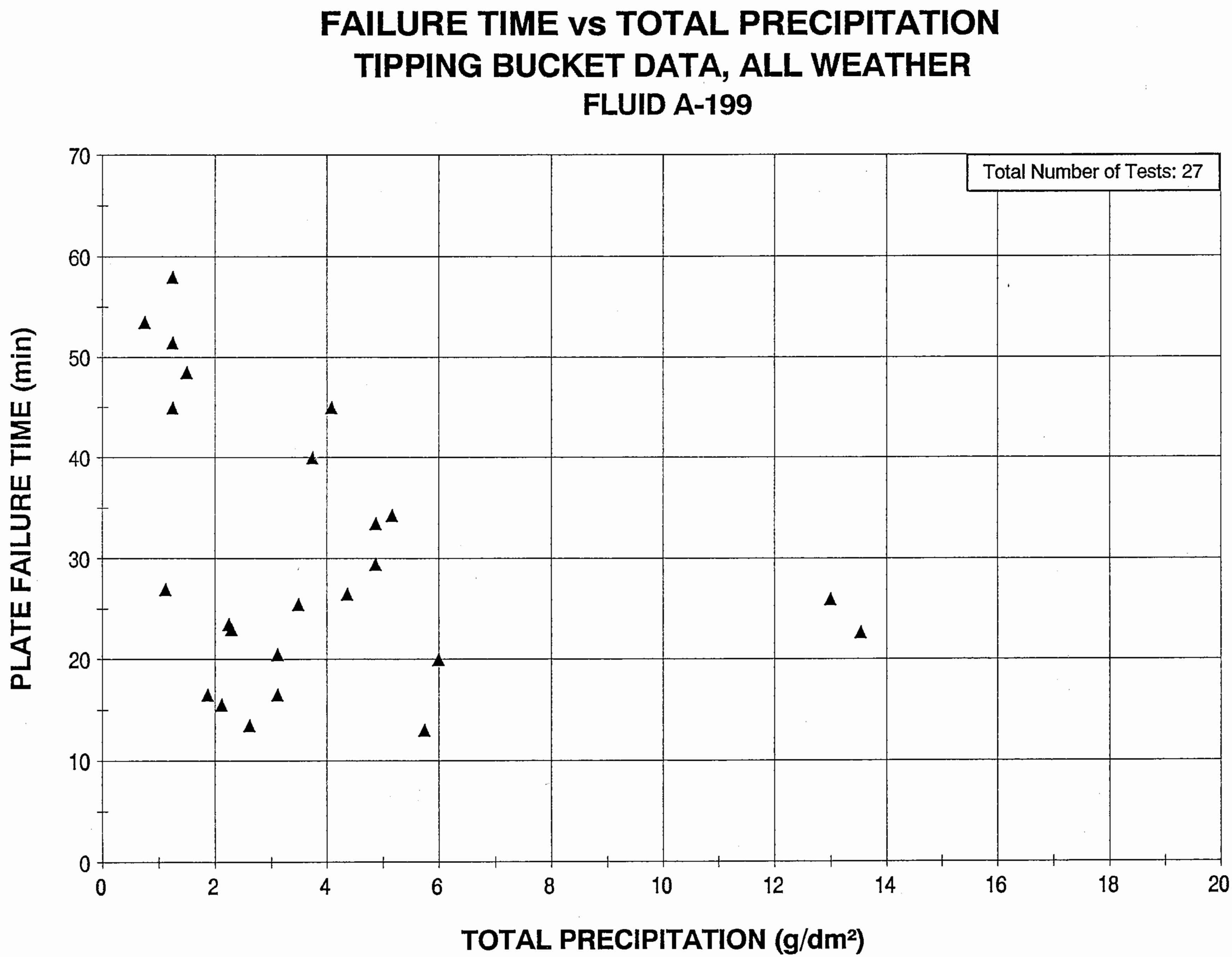
FAILURE TIME vs TOTAL PRECIPITATION
ALL DATA, FREEZING RAIN/DRIZZLE
FLUID A-202

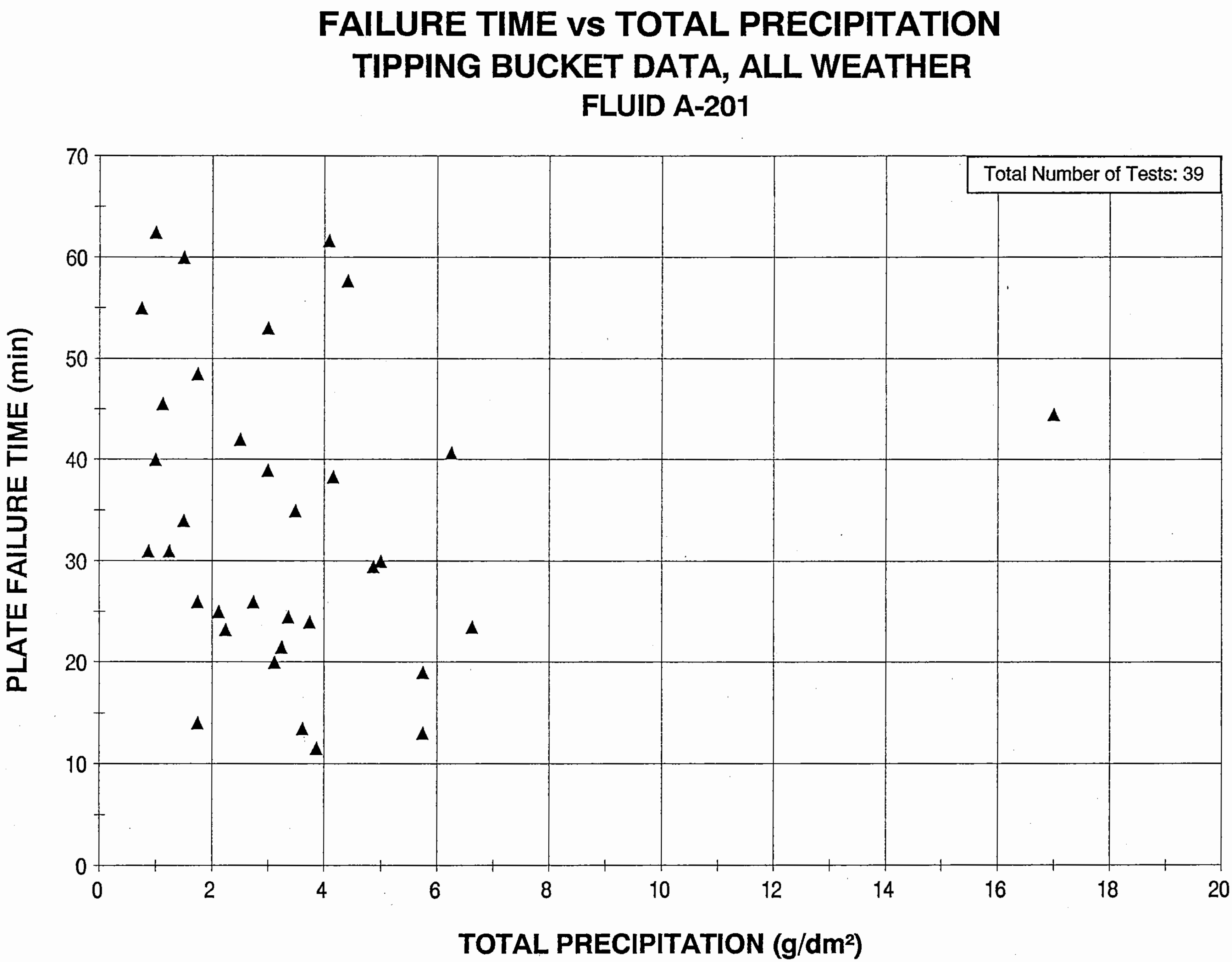


FAILURE TIME vs TOTAL PRECIPITATION
TIPPING BUCKET DATA, ALL WEATHER
TYPE II FLUIDS



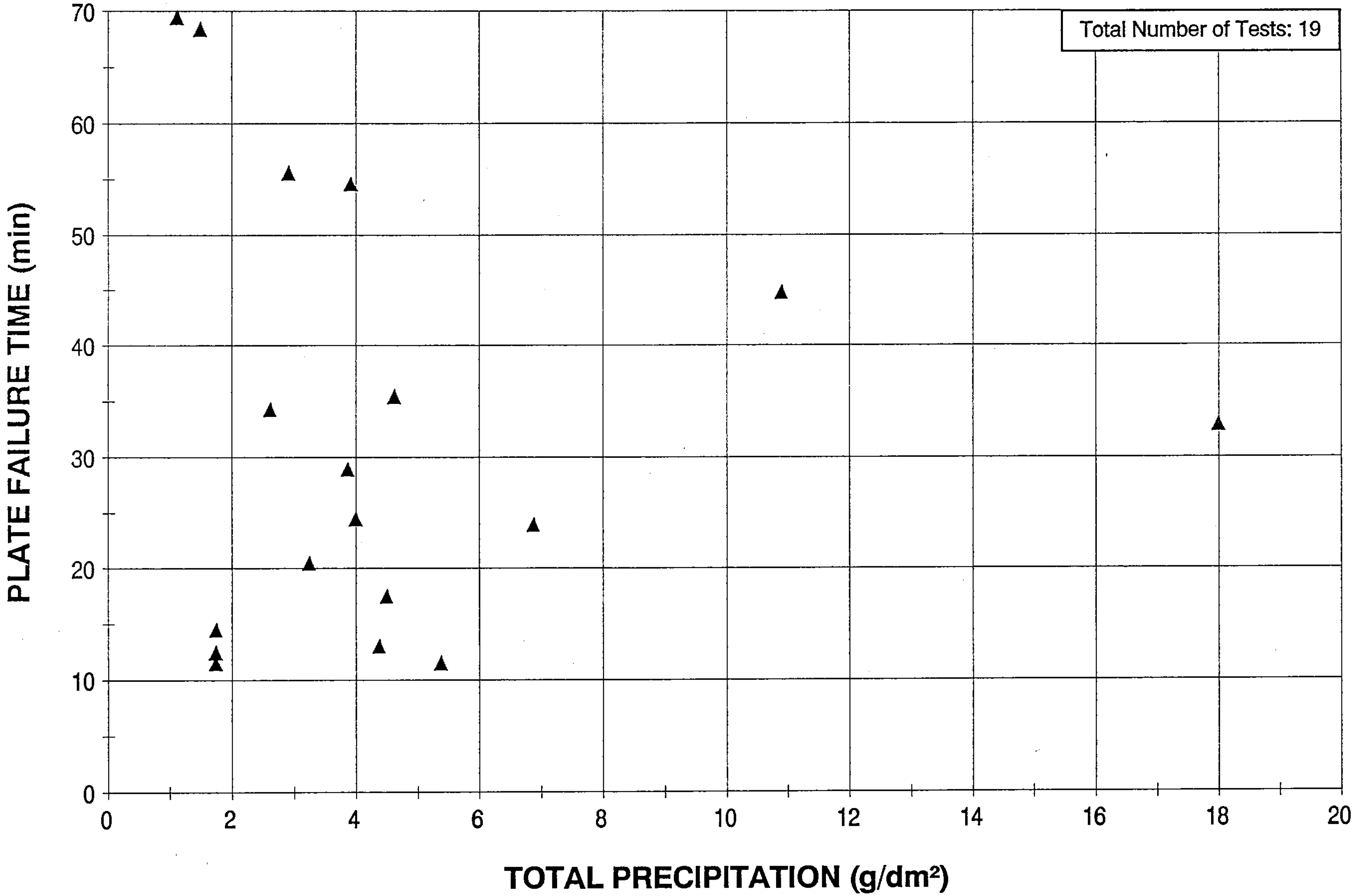

FAILURE TIME vs TOTAL PRECIPITATION
TIPPING BUCKET DATA, ALL WEATHER
TYPE 1.5 FLUIDS
Total Number of Tests: 35
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
2
4
6
8
10
12
14
16
18
20

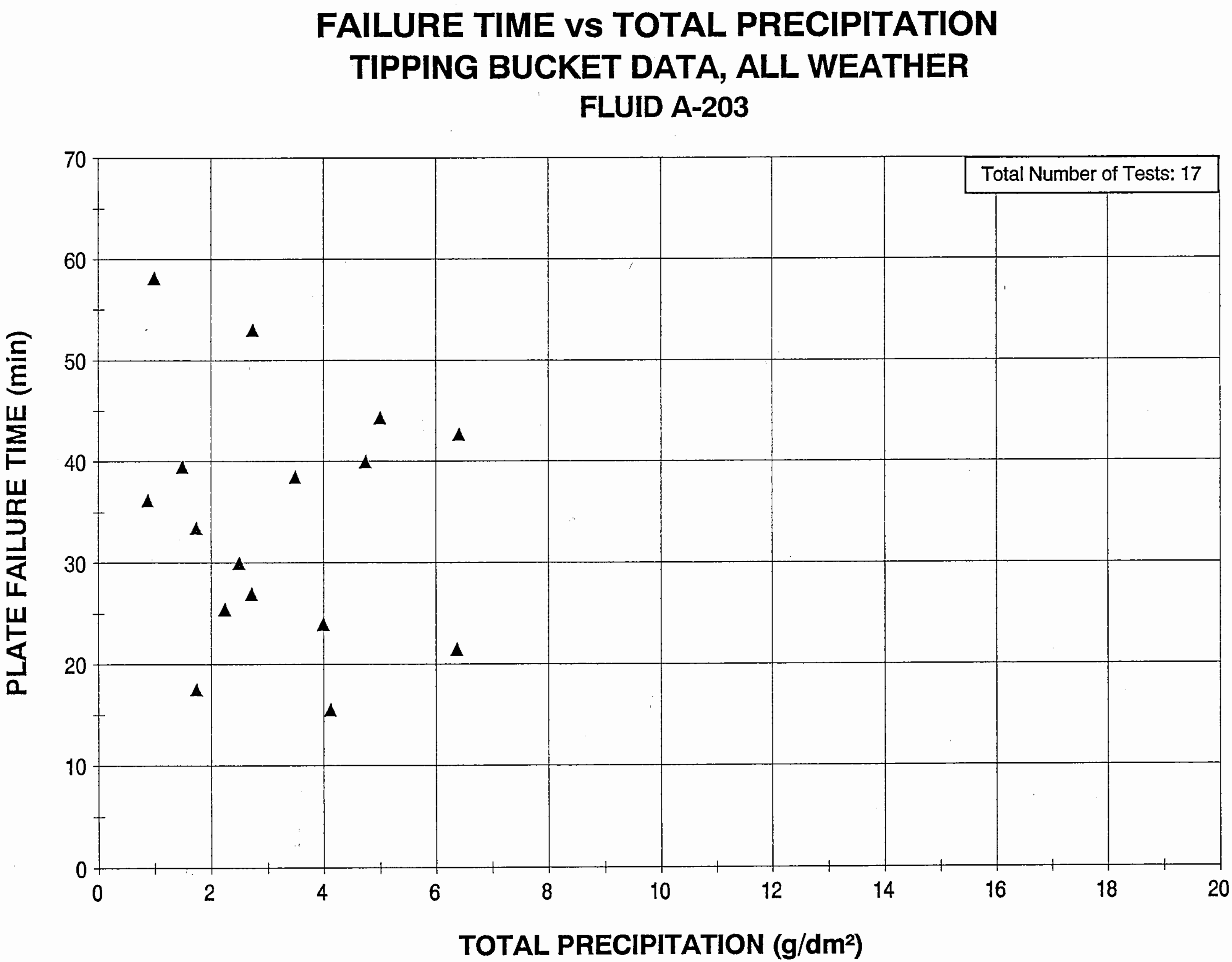

FAILURE TIME vs TOTAL PRECIPITATION
TIPPING BUCKET DATA, ALL WEATHER
FLUID A-199
Total Number of Tests: 27
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20



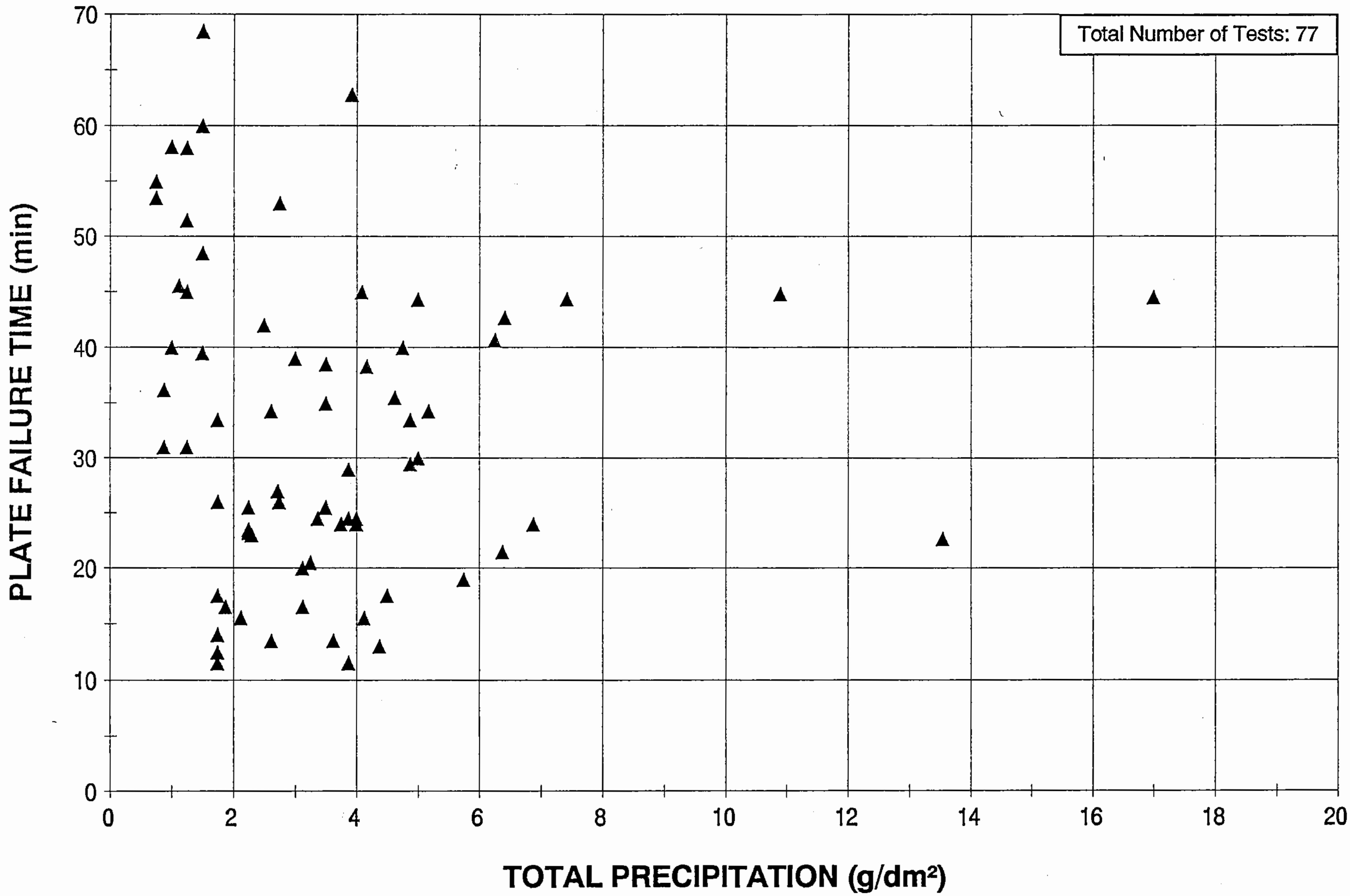
FAILURE TIME vs TOTAL PRECIPITATION
TIPPING BUCKET DATA, ALL WEATHER
FLUID A-201
Total Number of Tests: 39
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20

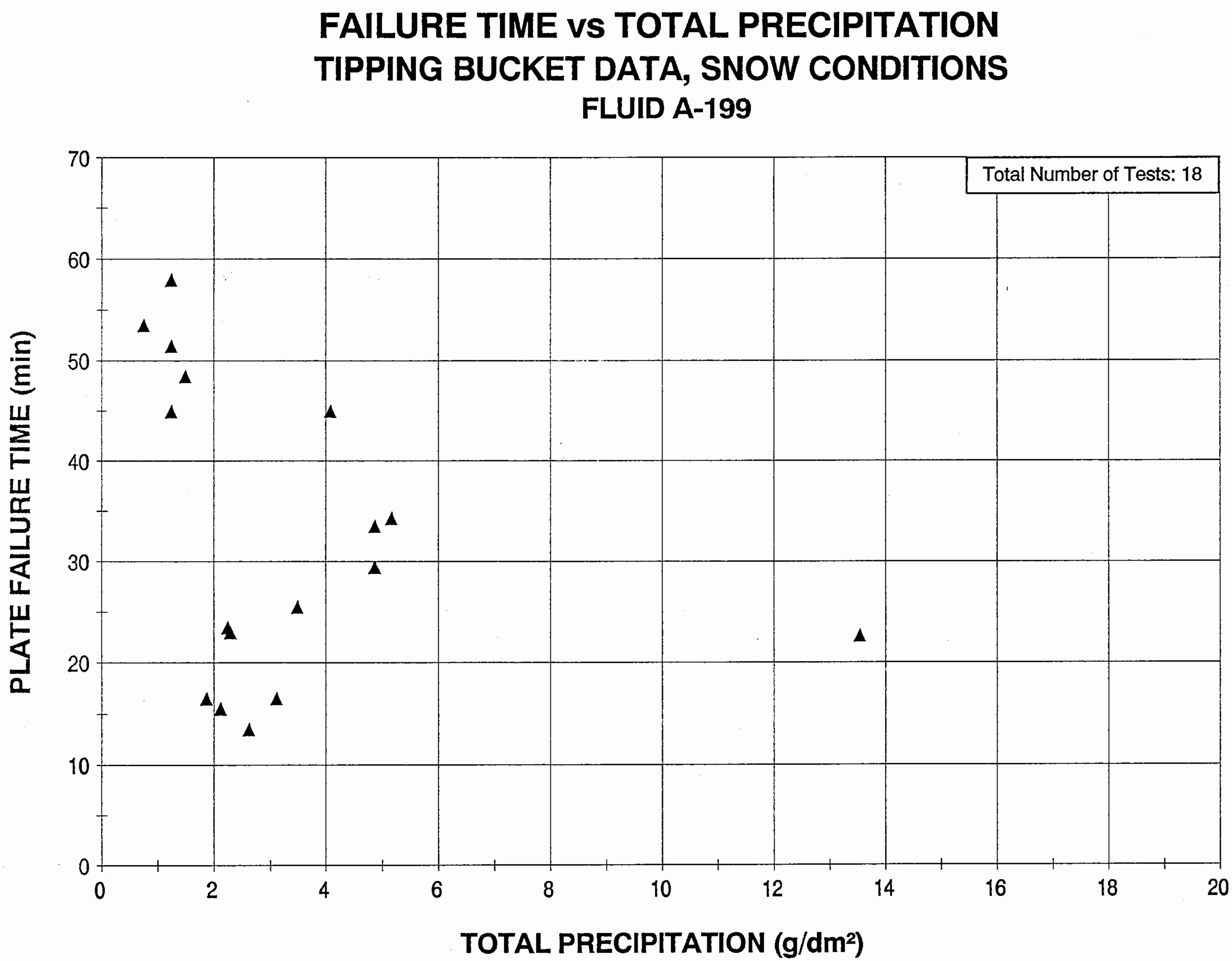
FAILURE TIME vs TOTAL PRECIPITATION
TIPPING BUCKET DATA, ALL WEATHER
FLUID A-202



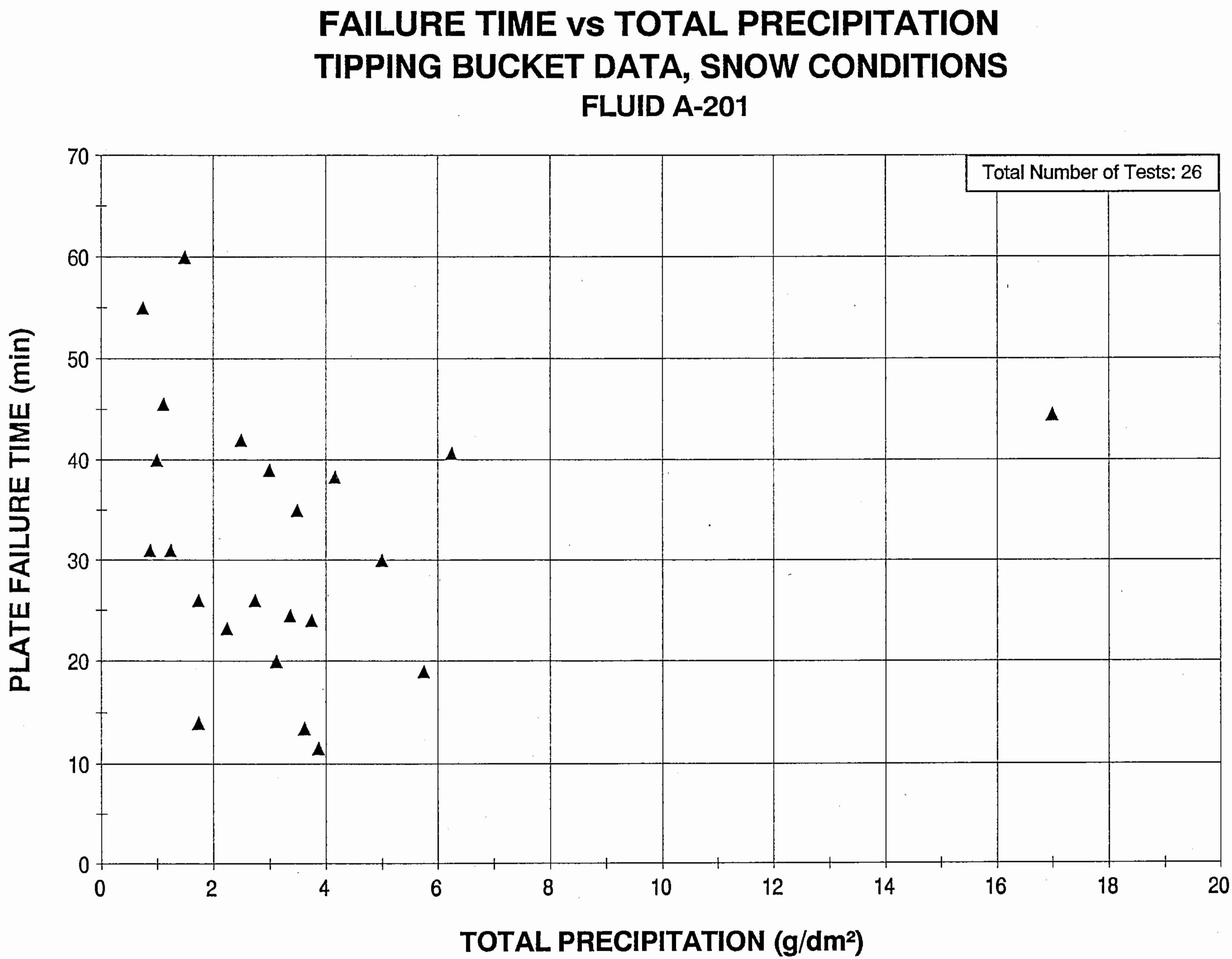

FAILURE TIME vs TOTAL PRECIPITATION
TIPPING BUCKET DATA, ALL WEATHER
FLUID A-203
Total Number of Tests: 17
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
2
4
6
8
10
12
14
16
18
20

FAILURE TIME vs TOTAL PRECIPITATION
TIPPING BUCKET DATA, SNOW CONDITIONS
TYPE II FLUIDS

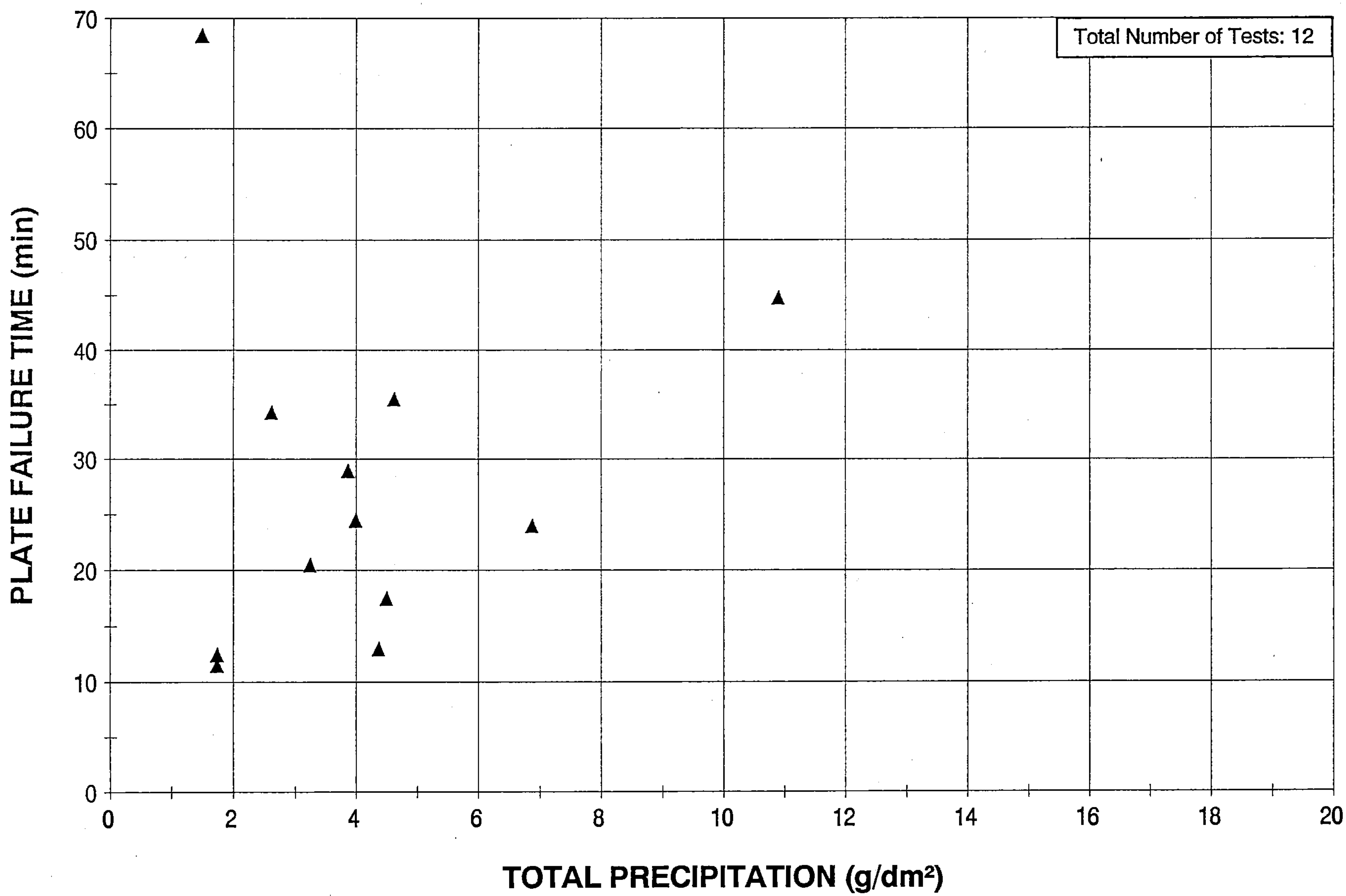




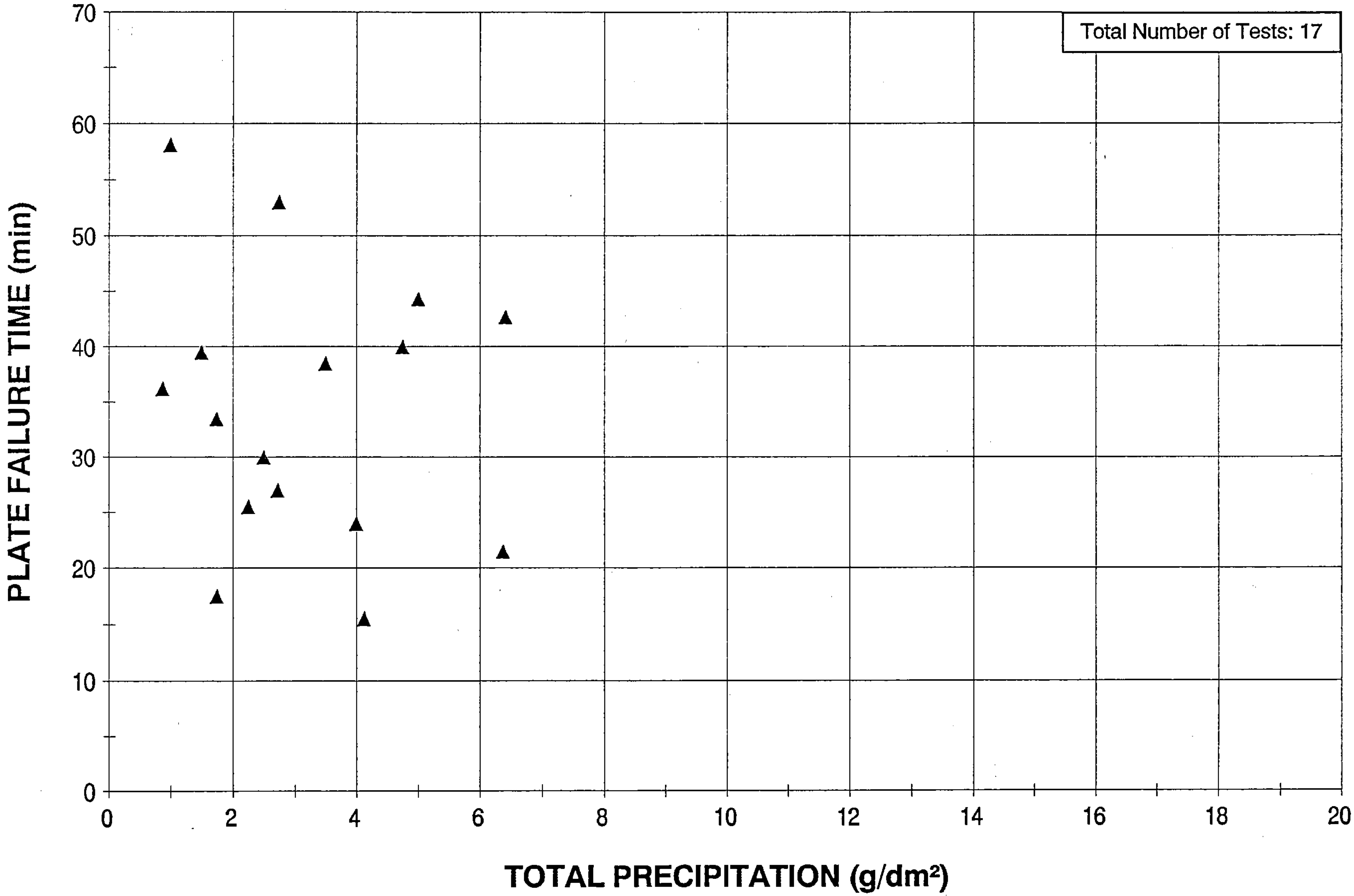
FAILURE TIME vs TOTAL PRECIPITATION
TIPPING BUCKET DATA, SNOW CONDITIONS
FLUID A-199
Total Number of Tests: 18
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20

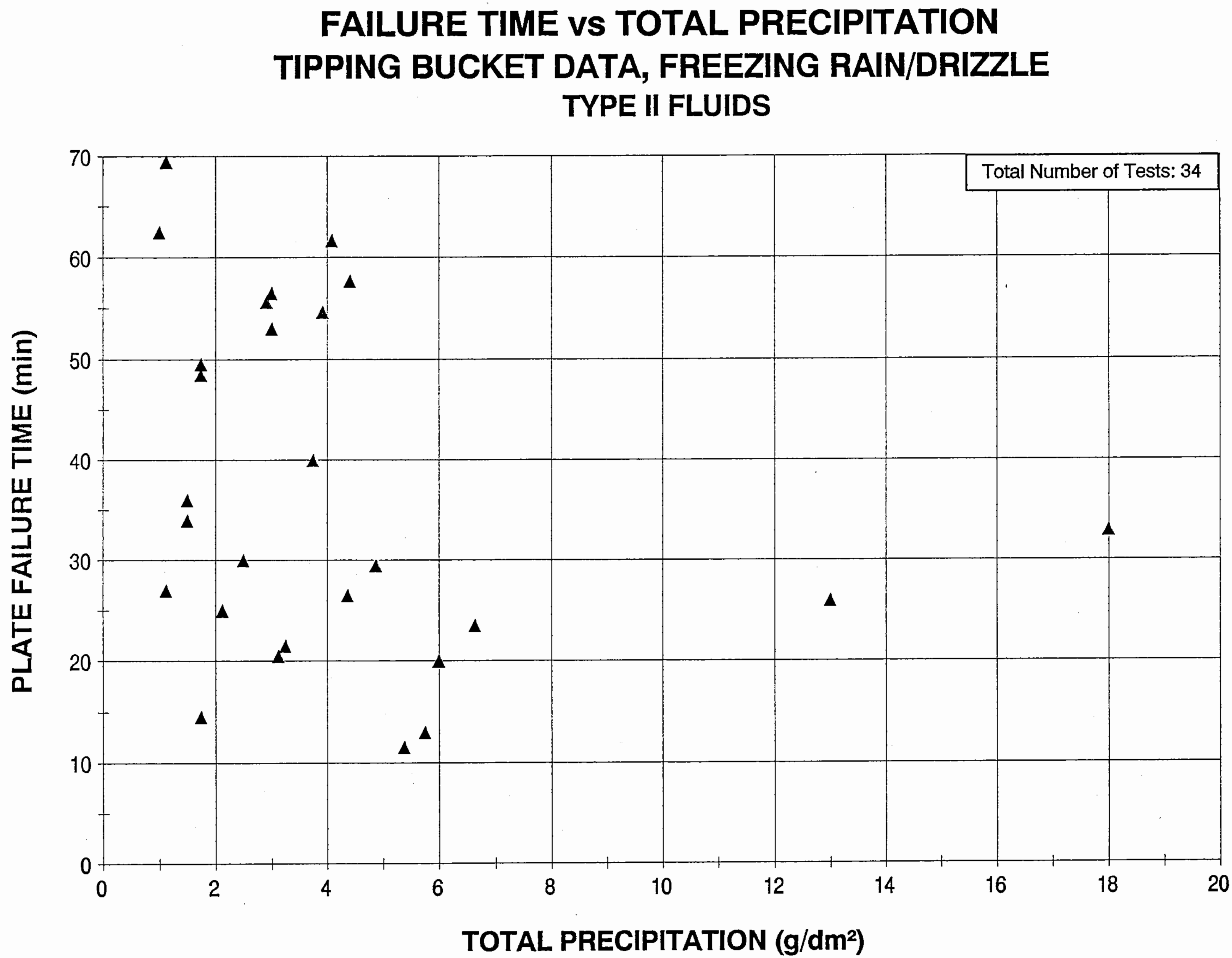

FAILURE TIME vs TOTAL PRECIPITATION
TIPPING BUCKET DATA, SNOW CONDITIONS
FLUID A-201
Total Number of Tests: 26
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20

FAILURE TIME vs TOTAL PRECIPITATION
TIPPING BUCKET DATA, SNOW CONDITIONS
FLUID A-202

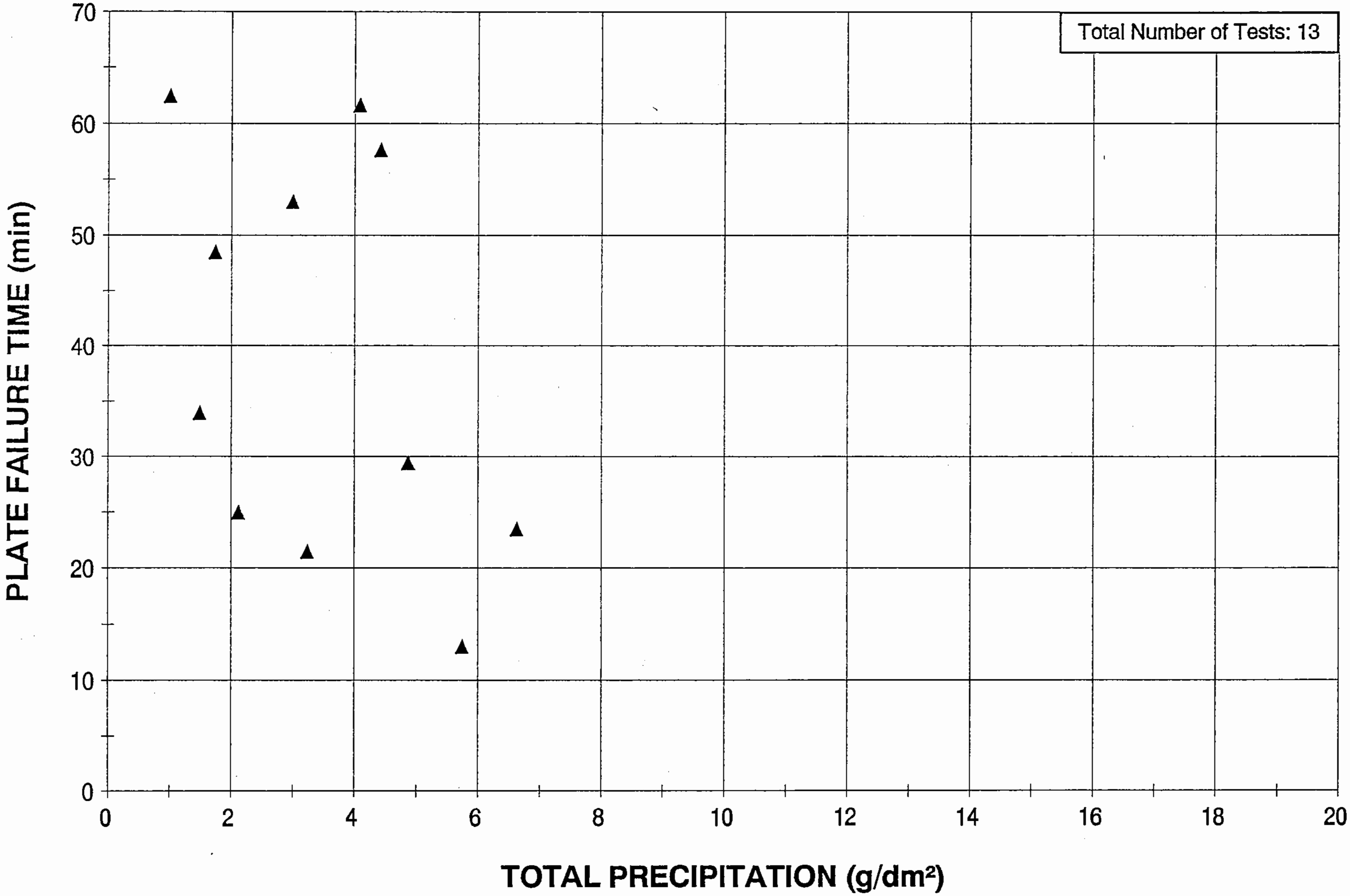


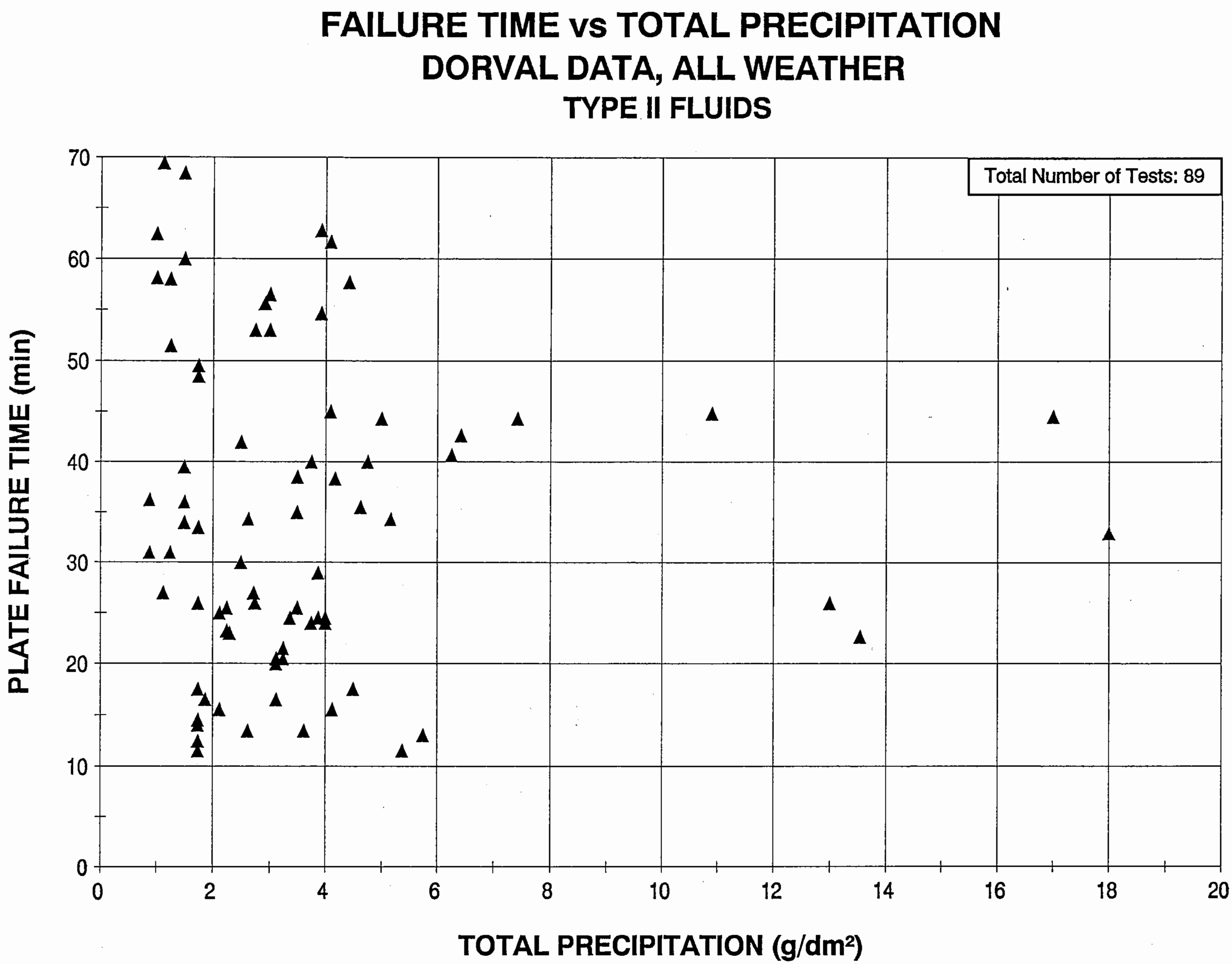
FAILURE TIME vs TOTAL PRECIPITATION
TIPPING BUCKET DATA, SNOW CONDITIONS
FLUID A-203



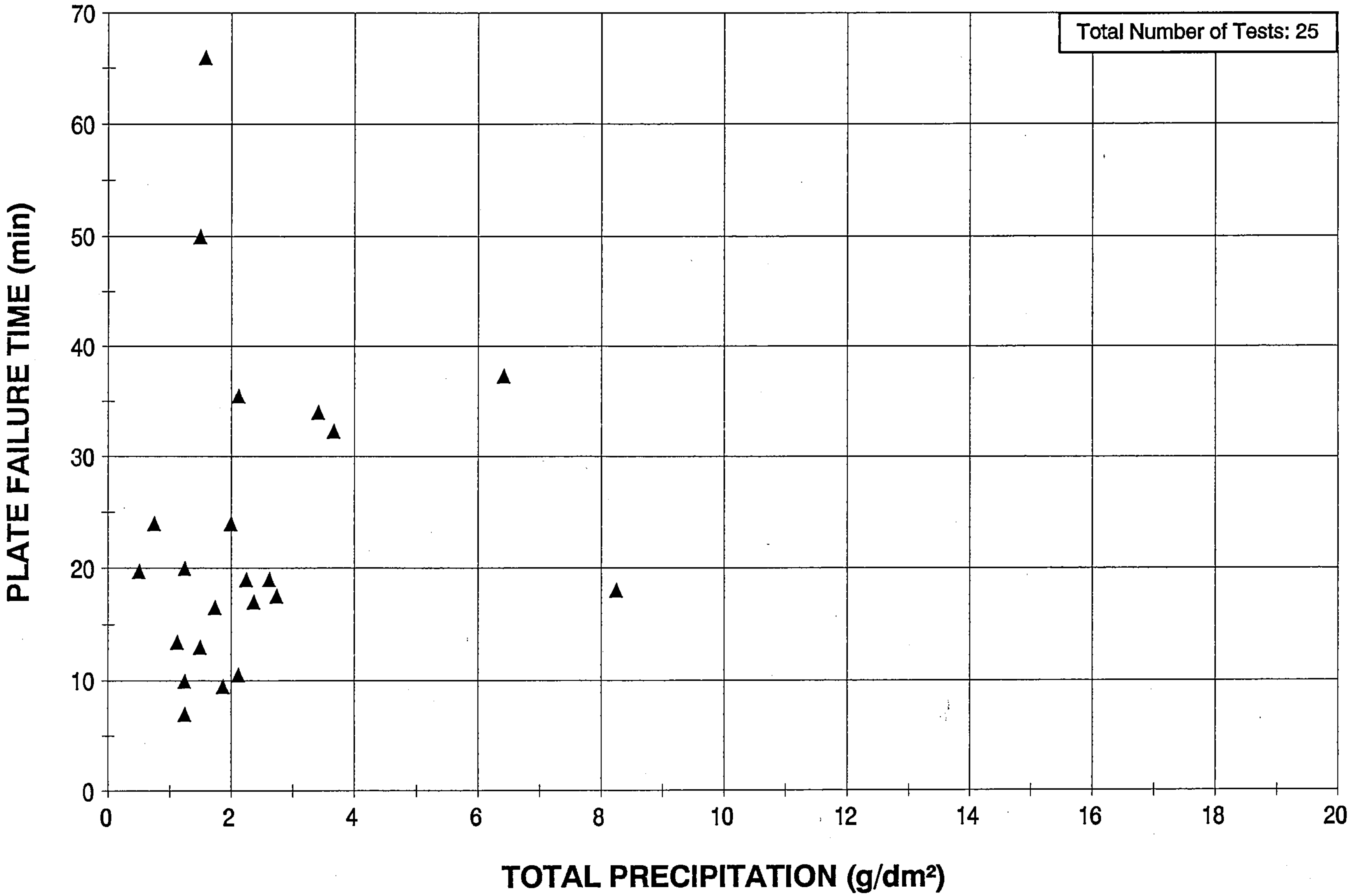

FAILURE TIME vs TOTAL PRECIPITATION
TIPPING BUCKET DATA, FREEZING RAIN/DRIZZLE
TYPE II FLUIDS
Total Number of Tests: 34
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20

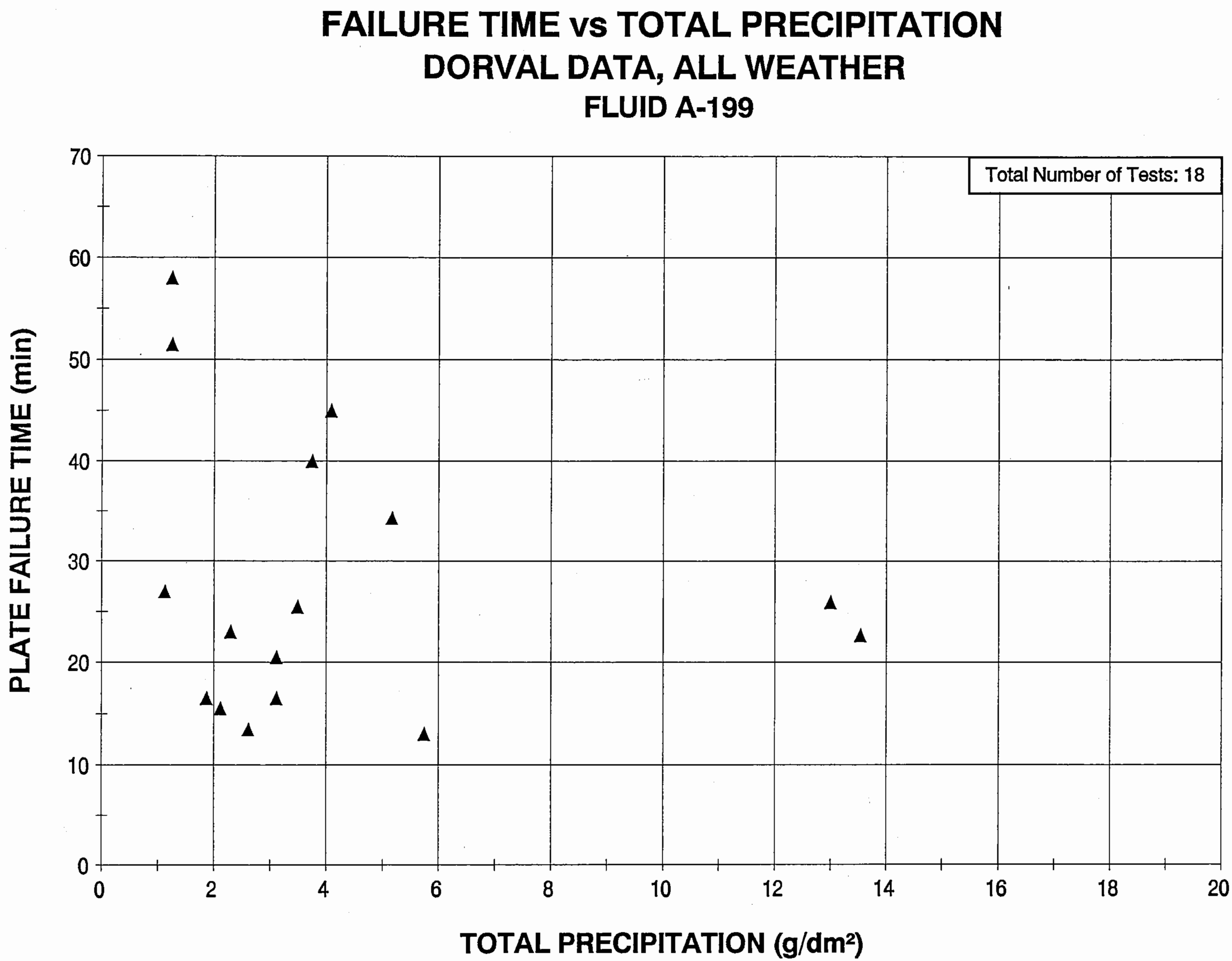
FAILURE TIME vs TOTAL PRECIPITATION
TIPPING BUCKET DATA, FREEZING RAIN/DRIZZLE
FLUID A-201

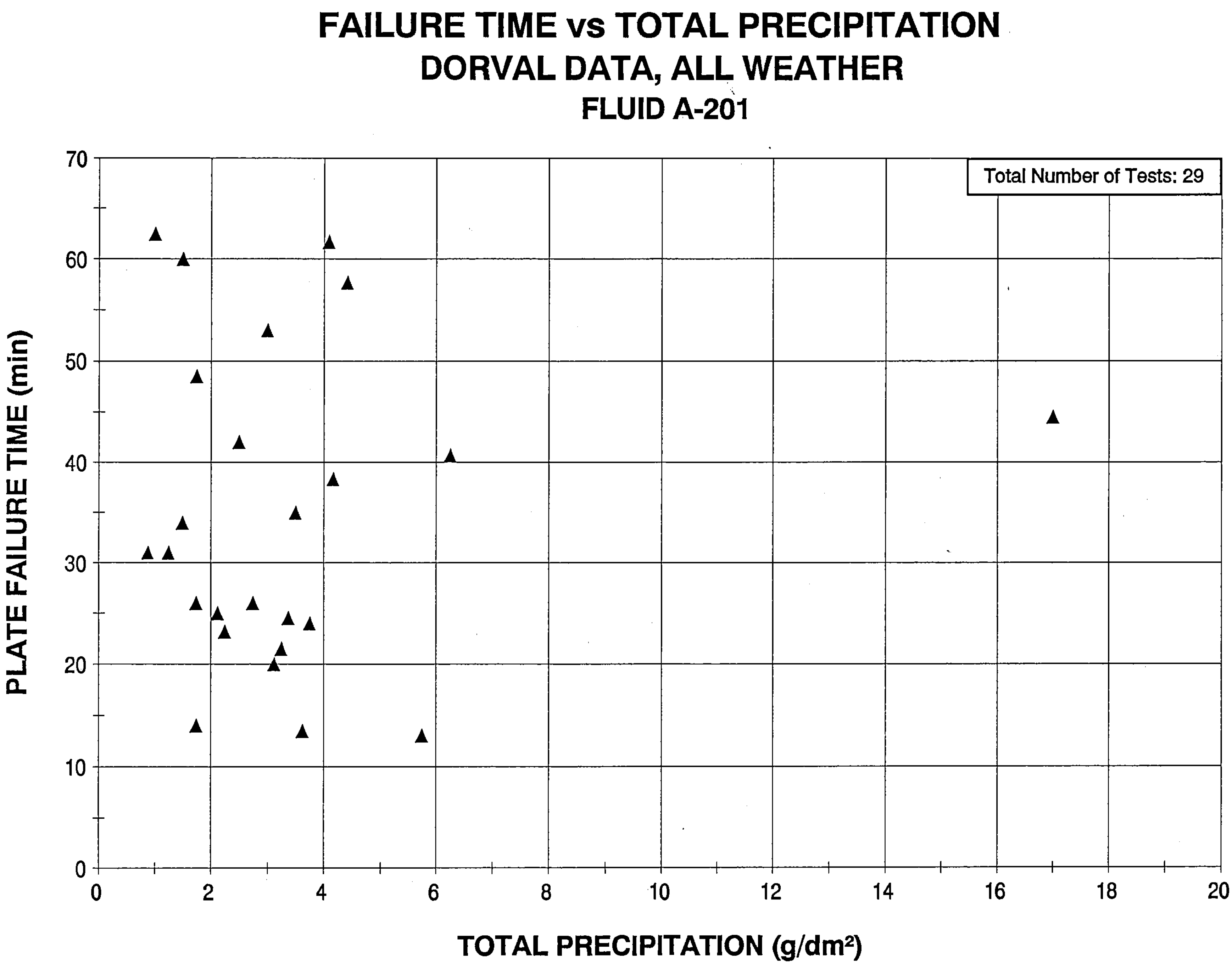



FAILURE TIME vs TOTAL PRECIPITATION
DORVAL DATA, ALL WEATHER
TYPE II FLUIDS
Total Number of Tests: 89
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20

FAILURE TIME vs TOTAL PRECIPITATION
DORVAL DATA, ALL WEATHER
TYPE 1.5 FLUIDS

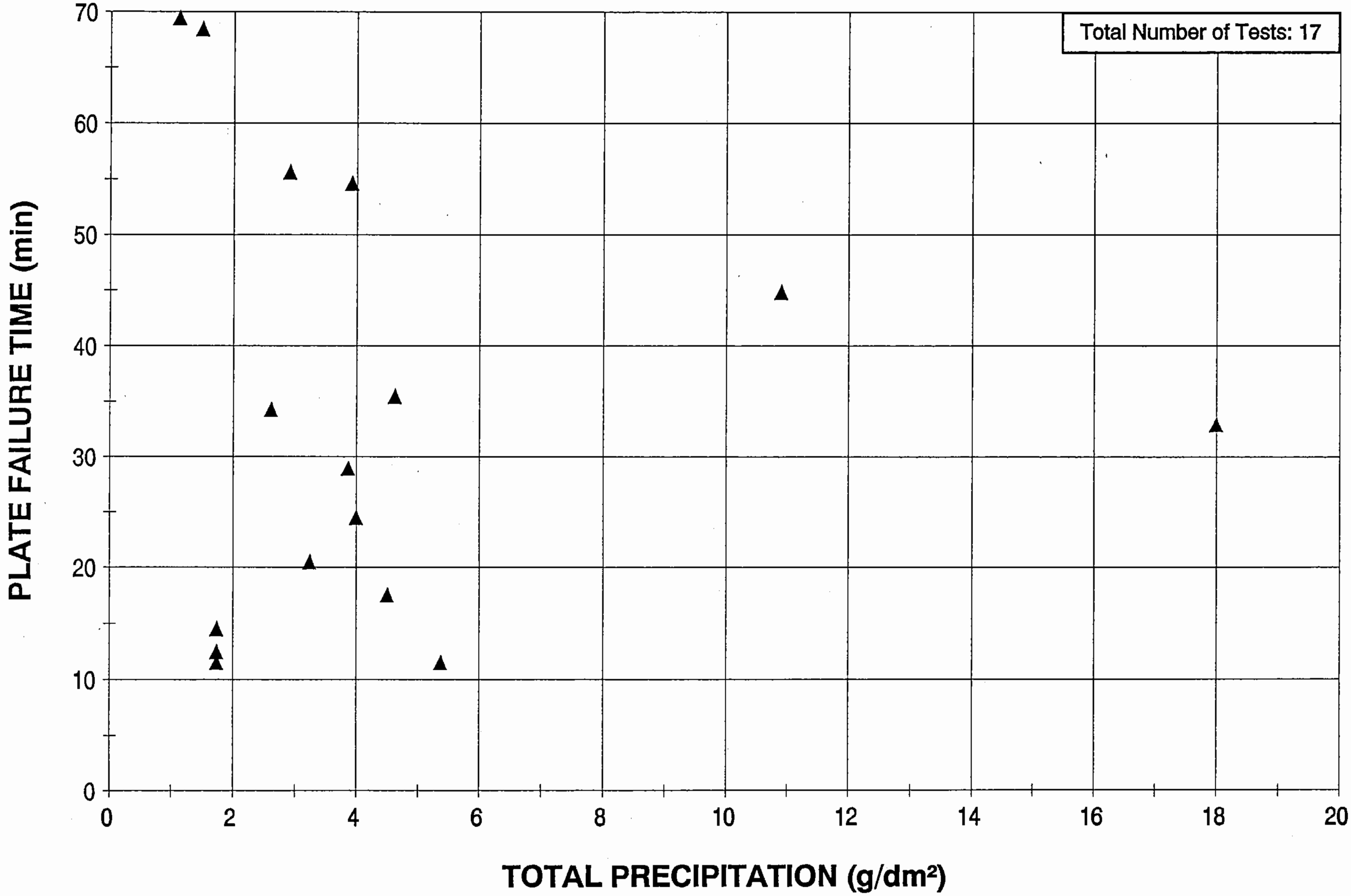


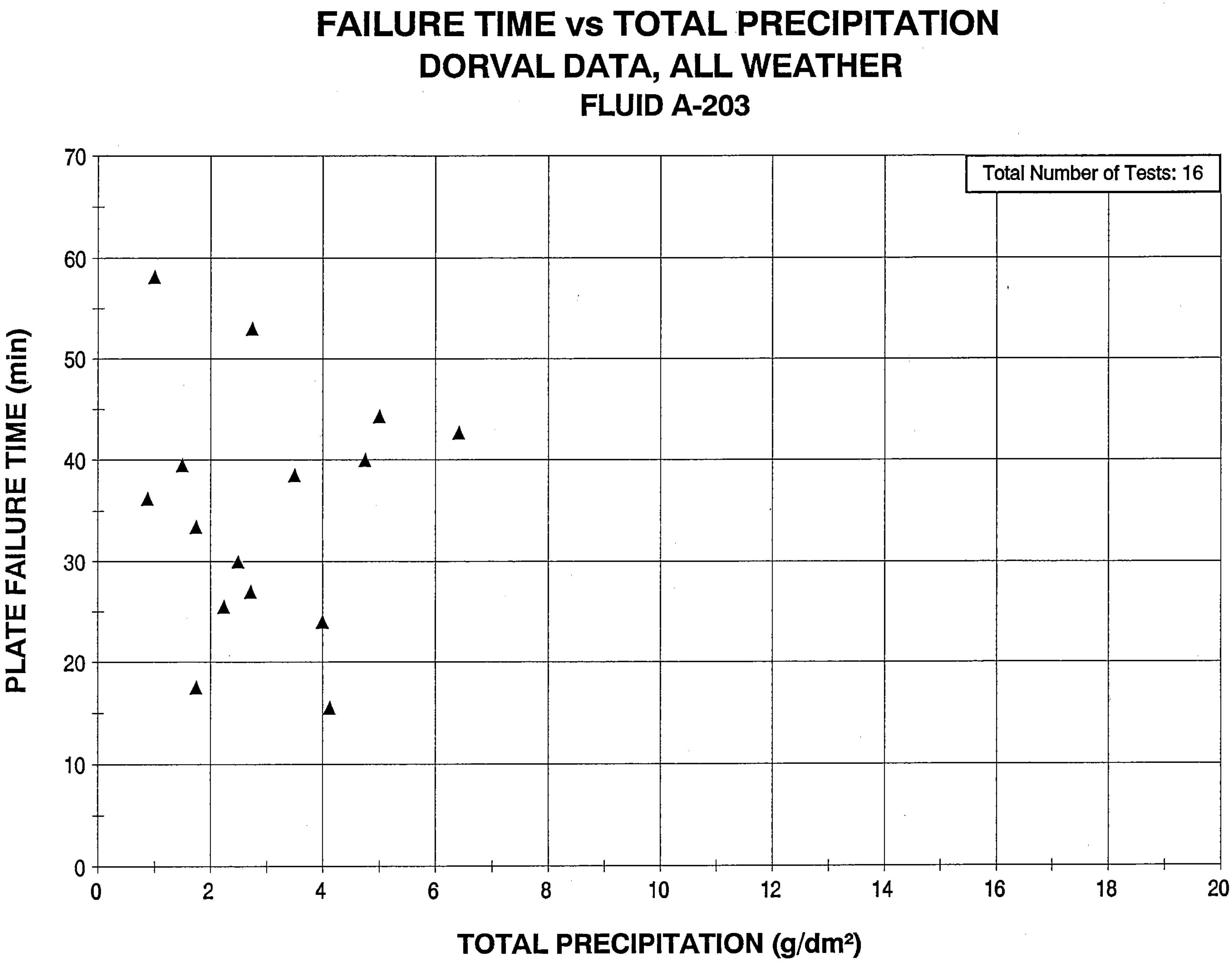

FAILURE TIME vs TOTAL PRECIPITATION
DORVAL DATA, ALL WEATHER
FLUID A-199
Total Number of Tests: 18
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20



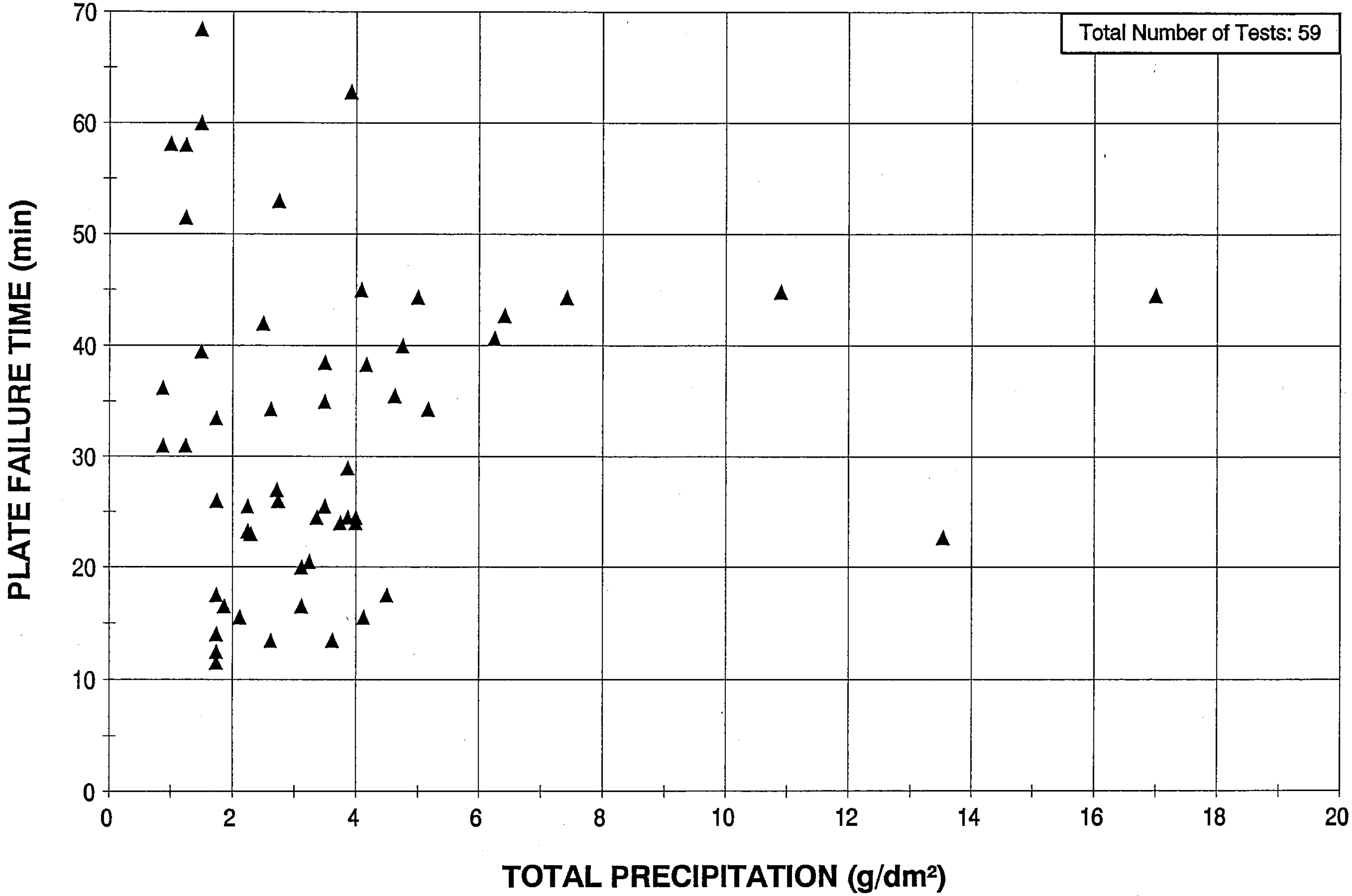
FAILURE TIME vs TOTAL PRECIPITATION
DORVAL DATA, ALL WEATHER
FLUID A-201
Total Number of Tests: 29
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
2
4
6
8
10
12
14
16
18
20

FAILURE TIME vs TOTAL PRECIPITATION
DORVAL DATA, ALL WEATHER
FLUID A-202

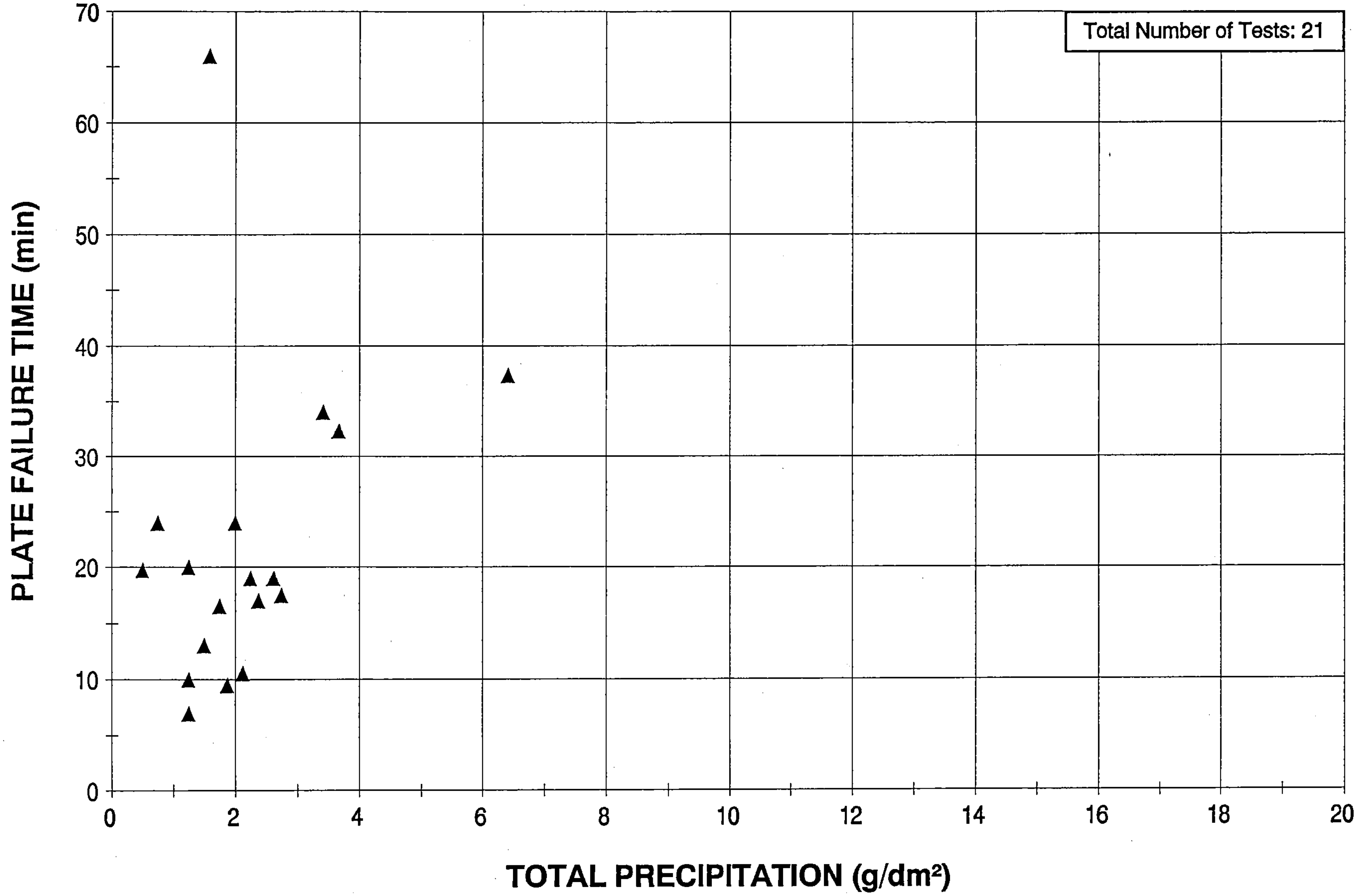



FAILURE TIME vs TOTAL PRECIPITATION
DORVAL DATA, ALL WEATHER
FLUID A-203
Total Number of Tests: 16
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20

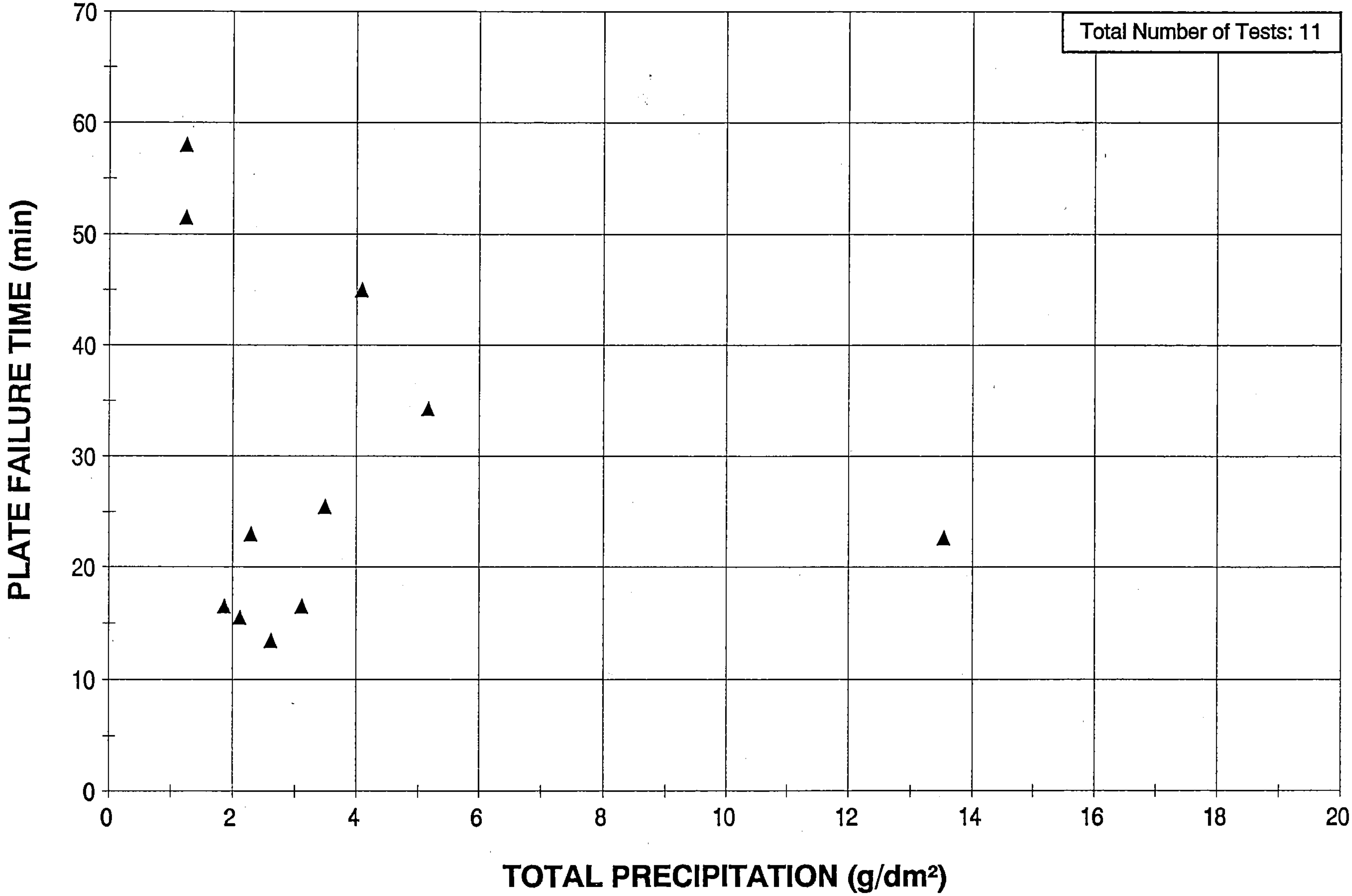
FAILURE TIME vs TOTAL PRECIPITATION
DORVAL DATA, SNOW CONDITIONS
TYPE II FLUIDS

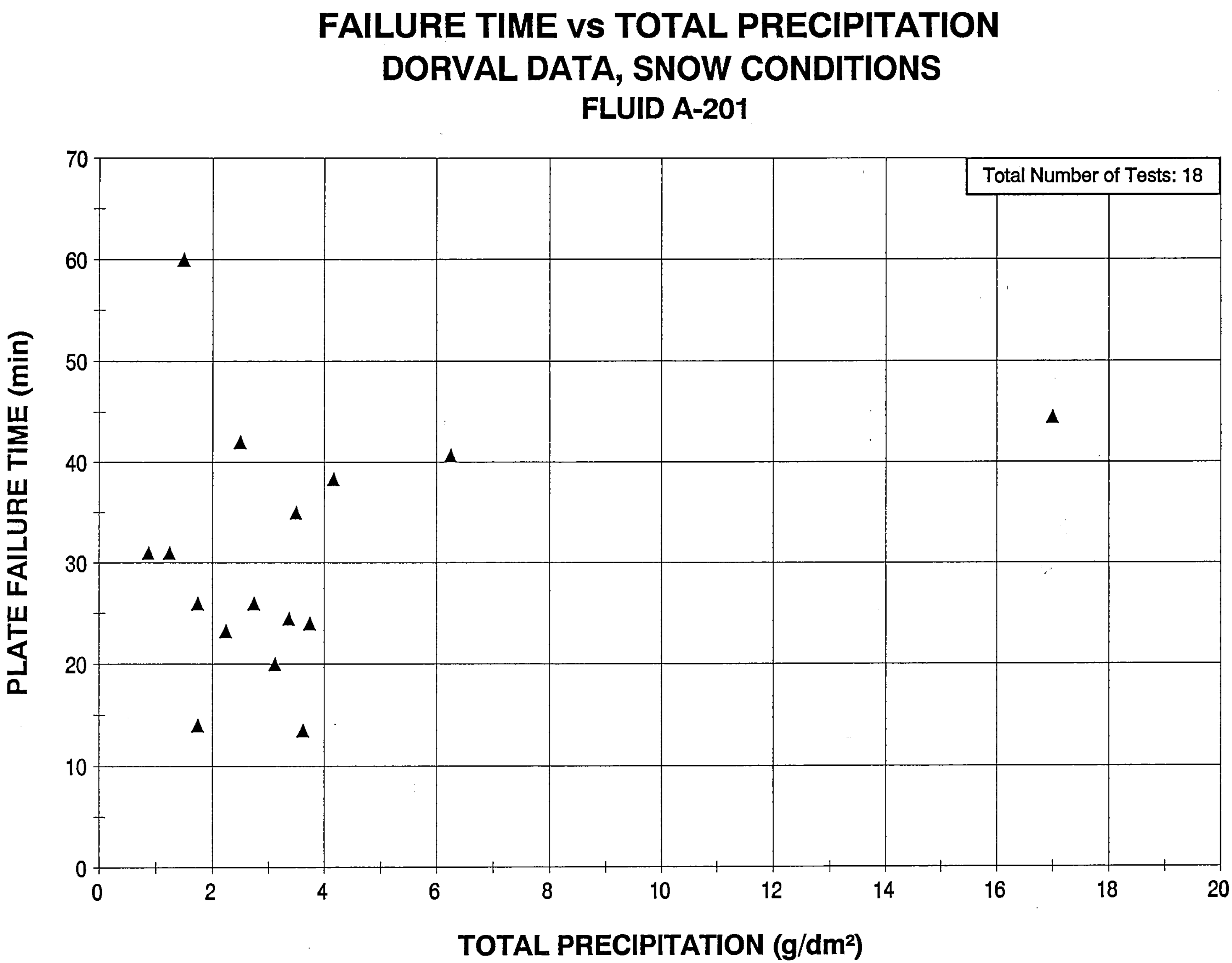


FAILURE TIME vs TOTAL PRECIPITATION
DORVAL DATA, SNOW CONDITIONS
TYPE 1.5 FLUIDS

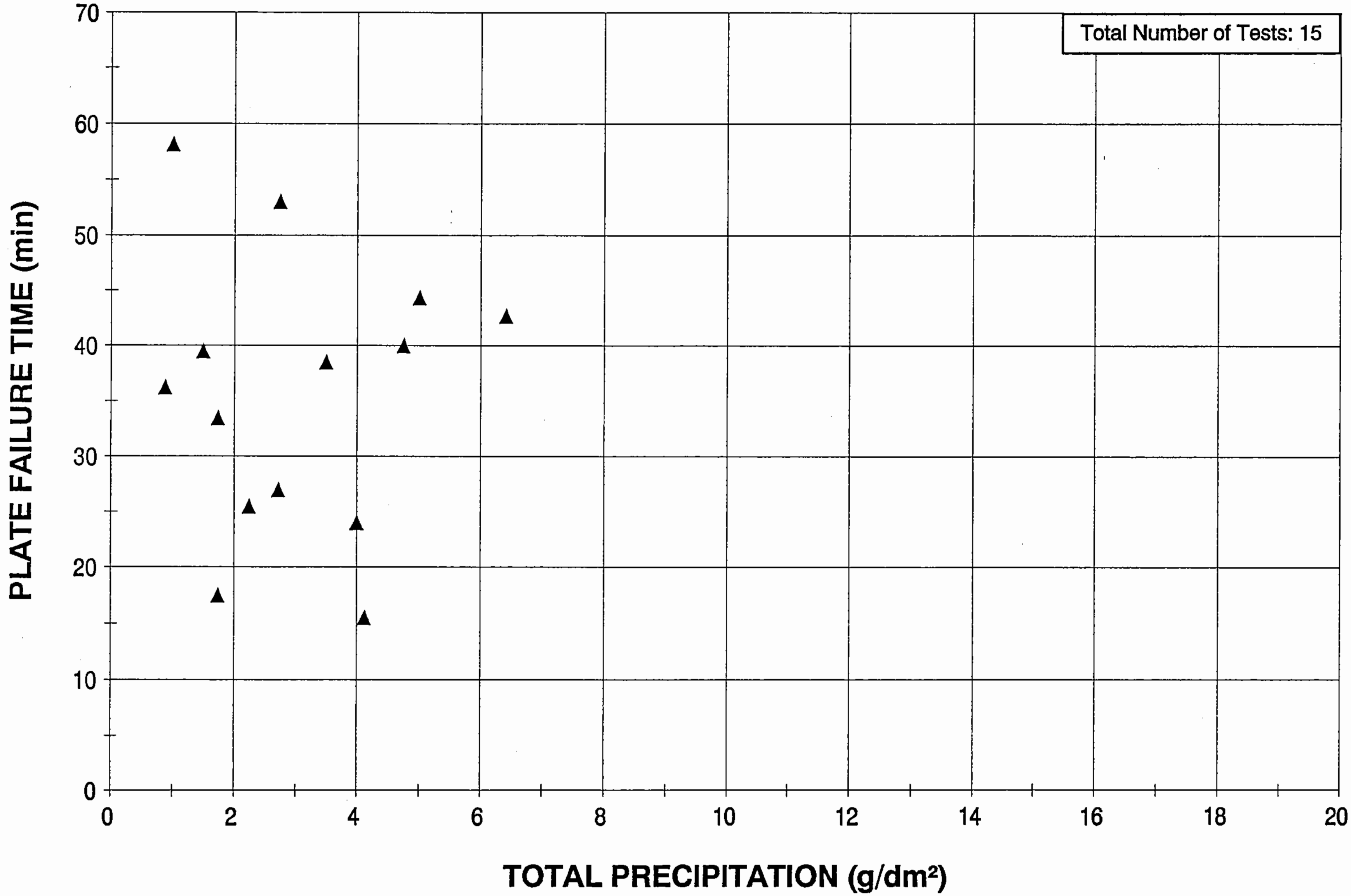


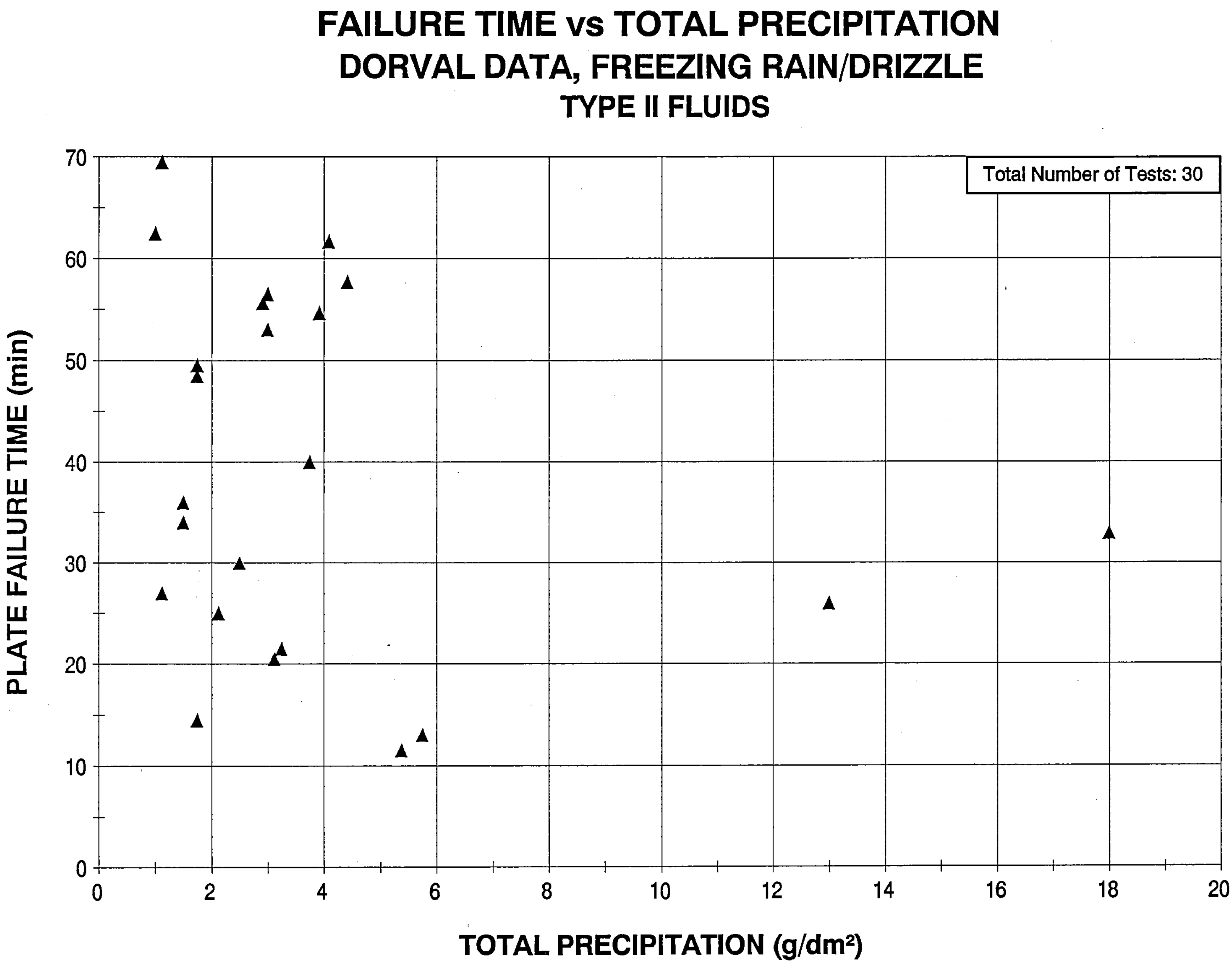
FAILURE TIME vs TOTAL PRECIPITATION
DORVAL DATA, SNOW CONDITIONS
FLUID A-199



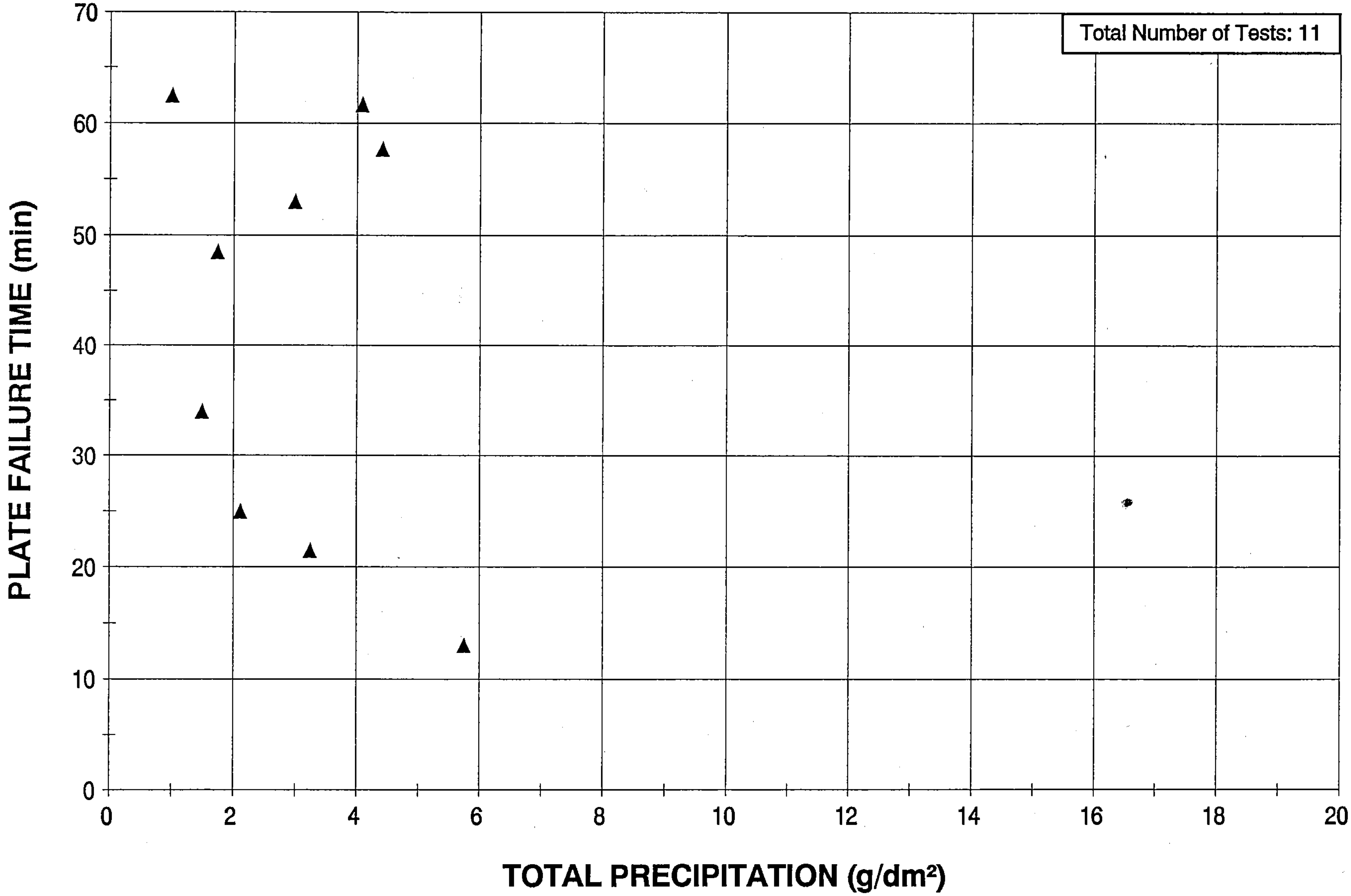

FAILURE TIME vs TOTAL PRECIPITATION
DORVAL DATA, SNOW CONDITIONS
FLUID A-201
Total Number of Tests: 18
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20

FAILURE TIME vs TOTAL PRECIPITATION
DORVAL DATA, SNOW CONDITIONS
FLUID A-203




FAILURE TIME vs TOTAL PRECIPITATION
DORVAL DATA, FREEZING RAIN/DRIZZLE
TYPE II FLUIDS
Total Number of Tests: 30
PLATE FAILURE TIME (min)
TOTAL PRECIPITATION (g/dm²)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20

FAILURE TIME vs TOTAL PRECIPITATION
DORVAL DATA, FREEZING RAIN/DRIZZLE
FLUID A-201



APPENDIX C

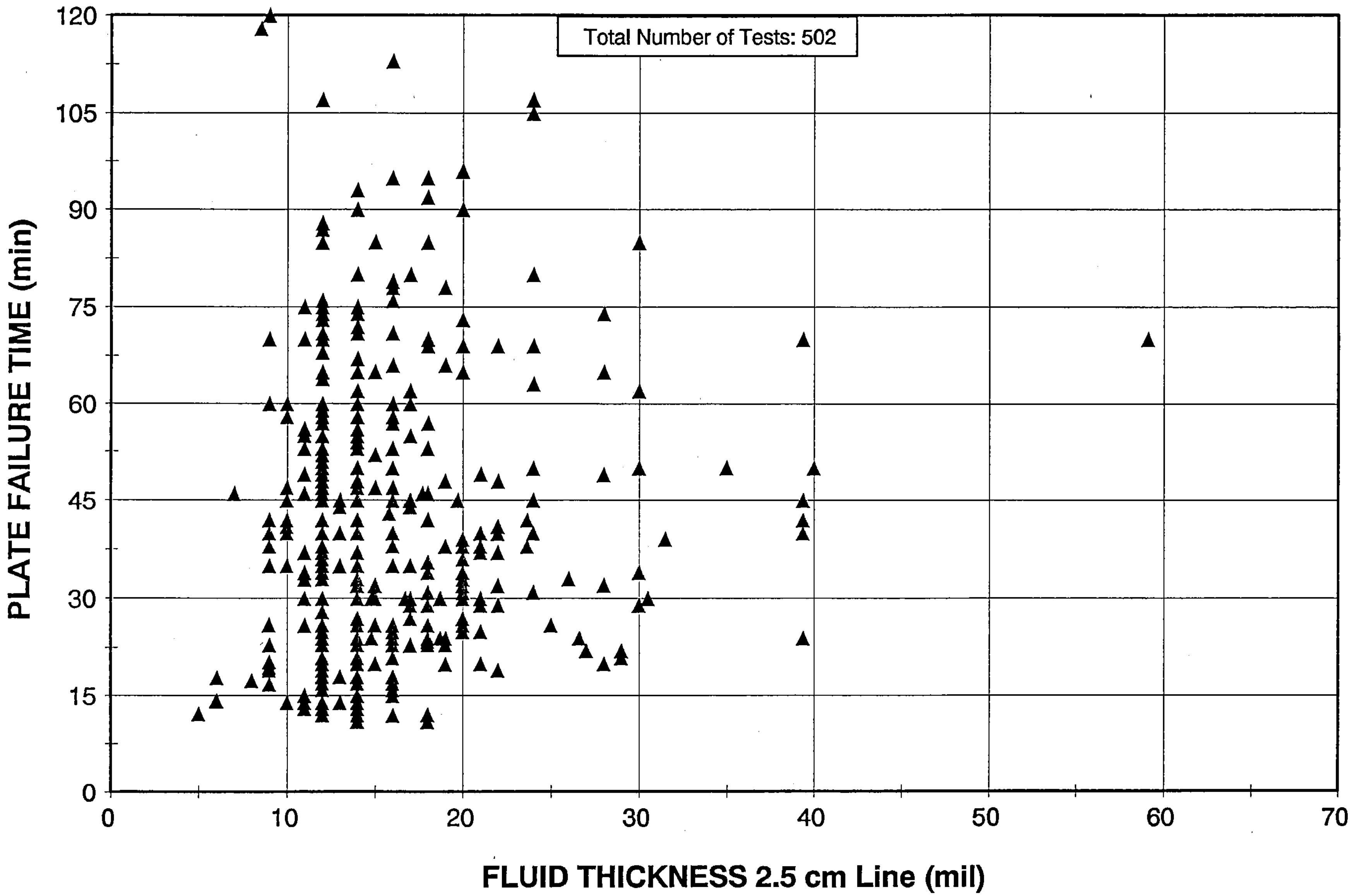
FLUID THICKNESS, TEMPERATURE, HUMIDITY, WIND AND OTHER MISCELLANEOUS CHARTS

APPENDIX C

LIST OF FIGURES

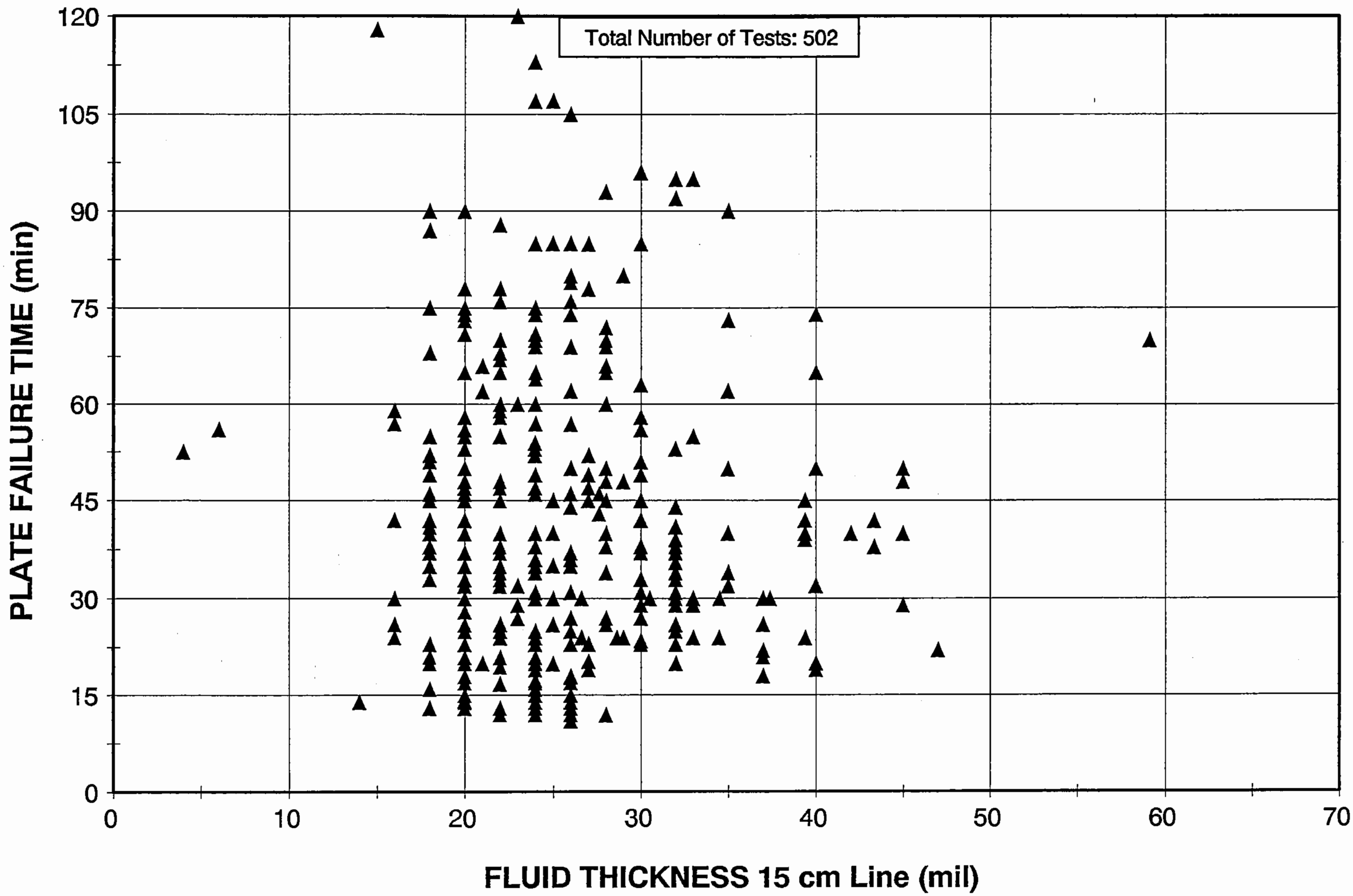
SCATTER OF FAILURE TIME vs FLUID THICHNESS AT 2.5 cm LINE

TYPE II FLUIDS



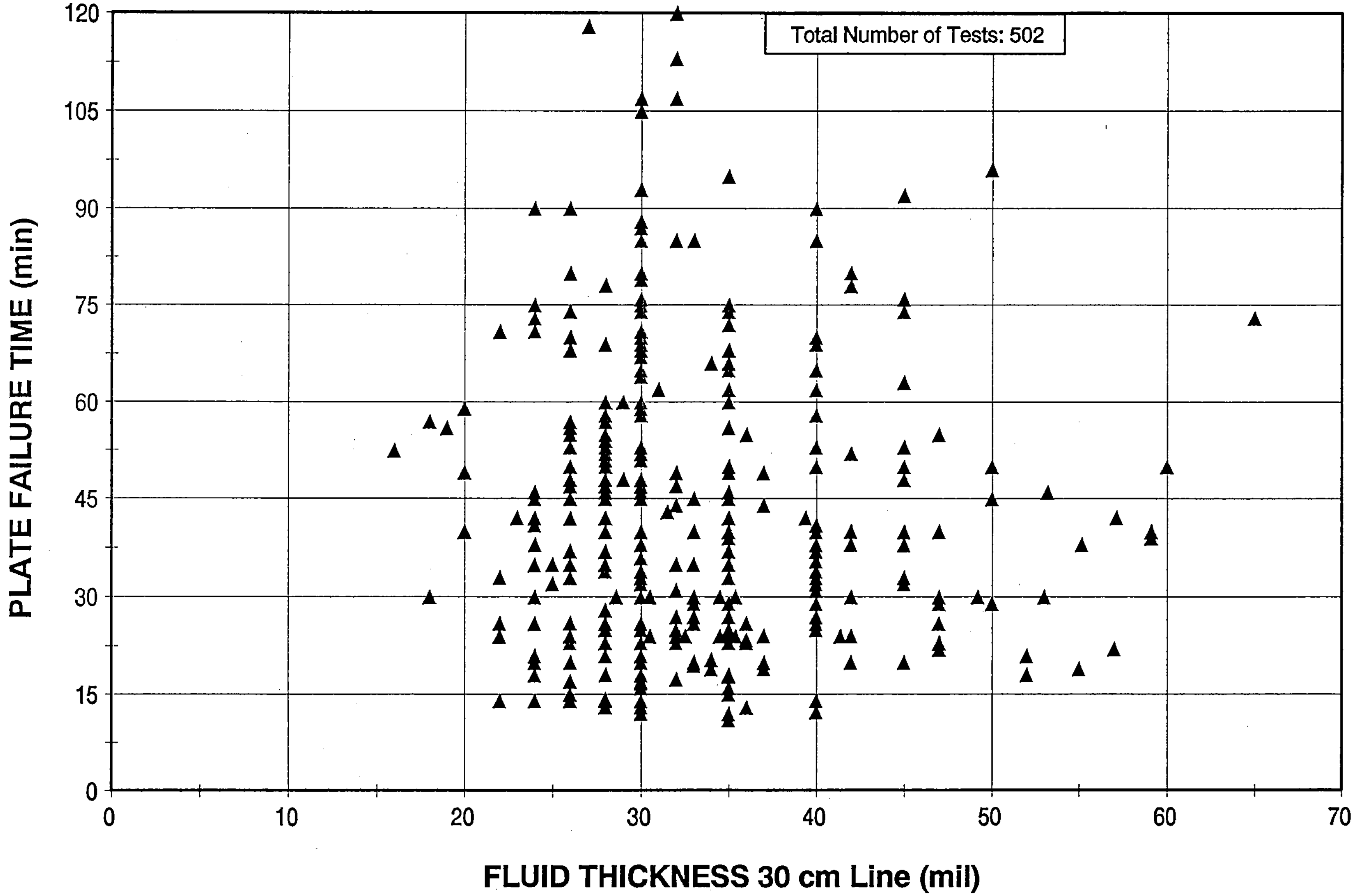
SCATTER OF FAILURE TIME vs FLUID THICHNESS AT 15 cm LINE

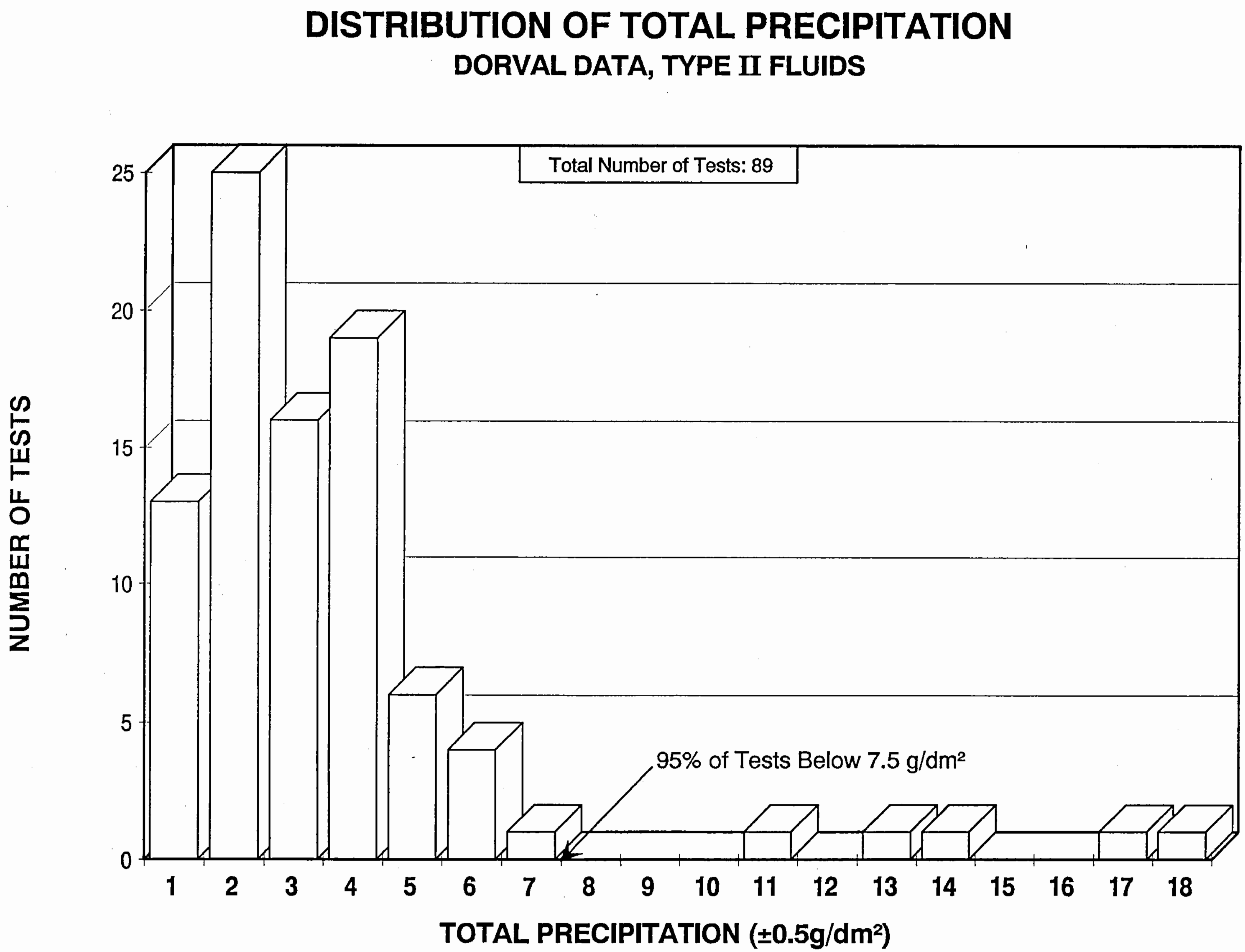
TYPE II FLUIDS



SCATTER OF FAILURE TIME vs FLUID THICKNESS AT 30 cm LINE

TYPE II FLUIDS

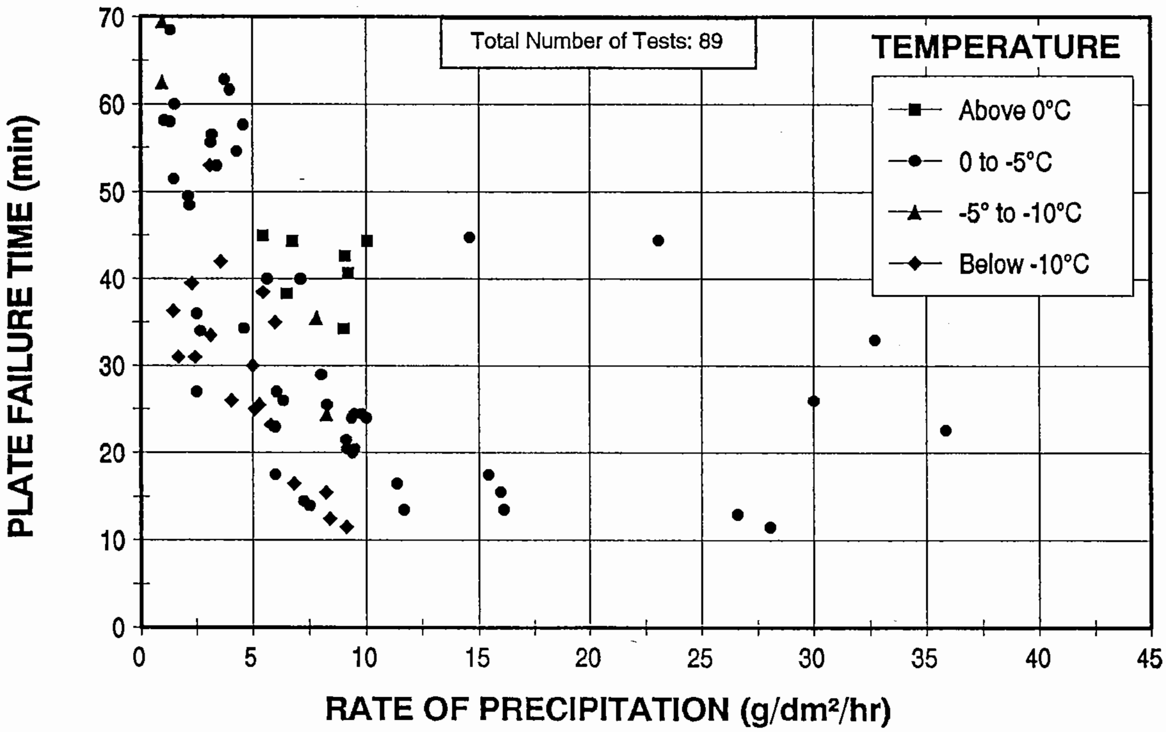




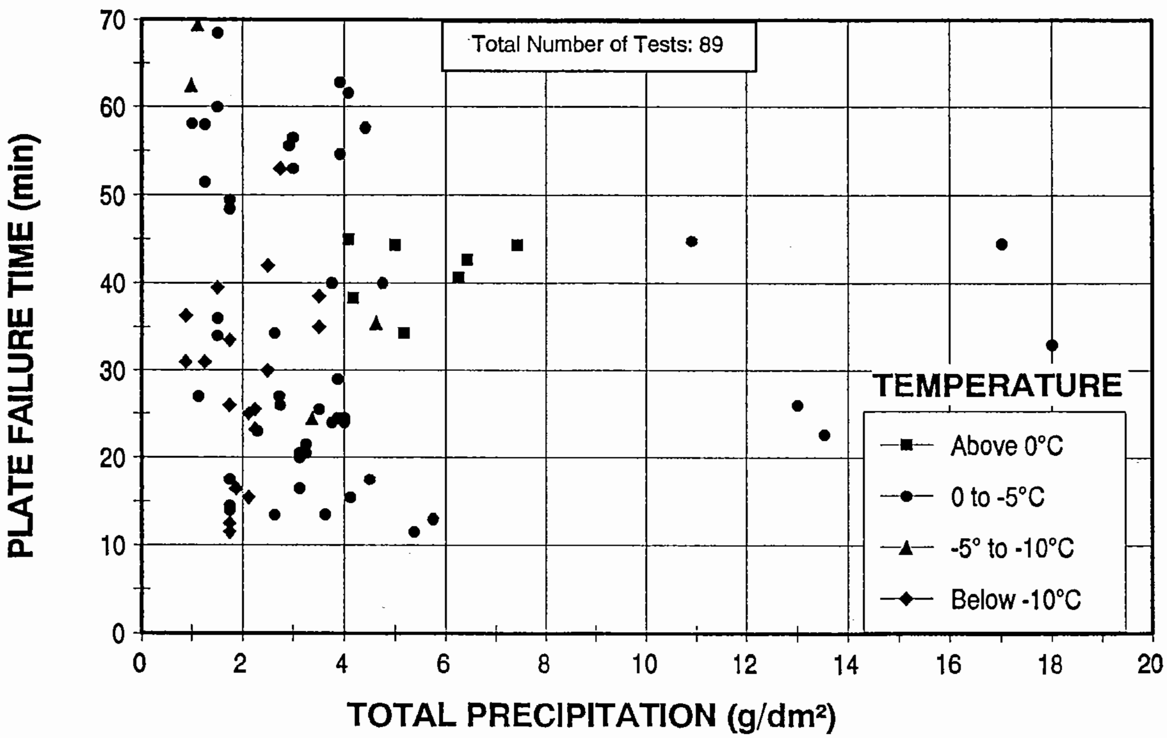
DISTRIBUTION OF TOTAL PRECIPITATION
DORVAL DATA, TYPE II FLUIDS
Total Number of Tests: 89
95% of Tests Below 7.5 g/dm²
NUMBER OF TESTS
0
5
10
15
20
25
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
TOTAL PRECIPITATION (±0.5g/dm²)

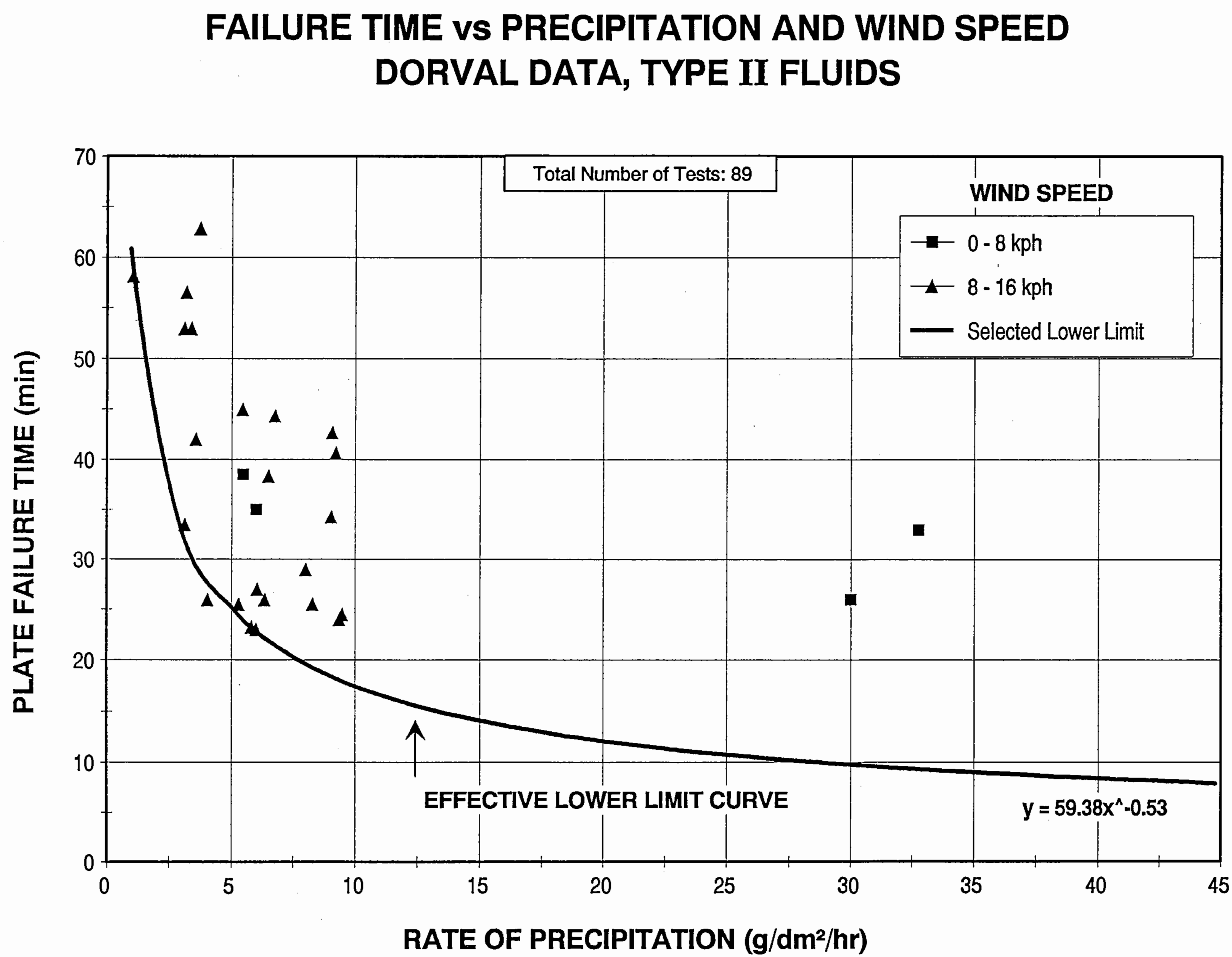
DORVAL DATA, TYPE II FLUIDS

FAILURE TIME vs RATE OF PRECIPITATION AND TEMPERATURE



FAILURE TIME vs TOTAL PRECIPITATION AND TEMPERATURE

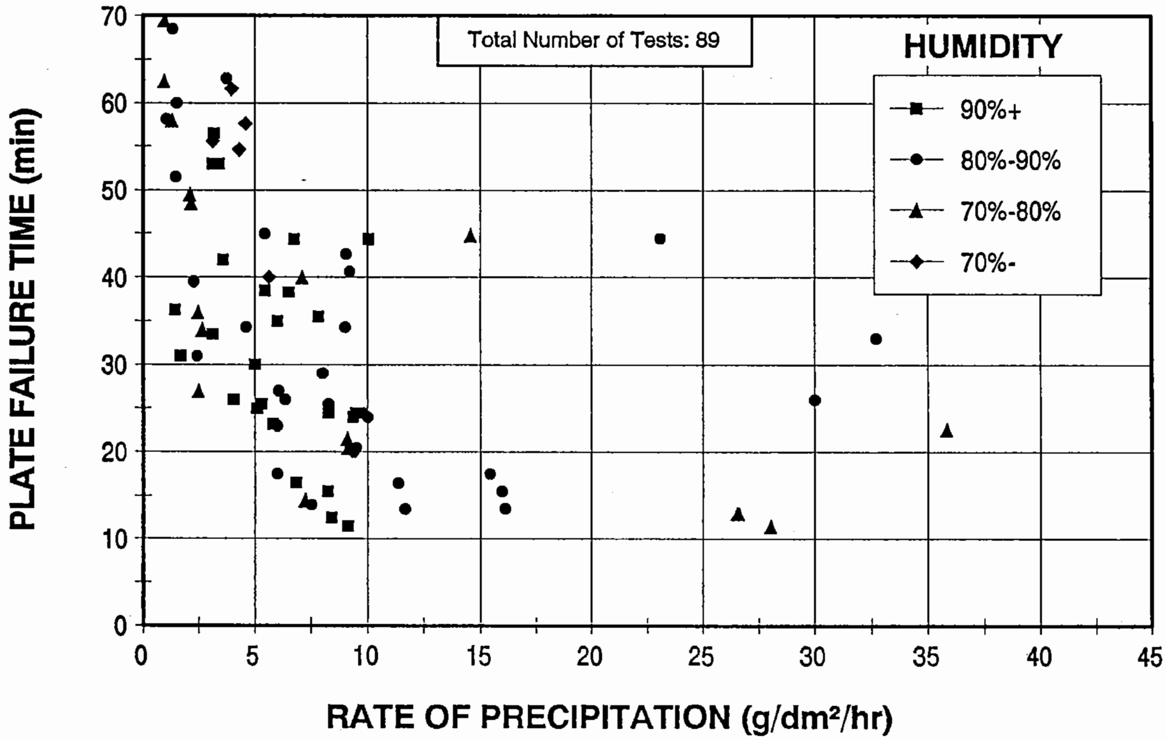




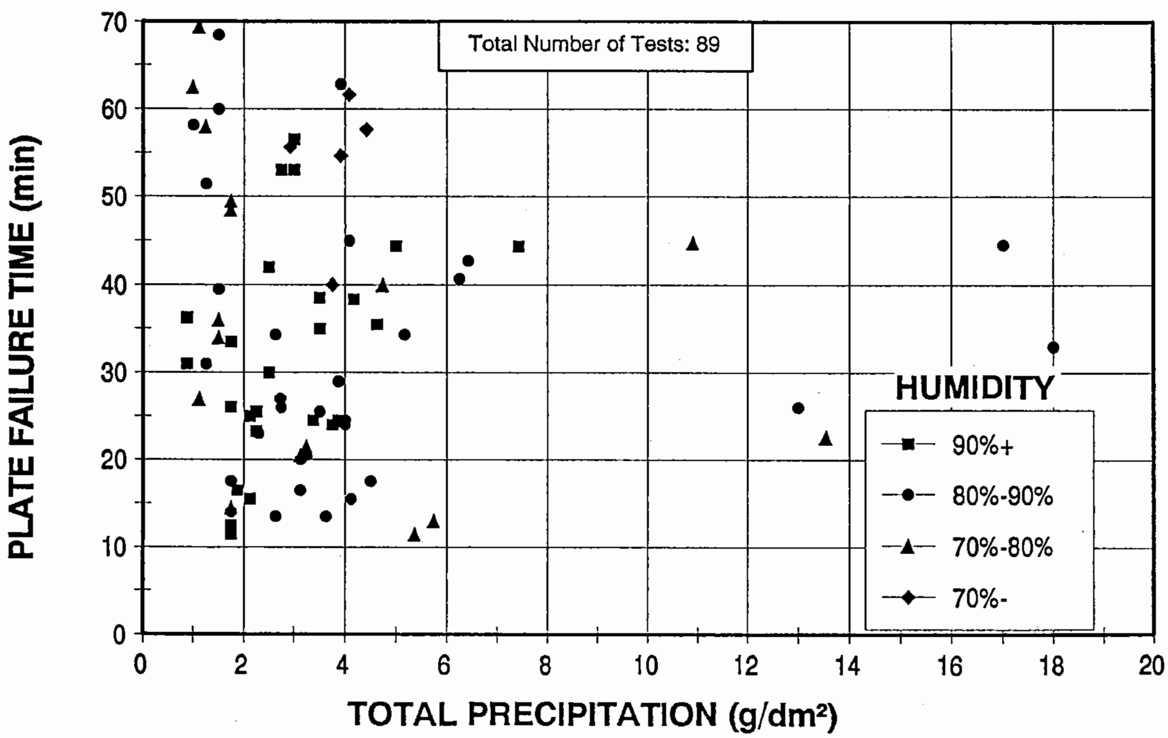
FAILURE TIME vs PRECIPITATION AND WIND SPEED
DORVAL DATA, TYPE II FLUIDS
Total Number of Tests: 89
WIND SPEED
0 - 8 kph
8 - 16 kph
Selected Lower Limit
EFFECTIVE LOWER LIMIT CURVE
y = 59.38x^-0.53
PLATE FAILURE TIME (min)
RATE OF PRECIPITATION (g/dm²/hr)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45

DORVAL DATA, TYPE II FLUIDS

FAILURE TIME vs RATE OF PRECIPITATION AND HUMIDITY

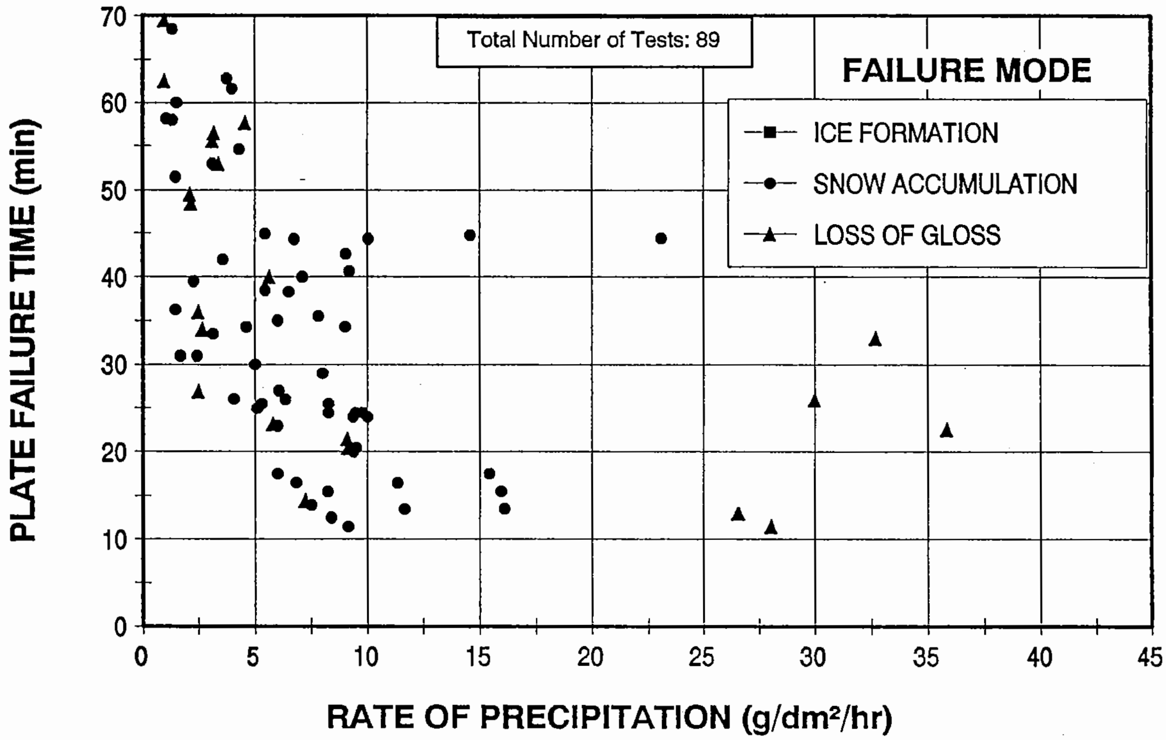


FAILURE TIME vs TOTAL PRECIPITATION AND HUMIDITY

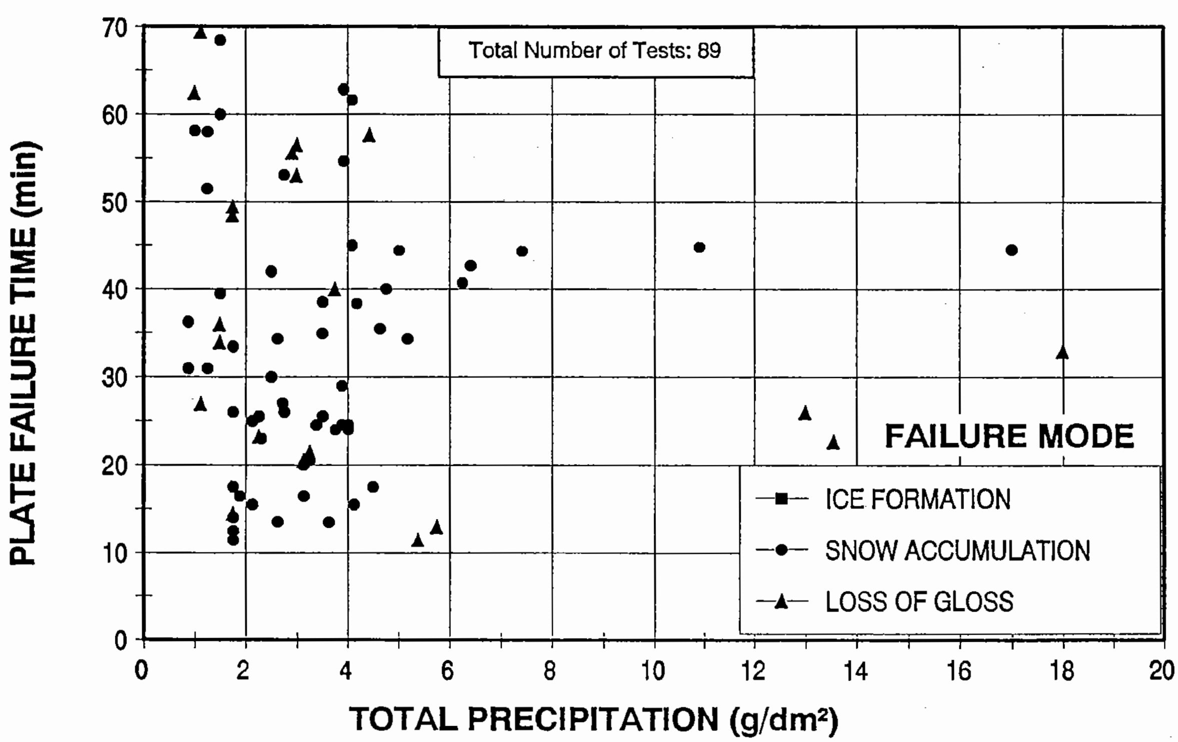


DORVAL DATA, TYPE II FLUIDS

FAILURE TIME vs RATE OF PRECIPITATION AND FAILURE MODE

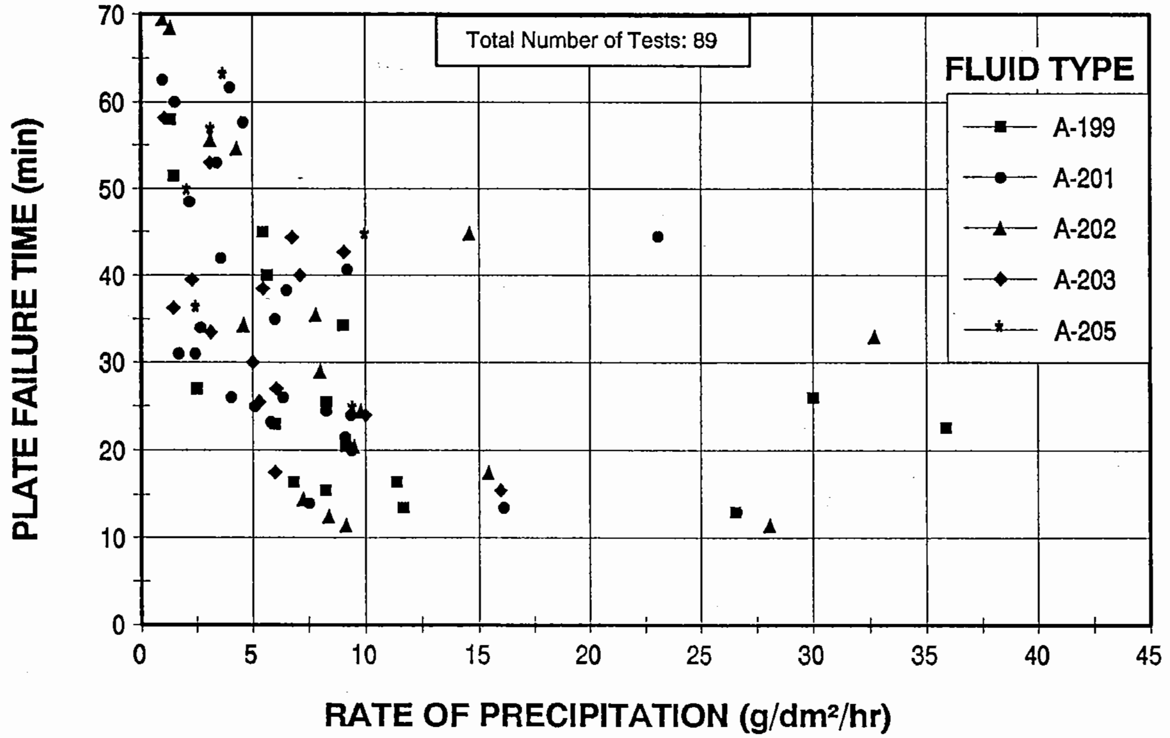


FAILURE TIME vs TOTAL PRECIPITATION AND FAILURE MODE

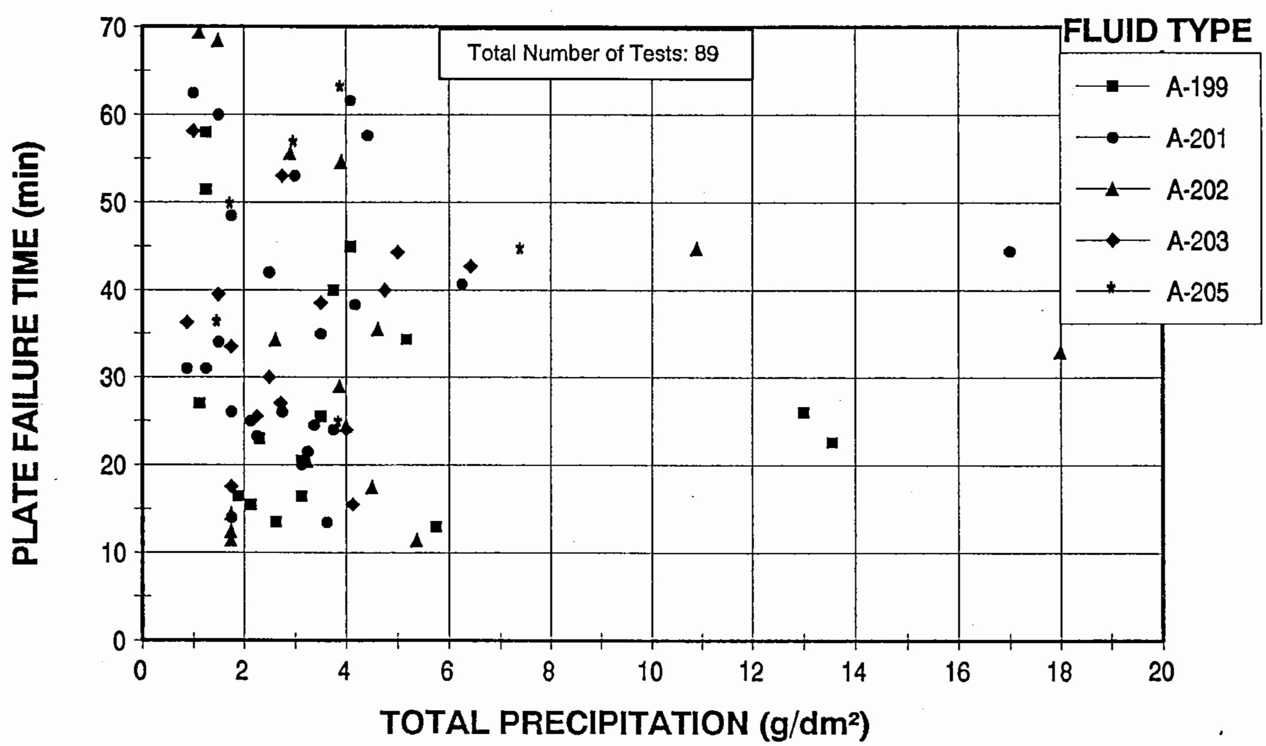


DORVAL DATA, TYPE II FLUIDS

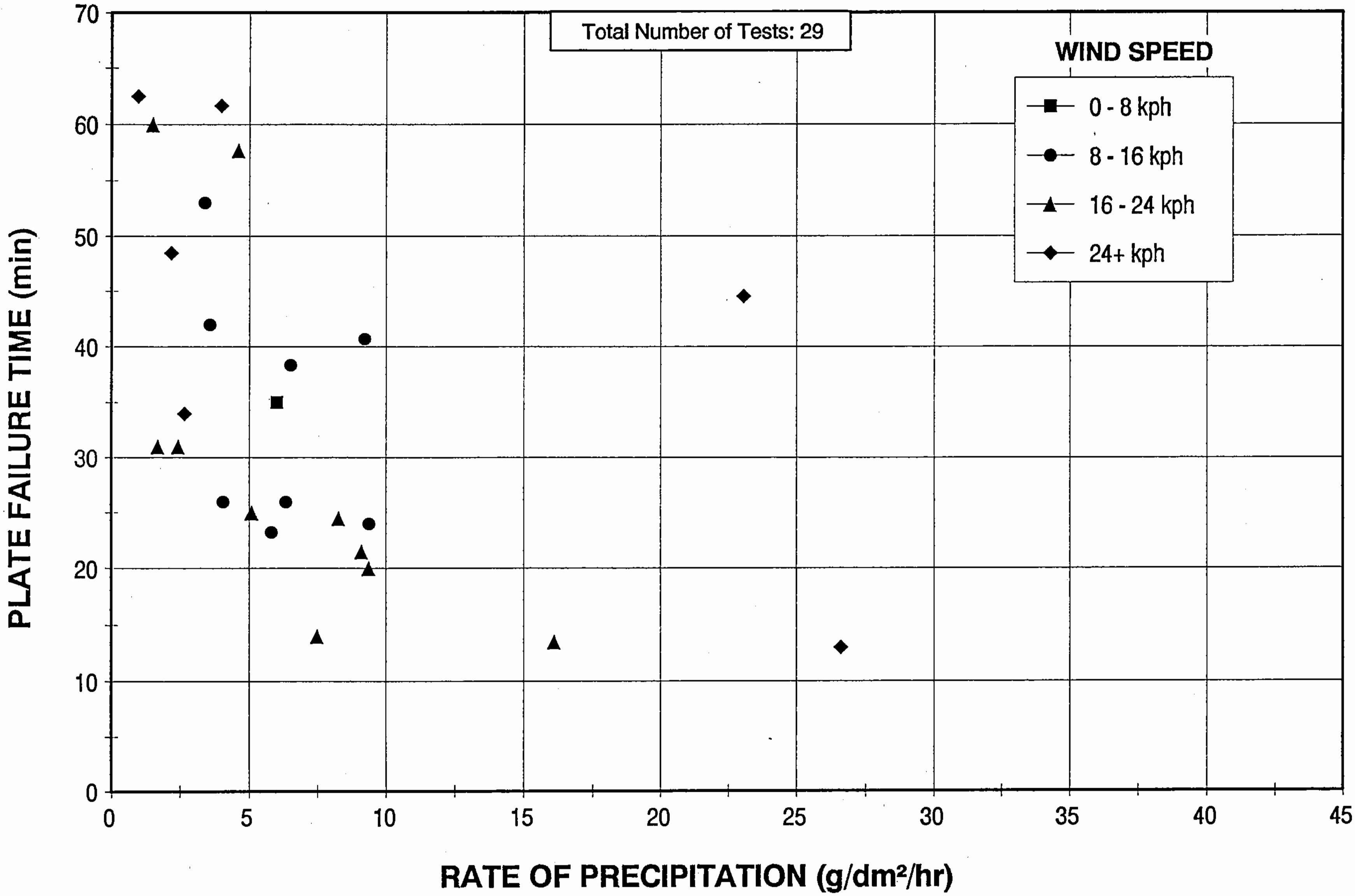
FAILURE TIME vs RATE OF PRECIPITATION AND FLUID TYPE



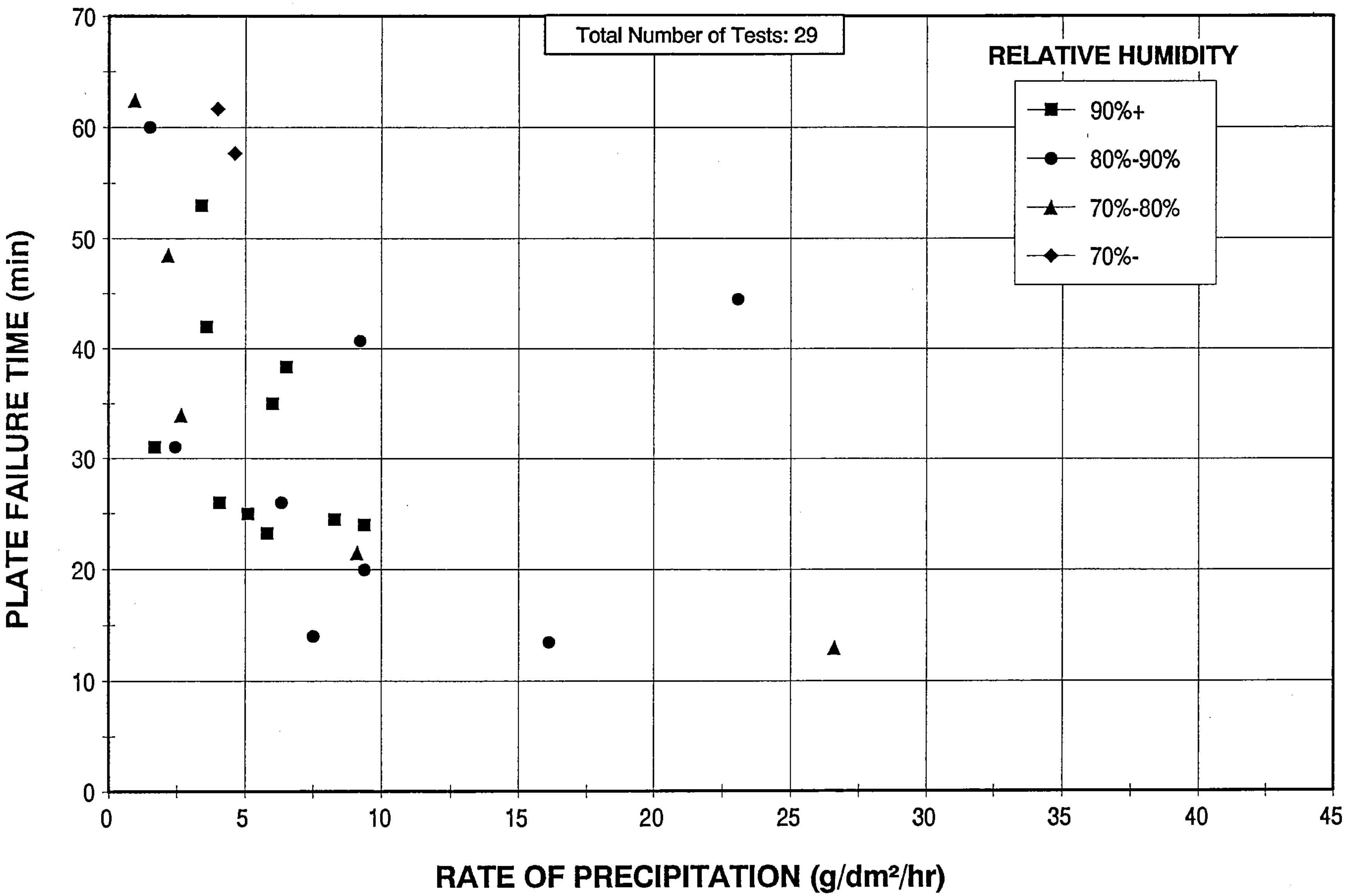
FAILURE TIME vs TOTAL PRECIPITATION AND FLUID TYPE



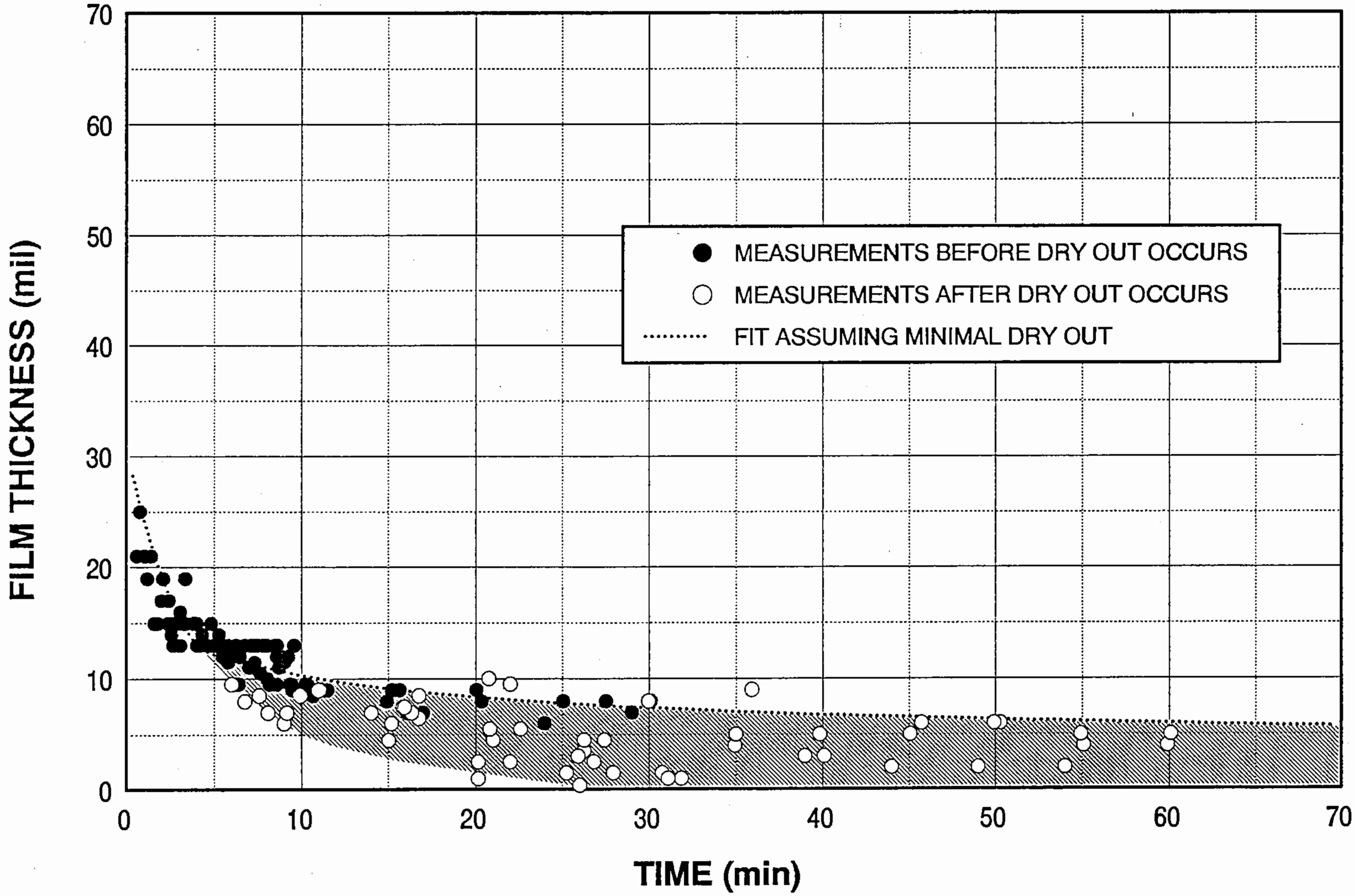
FAILURE TIME vs PRECIPITATION AND WIND SPEED
DORVAL DATA, FLUID A-201

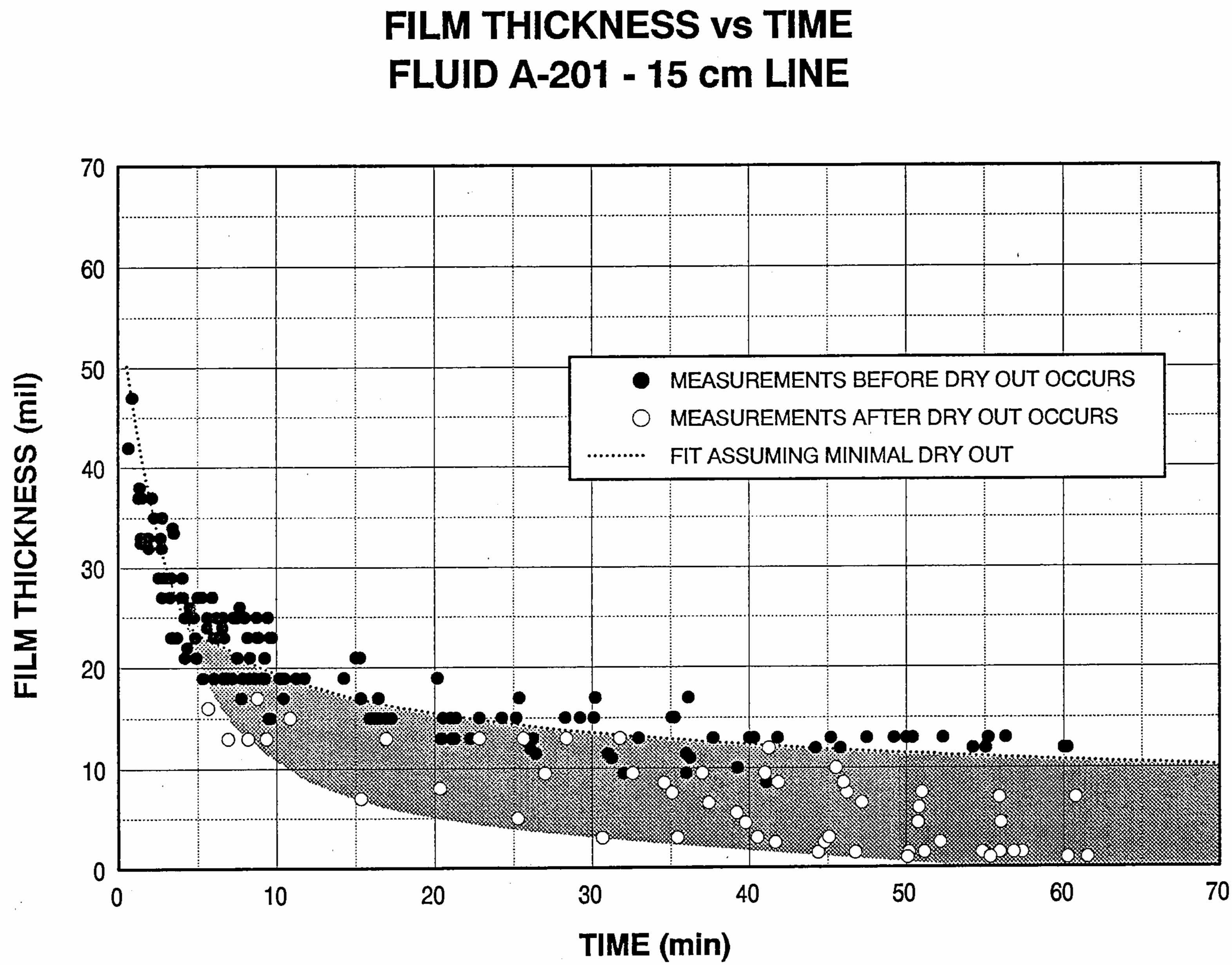


FAILURE TIME vs PRECIPITATION AND RELATIVE HUMIDITY
DORVAL DATA, FLUID A-201



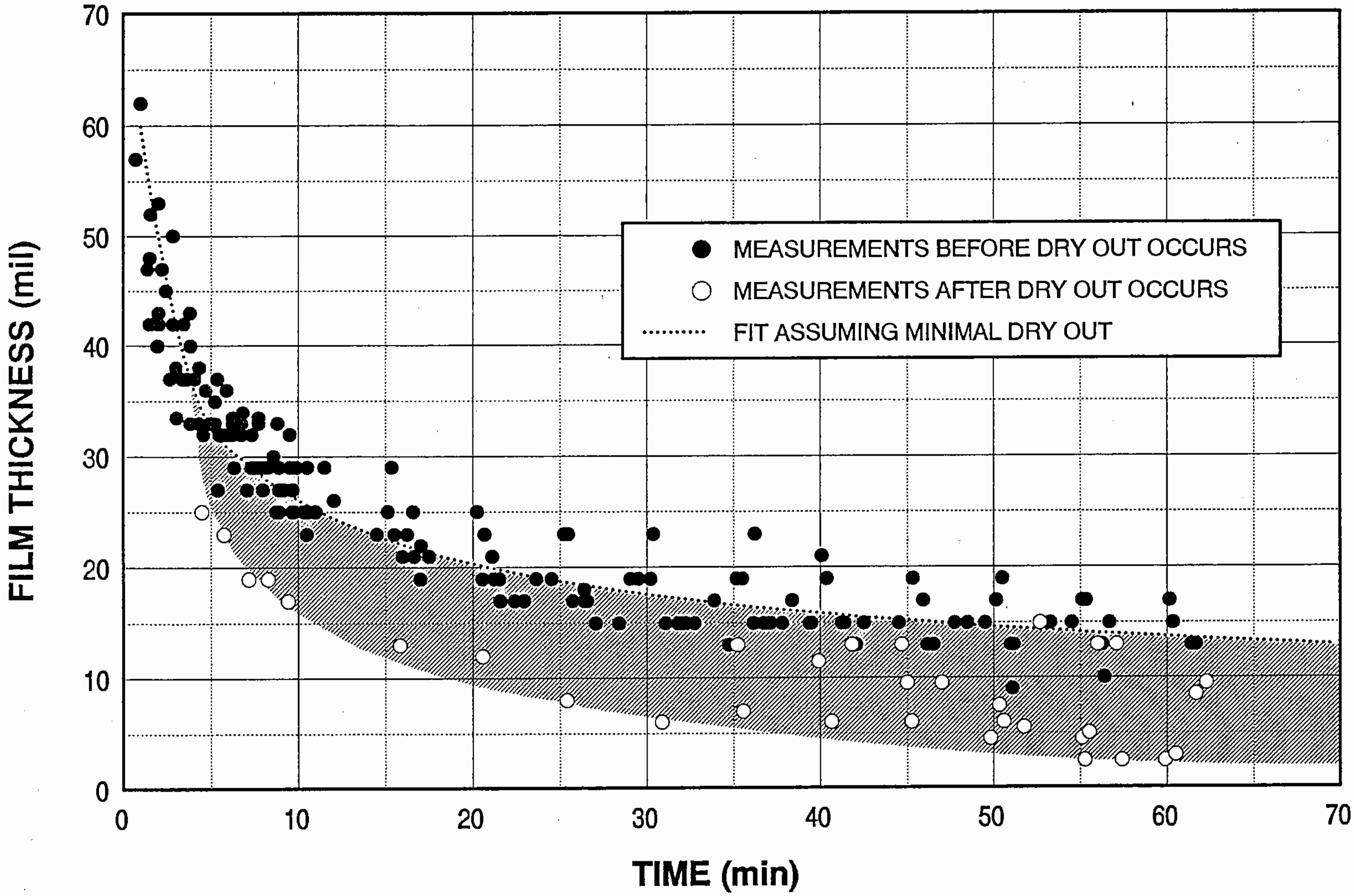
FILM THICKNESS vs TIME
FLUID A-201 - 2.5 cm LINE





FILM THICKNESS vs TIME
FLUID A-201 - 15 cm LINE
MEASUREMENTS BEFORE DRY OUT OCCURS
MEASUREMENTS AFTER DRY OUT OCCURS
FIT ASSUMING MINIMAL DRY OUT
FILM THICKNESS (mil)
TIME (min)
0
10
20
30
40
50
60
70

FILM THICKNESS vs. TIME
FLUID A-201 - 30 cm LINE



APPENDIX D

DETAILS OF STATISTICAL ANALYSIS

PROCEDURE

This is a two-fold study, the first one is the presentation of the correlations between the different variables and the second part is the investigation the predictiveness of the **Failure time** based on the other variables in the model.

VARIABLES

The following variables will be under study:

Average temperature	**Temp**
Average humidity	**Humid**
Average wind	**Wind**
Fluid thickness at the 1"line	**Line1**
Fluid thickness at the 6"line	**Line6**
Fluid thickness at the 12"line	**Line12**
Failure time	**Failure**
Total precipitation	**Totprec**
Precipitation type	**Prectype (*)**
Precipitation rate	**Precrate**

(*) This variable takes the value **1** if Freezing rain or Freezing Drizzle
and the value **0** if not.

CORRELATIONS

	Temp	Humid	Wind	Line1	Line2	Line3	Failure	Totprec	Prectype
Humid	-0.407								
Wind	-0.135	-0.178							
Line1	-0.632	0.409	-0.033						
Line2	-0.600	0.361	-0.074	0.736					
Line3	-0.392	0.289	-0.017	0.567	0.797				
Failure	0.224	-0.508	-0.262	-0.201	-0.271	-0.215			
Totprec	0.524	0.102	-0.151	-0.436	-0.426	-0.397	-0.096		
Prectype	0.147	-0.257	-0.111	-0.103	-0.026	-0.157	-0.000	0.187	
Precrate	0.233	0.294	-0.045	-0.210	-0.135	-0.164	-0.572	0.726	0.164

NOTE: The variable of interest **Failure time** is found to have the strongest correlation with the variables **Humidity.**

TRANSFORMATIONS

Let SFailure = square root of failure time,

Correlations

	Failure	SFailure
Temp	0.224	0.270
Humid	-0.508	-0.515
Wind	-0.262	-0.277
Line1	-0.201	-0.225
Line2	-0.271	-0.297
Line3	-0.215	-0.238
Totprec	-0.096	-0.040
Prectype	-0.000	0.032
Precrate	-0.572	-0.579

Note 1 Some transformations were performed on the variable **Failure time**, to see if the correlations could be increased. For example, the transformation **Square root of Failure time**, has increased slightly some of the correlations.

Note 2 From the examination of the correlations, we see that the failure time is inversely related to **Humidity** and **Wind.** That is for higher humidity or stronger wind, the failure time would be smaller.

Note 3 It is important to recognize here that the variable **Precrate** is not very reliable since it is obtained as a ratio of **Totprec** and **Failure.** So it cannot be used as a predictor of **failure time**, since it is a function of that variable. Another measure should be defined.

REGRESSIONS

In this section we will try to express **Failure time** as a function of the other variables available. We are then testing the following model:

$$\text{failure} = a_0 + a_1 \text{ temp} + a_2 \text{ humid} + a_3 \text{ wind} + a_4 \text{ line1} + a_5 \text{ line2} + a_6 \text{ line3} + a_7 \text{ totprec} + a_8 \text{ prectype}.$$

The overall significance of the model will be tested as well as the significance of the coefficients. Let us regress the variable **Failure time** on the other eight variables. We find the following:

The regression equation is

failure = 247 - 0.411 temp - 188 humidity - 2.89 wind + 0.82 line1 - 2.30 line2 + 0.10 line3 - 0.91 totprec - 10.6 prectype

Predictor	Coef	Stdev	t-ratio	p	
Constant	247.15	37.43	6.60	0.000	
temp	-0.4109	0.6088	-0.67	0.503	**not sign.**
humidity	-187.90	43.64	-4.31	0.000	
wind	-2.8926	0.7458	-3.88	0.000	
line1	0.824	1.193	0.69	0.493	**not sign.**
line2	-2.296	1.905	-1.20	0.234	**not sign.**
line3	0.102	1.465	0.07	0.945	**not sign.**
totprec	-0.907	1.954	-0.46	0.644	**not sign.**
prectype	-10.585	7.191	-1.47	0.147	**not sign.**

s = 17.74 **R-sq = 45.9%** R-sq(adj) = 37.2%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	13326.7	1665.8	5.29	0.000 **sign.**
Error	50	15732.5	314.7		
Total	58	29059.2			

The overall model is significant with a coefficient of determination of 45.9%. That is 45.9 % of the variation in failure time can be explained by regressing **Failure time** on those eight variables. But two many coefficients are not significantly different from zero, further regressions should be derived. At this initial stage, we can identify two variables who seem to contribute the most to predicting **Failure time**, that is **Humidity** and **Wind** (look at their p-value).

A stepwise regression is performed, excluding at each stage, the predictor with the smallest p-value, or significance. During the analysis, five observations were identified as outliers, or has having a too strong influence on the regression line.
Those observations are:

Observation **#1**	very high failure time
Observation **#2**	very high failure time
Observation **#35**	very low humidity
Observation **#36**	very low humidity
Observation **#37**	very low humidity.

The final model without those five observations is:

The regression equation is

failure = 292 - 278 humid - 2.11 wind

Predictor	Coef	Stdev	t-ratio	p	
Constant	292.33	38.20	7.65	0.000	
humid	-277.57	41.58	-6.68	0.000	sign.
wind	-2.1125	0.6198	-3.41	0.001	sign.

s = 15.10 R-sq = 49.0% R-sq(adj) = 47.0%

Analysis of Variance

SOURCE	DF	SS	MS	F	p	
Regression	2	11182.6	5591.3	24.52	0.000	sign.
Error	51	11629.8	228.0			
Total	53	22812.4				

REGRESSIONS

We now present a similar model, with **Square root of Failure time** as the dependent variable. Similar results to those obtained without the transformation are as follows:

The regression equation is

$$\textbf{(Failure)}^{1/2} = \textbf{27.7 - 23.7 humid - 0.199 wind}$$

Predictor	Coef	Stdev	t-ratio	p	
Constant	27.729	3.252	8.53	0.000	
humid	-23.749	3.542	-6.71	0.000	sign.
wind	-0.19863	0.05249	-3.78	0.000	sign.

s = 1.276 R-sq = 50.5% R-sq(adj) = 48.5%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	2	83.079	41.539	25.50	0.000 sign.
Error	50	81.449	1.629		
Total	52	164.527			

We note here that 50.5% of the variability in the **square root of the failure time** is explained by **humidity** and **wind.** We see that the two models are very similar, their coefficients of determination are also almost equal. The variables **Humidity** and **Wind** seem to affect **Failure time.**

REGRESSION MODEL FOR FAILURE TIME $\leq$ 60 MINUTES

We should also note that the model excluding all observations with **failure time** exceeding 60 minutes gave slightly different results. Eleven observations were not used because of the above restriction.

The regression equation is

failure = 99.1 - 93.1 humid + 1.92 totprec

48 cases used 11 cases contain missing values

Predictor	Coef	Stdev	t-ratio	p	
Constant	99.08	15.14	6.54	0.000	
humid	-93.13	17.15	-5.43	0.000	sign.
totprec	1.9180	0.7189	2.67	0.011	sign.

s = 8.983 R-sq = 44.1% R-sq(adj) = 41.6%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	2	2863.3	1431.6	17.74	0.000 sign.
Error	45	3631.5	80.7		
Total	47	6494.7			

Note: The coefficient of determination is not as strong as in the previous models. A new variable **total precipitation** became significant.

APPENDIX E

RESEARCH INTO SIMULATING ACTUAL PRECIPITATION CONDITIONS

APPENDIX E

RESEARCH INTO SIMULATING ACTUAL PRECIPITATION CONDITIONS

Snow-Making Machines

Another snow simulation option is the use of ski hill snow-making machines. If possible, this method could provide large volumes of data over relatively short periods of time. The precipitation produced by such snow-making machines is extremely crystalline in nature. What is produced is in the form of small ice pellets, more reminiscent of hail than any other precipitation form. These ice pellets may be slightly representative of freezing rain or freezing drizzle but they may not accompanied by the other atmospheric data usually associated with these conditions - namely high humidity and temperatures in the general area of the freezing point.

This experiment was not completed since the portable test stand was only completed by the month of March, at which time temperatures were climbing above the freezing point.

Snow Blowers

Manufacturers and distributors for snow blowing equipment were consulted in order to appraise the effectiveness of using these machines in simulating a localized snow storm. They provided information on the amount of control that can be exerted on the outgoing snow stream, on the modifications that can be made in order to increase the realism of the falling snow, on the characteristics of the outgoing snow, and on the atmospheric conditions that are optimal for simulating actual snow fall.

Control and specifications of interest were the direction and distance of the projected snow. Snow blowers have power ratings ranging from five to eleven horse power, providing a rate of output as high as several tonnes per minute. Certain models feature an infinitely variable weight transfer and auger height adjustment system. This effectively controls the amount of snow entering the snowblower which, in turn, controls the output rate of the snow. The gears control the forward speed which also affects the rate of projection of the snow. The snow jet can be directed on a 180° radius, with distances ranging from five to forty feet. The snow chutes can either have a square or round cross-section. Experience has it that the square chutes provide a denser jet than the round ones. Whether the snow jet is dispersed or compact is a factor of the chute design and angle of deflection. The coverage of the falling snow normally ranges from nine to twenty five square feet, although a greater surface could be obtained depending on the operating conditions.

Snowblowers are primarily conceived to mulch snow and project it at a given distance in as straight a line as possible. The chute is designed to compact the snow and send it in the desired direction. Modifications can be made to the chute in order reduce the level of compaction and increase the dispersion of the snow stream. If these are to be performed by the manufacturer, including design and testing, they would be costly. A cheaper alternative would be to remove the top segment of the chute, which is the main compacting agent. The snow would then be projected to it's maximum height, falling at a distance of about ten feet away from the snow blower. One would still retain some control over the direction of the jet, but the area of coverage would be much greater than if the chute were left intact. However, if the entire chute were removed, all control over the direction of the snow would be lost. The objective is to throw the snow as high as possible where it is subject to be dispersed and fall in a more granular form. Furthermore, by regulating the forward motion and auger height of the snowblower, one has control over the intensity of the falling snow.

The snowblower is designed to mulch whatever is fed into it. After a few passes, the corn meal was reduced to a fine powder. The problem with snow is that the mulching action will tend to heat up the snow, thus increasing its cohesion and the likelihood of it being compacted. In order for the resulting snow to be in a powdery form, the temperature must be cold enough, the chute should be set for minimum compaction and the quantity of input snow should be small enough to minimize compaction. It is to be noted that even the minimum rate of falling snow is substantially higher than most naturally occurring snow storms.

The greatest factors affecting the output snow are the atmospheric conditions and the type of snow used on input. Cold temperatures and dry conditions produce a lighter, more crystalline, snow which is easily dispersed. Furthermore, gusting winds will scatter the snow while it is in the air such as to provide more realism when it hits the ground. If the snow is heavy and wet, and if it is warm outside, the snow will be compacted by the snowblower and remain that way until it hits the ground. It was also mentioned that the ideal situation would be to plough through virgin snow that has not yet been compacted or piled into a snow bank.

In order to improve control over the dispersion of the snow jet, modifications made to the snowblower by the manufacturer would be costly. It was mentioned that such work would require research and development in an area of little interest to the manufacturer as such. Considering these costs alone, production of a single modified snowblower would be unrealistic. A less expensive approach would be to modify the equipment ourselves.

Some of the sources expressed doubt as to the realism of the simulated snow storm provided by the snow blower. It is to be noted that the design of the snow blower is to compact and discard the snow.

Other sources said that with the proper atmospheric conditions and particularly, with the proper kind of snow, a fairly accurate replica of a snow storm could be provided by the snow blower.

APPENDIX F

WORKSHOP ON CANADIAN RESEARCH IN AIRCRAFT GROUND DEICING

TDC # T8200-9-9512
APS Report# 971-7

CANADIAN RESEARCH IN AIRCRAFT GROUND DE-ICING WORKSHOP

AUGUST 16, 1991

WORKSHOP ON

CANADIAN RESEARCH IN AIRCRAFT GROUND DE-ICING WORKSHOP

Prepared on behalf of

TRANSPORTATION DEVELOPMENT CENTRE
TRANSPORT CANADA

BY

AVIATION PLANNING SERVICES LTD.

August 1991

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1. INTRODUCTION

The workshop "Canadian Research in Aircraft Ground Deicing", sponsored by the Transportation Development Centre, the National Research Council Canada and the Canadian Aeronautics and Space Institute, was held at ICAO in Montreal on May 8th and 9th, 1991. Aviation Planning Services Ltd. undertook the task of coordinating the entire conference. The goals of the workshop were: to disseminate the knowledge currently available on deicing aircraft, with emphasis on the new Type II fluids; to identify the important gaps in knowledge that need research; to make recommendations and prioritise research areas; and finally to incorporate any recommendations made in a set of proceedings of the workshop to be published later in the year.

The workshop was conducted with the help of experts, who were chosen for their knowledge and expertise in aircraft ground deicing and Type II fluids; they were drawn from such organizations as: Air Canada, Boeing de Havilland, Environment Canada, FAA Technical Centre, National Research Council, Transport Canada, Union Carbide of Canada, the University of Québec at Chicoutimi and various others from the aviation industry.

2. SOLICITATION OF PARTICIPANTS

A letter of invitation (see Attachment 1) was prepared and sent to approximately 200 people from various organizations in the aviation industry.

Of the 200 people invited, 128 enrolled for the conference. The actual attendance (see Attachment 2) for the workshop was 109. Of the 128 enrolled, approximately 30 did not show up. There was approximately 11 people who were not enrolled who came to the conference at the last minute.

Twelve speakers with various backgrounds in Aviation, especially pertaining to the area of Deicing were selected to speak at the workshop (See attachment 3). The topics of discussion are also provided in attachment 3.

The staff at APS handled and coordinated all requests and queries from participants and speakers before and after the workshop.

3. WORKSHOP FACILITIES PLANNING

A facility with the capacity to hold all the invitees was a necessity in order to stage this workshop.

Choosing the conference room involved phoning a number of sites, viewing them, securing price estimates, assessing suitability, making appropriate contractual arrangements, and providing liaison with TDC as required. Finally, it was decided by APS and TDC that the conference rooms provided by the International Civil Aviation Organization (ICAO) located at 1000 Sherbrooke Street West, Montreal best suited the needs of the workshop.

For the first day, one room was used, this room held 150 people. For the second day (morning only), 2 rooms were used, both holding up to 70 people.
The lunch on May the 8th for all participants and speakers was catered by the cafeteria of ICAO.

Recording equipment and simultaneous translations were secured through a company called Canadian Conferences.

4. DOCUMENTS, HANDOUTS AND TAPE TRANSCRIPTION

Preparation of documents for the workshop were a combined effort of TDC and APS. Abstracts of the presentations were collected two days prior to the conference in order to aid the translators. These abstracts (as well as the tape transcriptions), will be issued by NRC in a separate document.

Dissemination of the pre-workshop handouts, upon finalization of the workshop program, was carried out by APS. In addition, APS responded to any requests from the potential participants.

5. WORKSHOP

This activity involved a final inspection of all the arrangements including a visit to the site, sampling, and testing prior to the workshop.

The day before the conference, final preparation of the presentation material, preparation of name tags for participants and attending to last minute details for the luncheon.

Subcontractor management required supervision and on line direction of the subcontractors who provided the recording, translation, catering etc.

Post workshop coordination involved the coordination and supervision of the dismantling and returning of equipment/facilities, as required.

6. RECOMMENDATIONS

On day two, the participants were divided into three groups. The first group was the Cockpit Decision Information Group (C), the second group was the Ground Operations Group (G), and the third group was the Physics and Testing Group (P).

A total of 20 recommendations were made from the three groups. Questionnaires were prepared by TDC (see Attachment 4) and sent to all speakers and participants in order to determine: their organization; their area of activity; their scheduling preference for the next meeting, and to prioritize the recommendations set forth during the workshop.

Of the 109 questionnaires sent, APS has received 48 responses to date.

The results of the responses are provided in Table 6.1 and 6.2.

The following conclusions can be derived from Table 6.1.

1) The two largest groups represented were from Transport Canada and Commuter Air Carriers.

2) The two largest area of activities represented were from Scientific Research and Aircraft Operations.

3) The two most favoured dates for the scheduling of the next meeting were September or November 1991.

The results of Table 6.2 are depicted graphically in Figure 6.1 through 6.8. Table 6.1 provides a summary of the responses as a function of priority and recommendation. It can be clearly seen from Figure 6.1 that recommendations one and four are the most important. Not only do they have the highest response tally, but they also have a large number of first priority responses.

Figure 6.2 graphically depicts the first priority responses for each recommendation. Similarly, Figures 6.3 through 6.8 graphically depict responses for priorities two through seven.

If one were to use a simple binary analysis technique and provide a weight to the priorities, the recommendation ranking in Table 6.3 would result.

TABLE 6.1
GENERAL QUESTIONNAIRE FEEDBACK
AIRCRAFT GROUND DEICING WORKSHOP

	CATEGORY OF ORGANIZATION	TALLY
1)	Aircraft Manufacturing	0
2)	Aircraft Component Supplier	1
3)	De/anti-icing fluid supplier	1
4)	Airport Equipment Supplier	1
5)	Transport Canada	11
6)	Other Government Department	5
7)	Industry Organization	1
8)	Air Canada or Canadian	3
9)	Commuter Air Carrier	9
10)	Fixed Base Operator	3
11)	Consultant	1
12)	University	3
13)	Other	9
	TOTAL	48

	AREA OF ACTIVITY	TALLY
1)	Aircraft Operation	9
2)	De/anti-icing Operations	6
3)	Regulations	5
4)	Safety Practices	3
5)	Accident Investigation	1
6)	Polution Control	0
7)	Airport Operations	2
8)	Aircraft Maintenance	5
9)	Equipment Procurement	2
10)	Fluid Procurement	1
11)	Air Traffic Operations	0
12)	Scientific Research	10
13)	Operational Research	0
14)	Engineering Design	1
	No Response	3
	TOTAL	48

	NEXT MEETING	TALLY
1991	August	1
1991	September	9
1991	October	5
1991	November	7
1991	December	1
1992	January	0
1992	February	3
1992	March	6
1992	April	3
1992	May	6
	Earlier	
	Later	1
	Never	
	No Response	6
	TOTAL	48

TABLE 6.2
QUESTIONNAIRE FEEDBACK-RECOMMENDATIONS
AIRCRAFT GOUND DEICING WORKSHOP

RECOMMEND.	DESCRIPTION	PRIORITY 1	2	3	4	5	6	7	TOTAL
1	Create an overall industry Aircraft Ground Deicing Committee (AGDC) to include representation from Airport Operators, Airlines, Fluid Manufacturers, Research Groups, Industry Association, Environmental Groups.	21	1	3	2	2	0	1	30
2	Use the AGDC as a clearing house for information on all ground de/anti-icing research and development activities in North America and Europe.	0	8	6	2	0	2	4	22
3	Organize and implement programs of activity through the AGDC, identifying participants and timeframes to accomplish the accepted recommendations of this workshop and any subsequent AGDC recommendations.	2	4	4	3	1	1	2	17
4	Develop a total system, suitable for all aircraft types and all airports, that would provide last minute "clean-wing" information to the captain.	16	7	1	1	1	3	1	30
5	Explore concepts for complete systems, including industry operational guidelines, for ground deicing and establish whether national or site specific systems are more appropriate to Canadian needs.	1	4	4	2	3	2	4	20
6	Encourage operators to use alternative means of deicing if warranted.	0	0	2	4	1	1	1	9
7	Evaluate the impact of ground deicing at a major hub on operations at the rest of the system of airports.	0	0	3	4	3	1	1	12
8	Evaluate the economic impacts of ground deicing systems to establish what the industry is prepared to invest.	0	1	2	1	5	4	2	15
9	Improve communication between ATS/FSS and aircrew to minimize early starts and deicing.	1	4	3	0	5	1	3	17
10	Improve forecasting of types of precipitation.	1	2	2	3	1	5	2	16
11	Develop instrumentation to provide meteorological data to the pilot on precipitation type, accumulation and other features that will affect the holdover times.	0	2	1	5	2	1	0	11
12	Continue development of sensors - electronic and optical - for detection of wing contaminants.	0	2	4	3	5	1	1	16
13	Improve information regarding holdover times, including effects of meteorological conditions.	1	4	5	5	2	4	1	22
14	Conduct futher precipitation field tests, instrumented to determine what happens on the test plate.	0	1	0	1	0	1	1	4
15	Conduct wind tunnel and flight tests with fluids that have been "contaminated" with ice/snow/slush to establish clearing mechanism.	2	0	0	6	2	2	1	13
16	Develop theoretical models for the effects of precipitation of anit-icing fluids.	0	1	1	1	1	1	1	6
17	Determine the effects of ground icing and snow adherence on aircraft quantifying all concepts and the variations with aircraft type.	1	2	0	2	0	2	4	11
18	Continue aircraft manufacturers research on the effects of de/anti-icing fluids on the operations of their aircraft.	1	2	1	3	5	4	2	18
19	Establish the critical locations on aircraft for sensors that can detect breakdown of anti-icing fluid protection.	0	0	3	0	2	1	1	7
20	Determine the effect of de/anti-icing fluids on supercritical wing profiles as used on Canadian aircraft.	1	2	1	0	1	3	1	9
TOTAL		48	47	46	48	42	40	34	305

FIGURE 6.1
RESPONSE AS A FUNCTION OF PRIORITY vs RECOMMENDATION
DEICING WORKSHOP

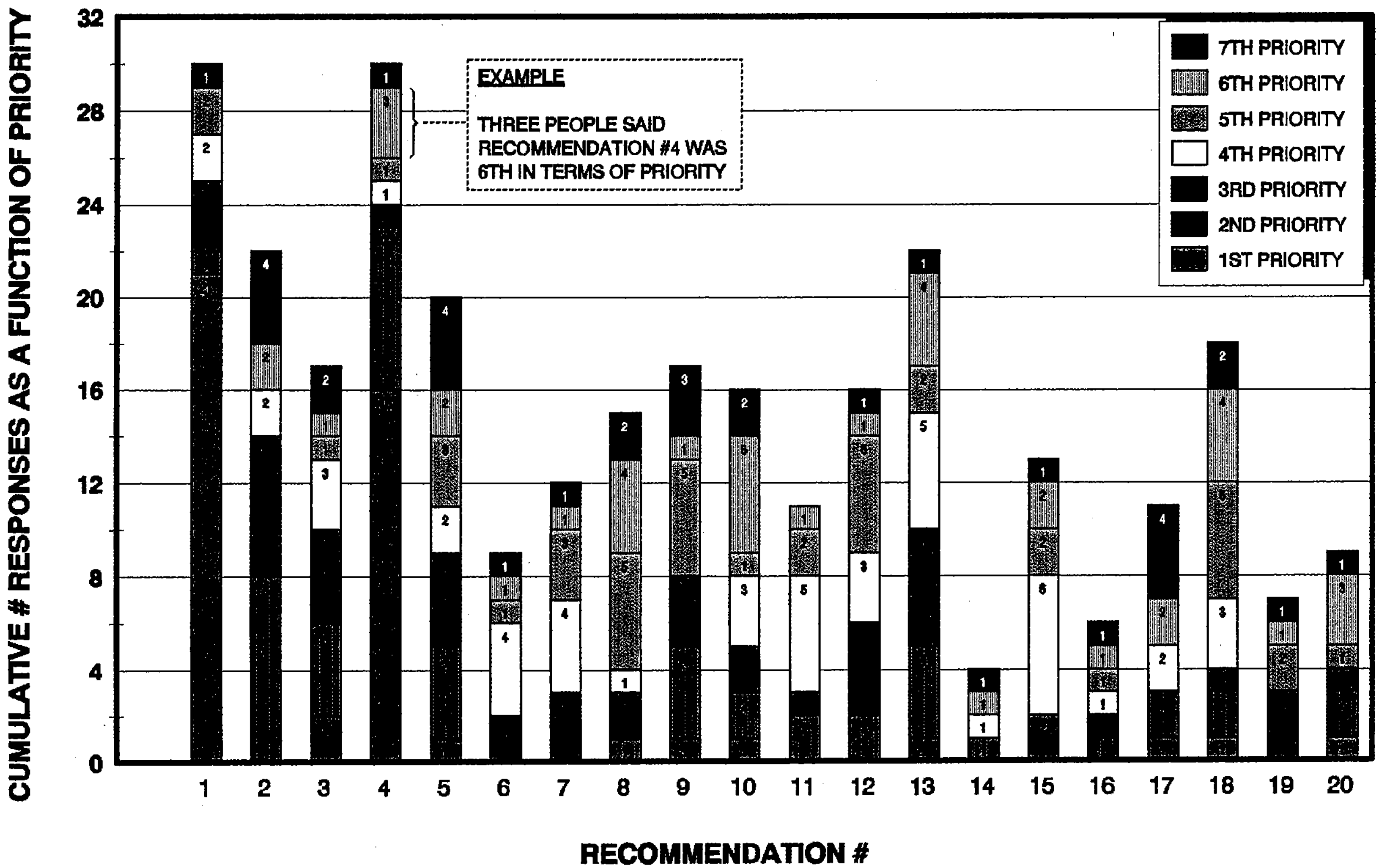

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FIGURE 6.2
RESPONSE vs RECOMMENDATION
DEICING WORKSHOP

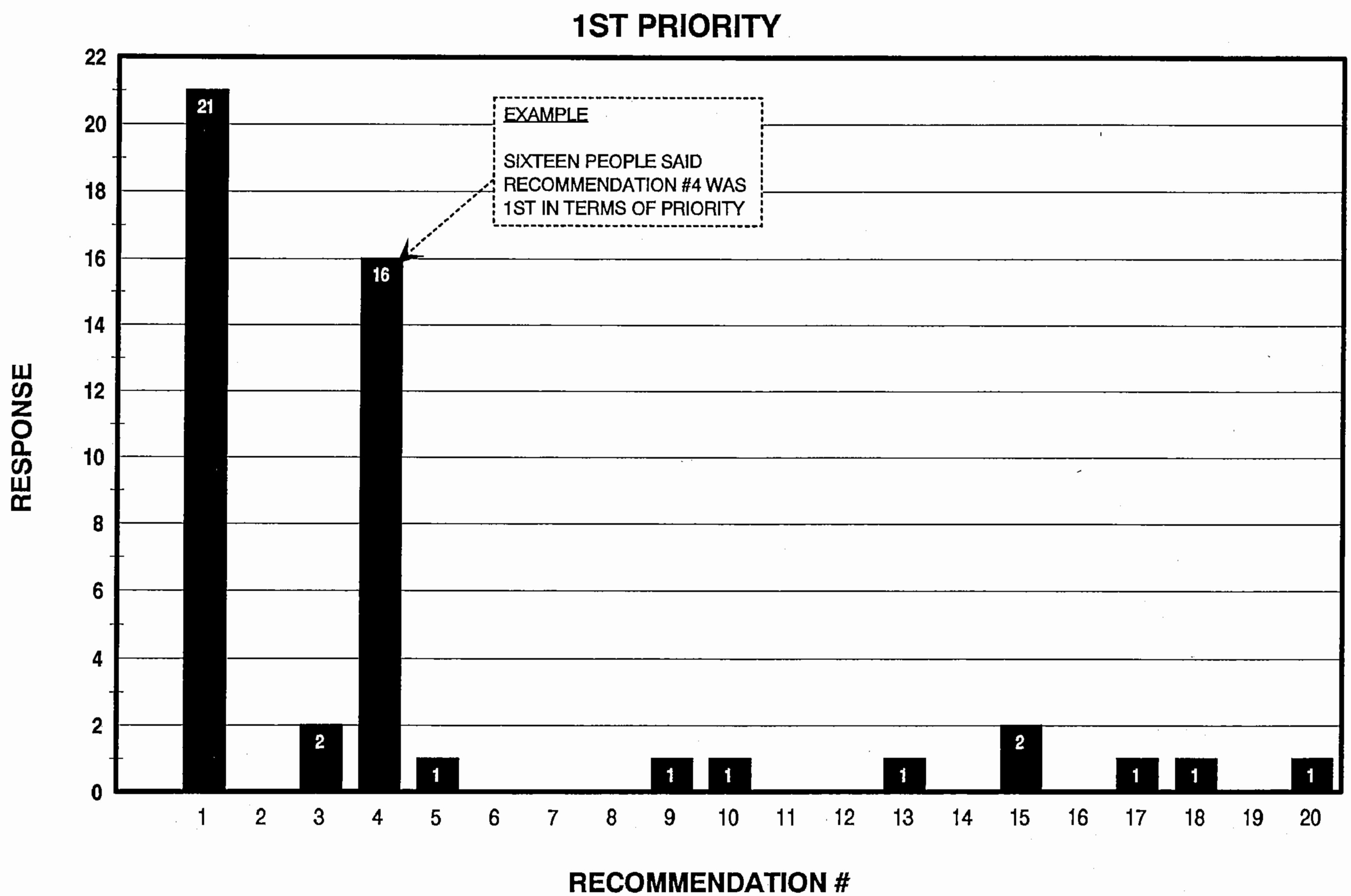
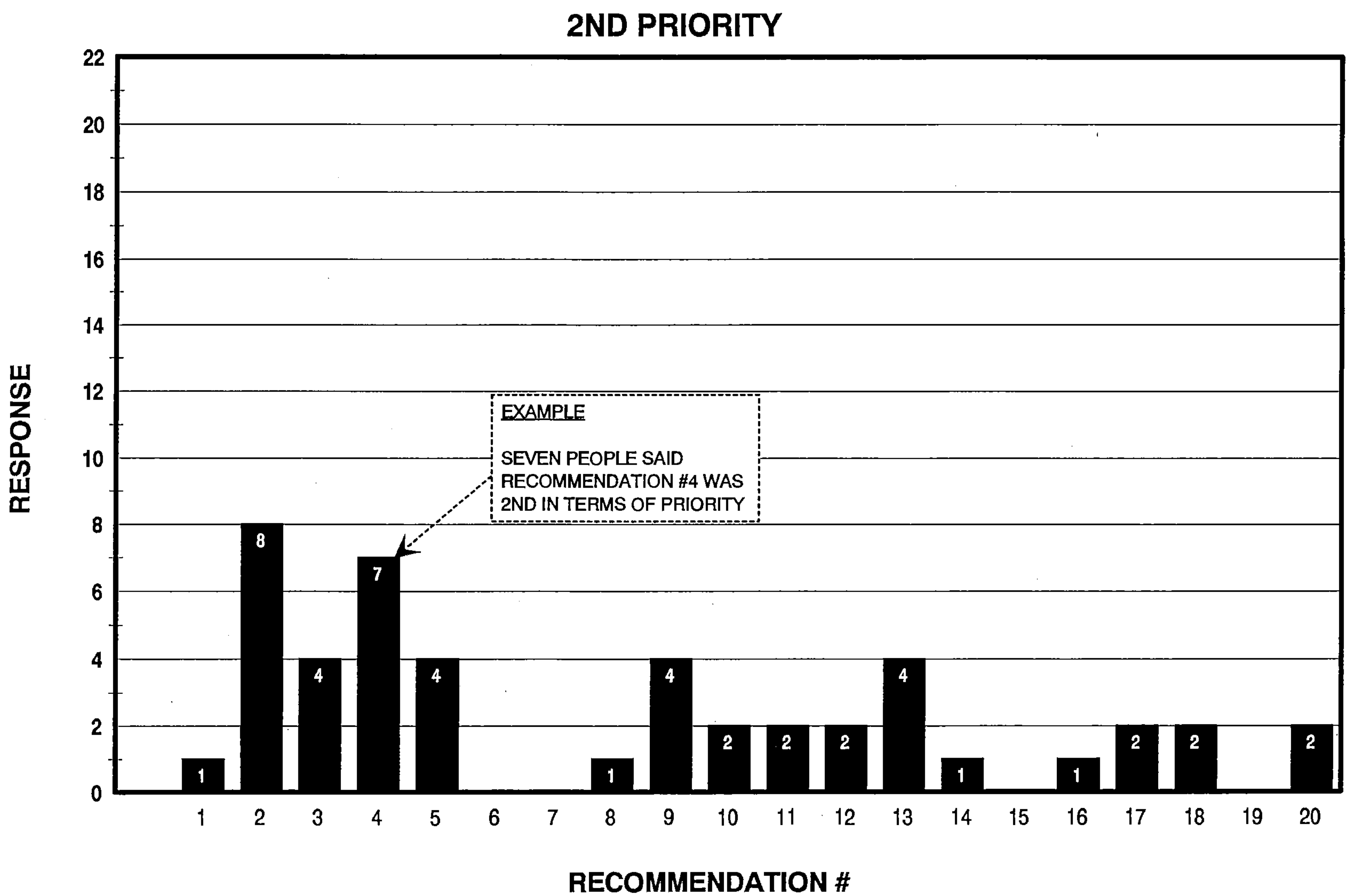


FIGURE 6.3
RESPONSE vs RECOMMENDATION
DEICING WORKSHOP



F-13

FIGURE 6.4
RESPONSE vs RECOMMENDATION
DEICING WORKSHOP

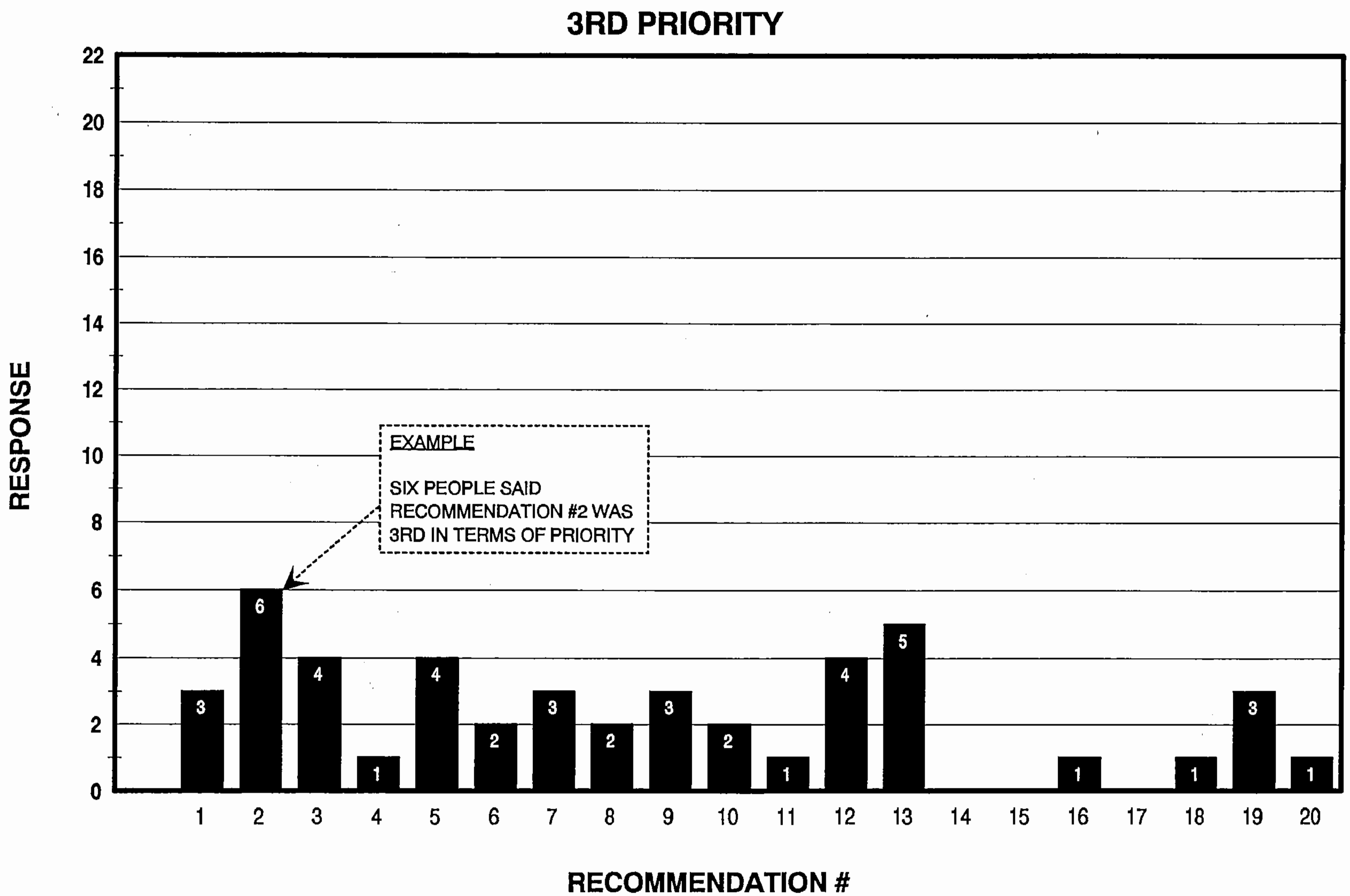
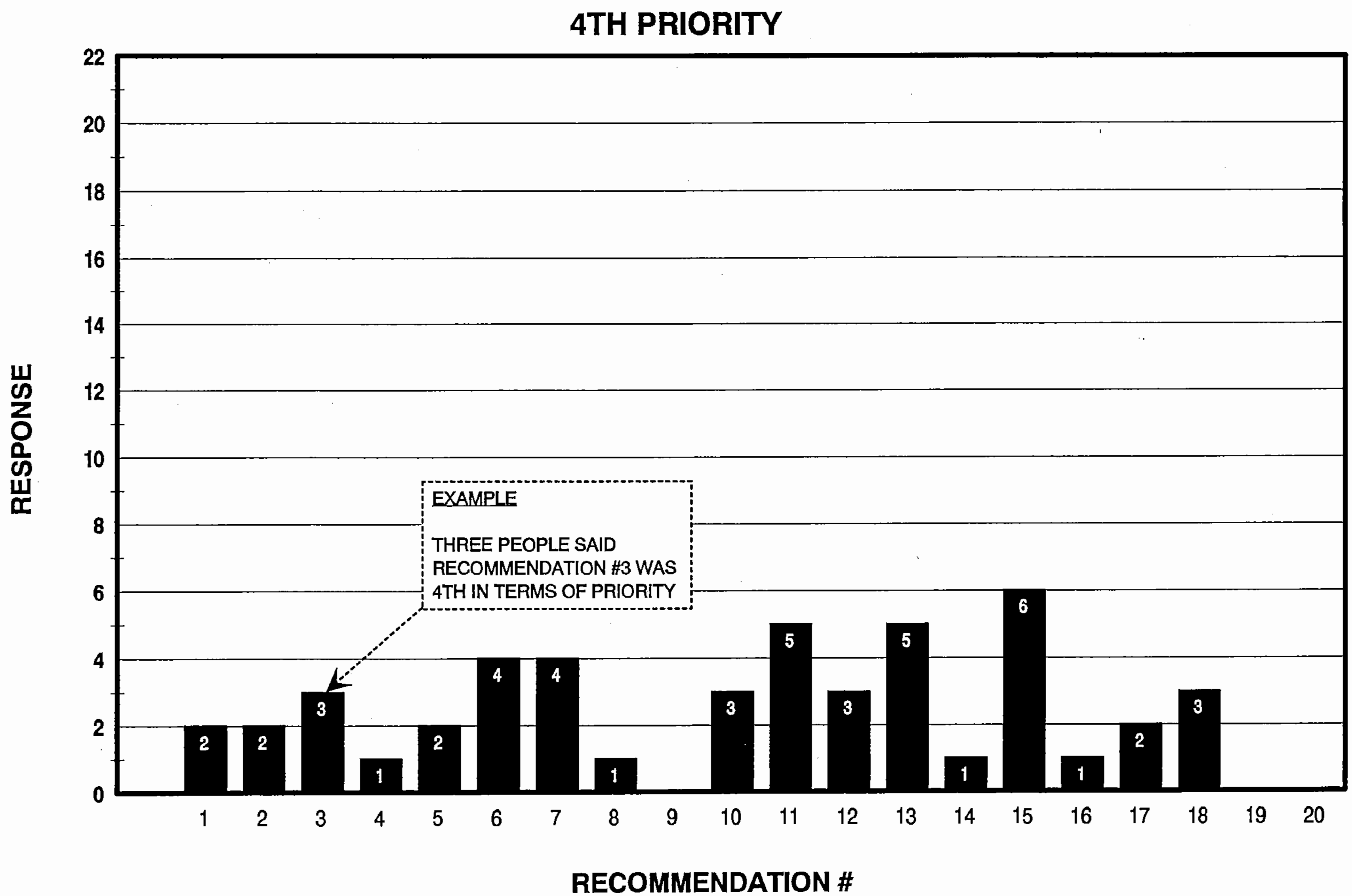


FIGURE 6.5
RESPONSE vs RECOMMENDATION
DEICING WORKSHOP



F-15

FIGURE 6.6
RESPONSE vs RECOMMENDATION
DEICING WORKSHOP

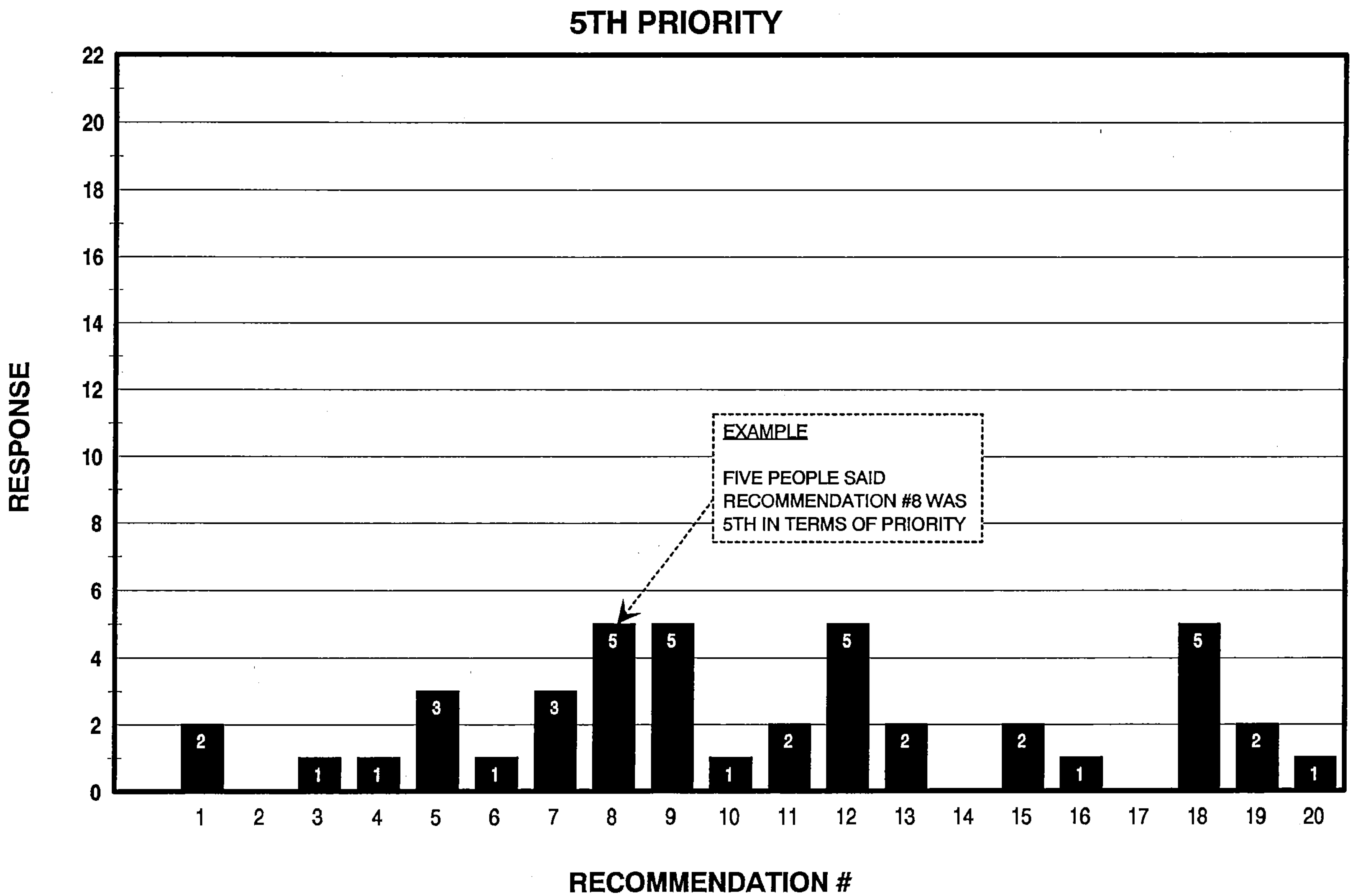


FIGURE 6.7
RESPONSE vs RECOMMENDATION
DEICING WORKSHOP

6TH PRIORITY

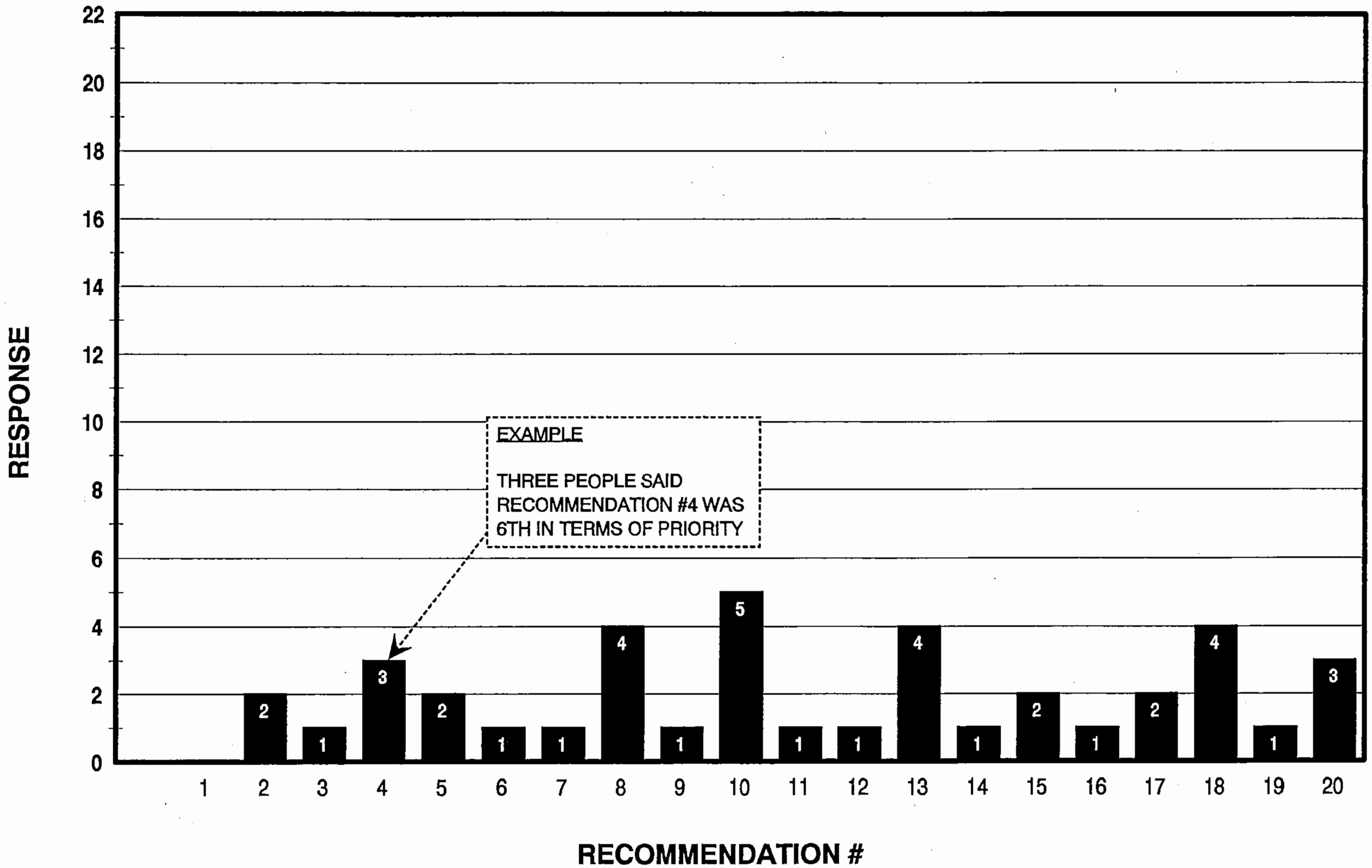
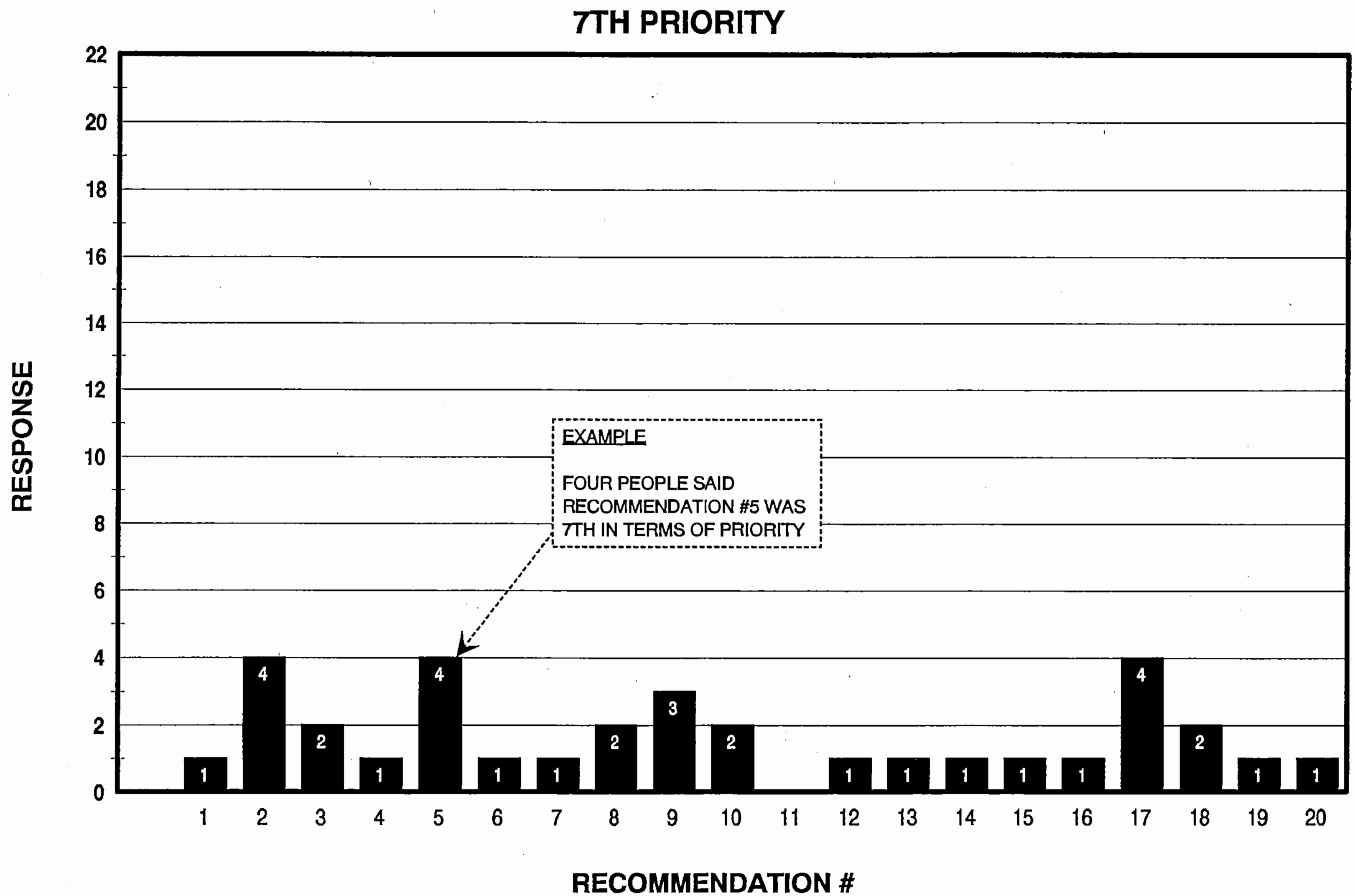


FIGURE 6.8
RESPONSE vs RECOMMENDATION
DEICING WORKSHOP



F-18

TABLE 6.3
RANKING OF RECOMMENDATIONS
AIRCRAFT GROUND DEICING WORKSHOP

RANK NO.	RECOMMENDATION NO.	DESCRIPTION
1	1	Create an overall industry Aircraft Ground Deicing Committee (AGDC) to include representation from airport Operators, Airlines, Fluid Manufacturers, Research Groups, Industry Association, Environmental Groups.
2	4	Develop a total system, suitable for all aircraft types and all airports, that would provide last minute "clean wing" information to the captain
3	2	Use the AGDC as a clearing house for information on all ground de/anti-icing research and development activities in North America and Europe.
4	13	Improve information regarding holdover times, including effects of meteorological conditions.
5	3	Organize and implement programs of activity through the AGDC, identifying participants and timeframes to accomplish the accepted recommendations of this workshop and any subsequent AGDC recommendations.
6	5	Explore concepts for complete systems, including industry operational guidelines, for ground deicing and establish whether national or site specific systems are more appropriate to Canadian needs.
7	9	Improve communication between ATS/FSS and aircrew to to minimize early starts and deicing.
8	12	Continue development of sensors - electronic and optical - for detection of wing contaminants.
9	18	Continue aircraft manufacturers research on the effects of de/anti-icing fluids on the operations of their aircraft.
10	10	Improve forecasting of types of precipitation.
11	15	Conduct wind tunnel and flight tests with fluids that have been "contaminated" with ice/snow/slush to establish clearing mechanism.
12	11	Develop instrumentation to provide meteorological data to the pilot on precipitation type, accumulation and other features that will affect the holdover times.
13	8	Evaluate the economic impacts of ground deicing systems to establish that the industry is prepared to invest.
14	7	Evaluate the impact of ground deicing at a major hub on operations at the rest of the system of airports.
15	17	Determine the effects of ground icing and snow adherence on aircraft quantifying all concepts and the variations with aircraft type.
16	20	Determine the effect of de/anti-icing fluids on supercritical wing profiles as used on Canadian aircraft.
17	6	Encourage operators to use alternative means of deicing if warranted.
18	19	Establish the critical locations on aircraft for sensors that can detect breakdown of anti-icing fluid protection.
19	16	Develop theoretical models for the effects of precipitation of anti-icing fluids.
20	14	Conduct further precipitation field tests, instrumented to determine what happens on the test plate.

APPENDIX F

ATTACHMENT 1

SAMPLE LETTER OF INVITATION

489-971-7 April 15, 1991

1~ 2~ 3~
4~
5~
6~
7~
8~
9~
10~
11~

Subject: <u>Workshop on Canadian Research in Aircraft Ground Deicing</u>

Dear 1~ 3~,

We would like to invite you to participate in a two day workshop sponsored by the Transportation Development Centre (TDC) of Transport Canada (TC) and the Transportation Technology Program of the National Research Council (NRC) of Canada on the subject of Canadian research in aircraft ground deicing.

The workshop will be held May 8-9, 1991, in Montreal immediately following the CASI annual general meeting. The goals of the workshop are to disseminate the knowledge currently available on deicing aircraft, with emphasis on the new Type II fluids; to identify the important gaps in knowledge that need research; and, finally to make recommendations and prioritise research areas. A set of proceedings of the workshop will be published later in the year.

The workshop will open with an information session describing much of the current knowledge on ground deicing including some early results of TDC's recent programme of research activities. The information session will be followed by simultaneous working group sessions on the topics covered to aid in providing recommendations for those high-priority research topics. The Canadian orientation of the workshop will mean that there will be a greater emphasis on commuter and general aviation needs; however, much of what is discussed will be of universal interest to those concerned with the use of the Type II fluids.

The workshop will cover the following topics:

1) Meteorological information for ground icing
2) Type II deicing fluid effectiveness
3) Aerodynamic effects on commuter aircraft
4) Deicing fluid application considerations
5) Sensing ice/deicing fluid presence on aircraft surfaces
6) Aircrew information needs
7) Cockpit displays for ground deicing
8) Industry deicing application Practices
9) Environmental pollution
10) Health/toxicity considerations
11) Organisational responsibility issues
12) General aviation deicing fluid tests
13) Holdover time results from 1991 test program
14) Deicing fluid qualification testing

Technical and operational experts will make a short presentation on each of the above topics followed by a brief question period. The same topics will be dealt with in the subsequent working groups at greater depth; these discussions will focus on the information needs of the industry, culminating in recommendations for future research.

Experts have been chosen for their knowledge and expertise in aircraft ground deicing and Type II fluids; they have been drawn from such organizations as: Air Canada, Boeing De Havilland, Environment Canada, FAA Technical Centre, National Research Council, Union Carbide of Canada and the University of Quebec.

In order to select a site in Montreal (there are several options at present), an early indication of the numbers likely to attend is needed. If you plan to attend, please return or FAX a copy of this page with a copy of your business card or letterhead; indicate your areas of interest in the above topic list so that we can size the working sessions and cluster the topics accordingly.

Yours sincerely,

K. Romi Singh, Eng.
Executive Vice President

KRS/cm

APPENDIX F

ATTACHMENT 2

LIST OF ATTENDEES

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Mr. Gerald Zagury

APPENDIX F

ATTACHMENT 3

LIST OF SPEAKERS AND TOPICS

WORKSHOP ON CANADIAN RESEARCH IN AIRCRAFT GROUND DEICING

1. **Meteorological Information for Ground Deicing**
   Dr. Ron Stewart
   Cloud Physics Research Division, ARMP
   Atmospheric Environment Service

2. **Type II Deicing Fluid Effectiveness**
   Dr. Yaman Boluk
   Development Specialist
   Union Carbide Limited

3. **Aerodynamic Effects of Deicing Fluids on Commuter Aircraft**
   Dr. Norman D. Ellis
   Chief Aerodynamics
   Boeing Canada de Havilland

4. **Deicing Fluid Application Considerations**
   Mr. Tony Manzo
   Technologist, Materials and Processes
   Air Canada

5. **Sensing Ice and Deicing Fluid Presence**
   Dr. Stuart Inkpen
   Vice President Research
   Instrumar Limited

6. **Aircrew Information Needs**
   Captain C.H. Simpson
   Vice President, Flying Operations
   Air Canada

7. **Cockpit Displays for Ground Deicing**
   Dr. David Ostrey
   Principal Consultant
   Human Factors North

8./9. **Environmental Pollution/Health Toxicity Considerations**
   Mr. Youssef Sabeh
   Superintendent, Environment
   Transport Canada Montreal Airports

10. **Organizational Responsibility Issues**
   Mr. Peter Friedrichs
   Partner
   Hickling Corporation

11. **General Aviation Deicing Fluid Tests**
   Mr. Charles Masters
   Senior Program Manager
   FAA Technical Centre

12. **Holdover Time Results From 1991 Test Program**
   Mr. K. Romi Singh
   Executive Vice President
   Aviation Planning Services Ltd.

13. **Deicing Fluid Qualification Testing**
   Dr. Jean-Louis Laforte
   Directeur Groupe de l'ingénièrie
   Université du Québec à Chicoutimi

APPENDIX F

ATTACHMENT 4

SAMPLE POST CONFERENCE QUESTIONNAIRE

PLEASE COMPLETE
GROUND DEICING WORKSHOP FEEDBACK

ORGANIZATION

Please Categorise your organisation; circle one number:

1	Aircraft Manufacturing	8	Air Canada or Canadian
2	Aircraft component Supplier	9	Commuter air carrier
3	De/anti-icing fluid supplier	10	Fixed Base operator
4	Airport equipment supplier	11	Consultant
5	Transport Canada	12	University
6	Other Government Department (DND,AES,NRC,TSB)		
7	Industry Organisation (CALPA, ATAC etc)		
		13	Other(specify)________________

ACTIVITY

Within your organisation what is your department responsible for?
Circle one number

1	Aircraft operation	8	Aircraft maintenance
2	De/anti-icing operations	9	Equipment procurement
3	Regulations	10	Fluid procurement
4	Safety practices	11	Air traffic operations
5	Accident investigation	12	Scientific research
6	Pollution control	13	Operational research
7	Airport operations	14	Engineering design

NEXT MEETING

In which month do you think the next meeting should be? Circle one

1991	Aug	Sept	Oct	Nov	Dec
1992	Jan	Feb	Mar	Apr	May
			Earlier	Later	Never

RECOMMENDATION PRIORITIES

There are twenty recommendations and each is numbered.
Please indicate your perception of the priority order for those that are important to your organization.
Please place only one at each rank; add levels as needed

Priority Rank	1	2	3	4	5	6	7
Recommendation #							

PLEASE RETURN ON OR BEFORE JUNE 13, 1991 TO:

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AVIATION PLANNING SERVICES LTD.
1 Place Ville Marie, Suite 1725
Montreal, Quebec H3B 2C1
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GROUND DEICING WORKSHOP

RECOMMENDATIONS

INDUSTRY ACTION COMMITTEE

1 [HIGHEST PRIORITY FOR GROUP G] Create an overall industry Aircraft Ground Deicing Committee (AGDC) to include representation from:
   Airport Operators
   Airlines
   Fluid Manufacturers
   Research Groups
   Industry Associations
   Environmental groups. [G]

2 Use the AGDC as a clearinghouse for information on all ground de/anti-icing research and development activities in North America and Europe. (Involvement with the SAE ad hoc Committee on Aircraft Ground Deicing was accepted as the major interface for information.) [G]

3 Organise and implement programs of activity through the AGDC, identifying participants and timeframes to accomplish the accepted recommendations of this workshop and any subsequent AGDC recommendations. [G]

DEICING SYSTEMS AND PROCEDURES

4 [HIGHEST PRIORITY FOR GROUP C] Develop a total system, suitable for all aircraft types and all airports, that would provide last minute "clean-wing" information to the captain. (Ideally the system would also have the capability of providing secondary deicing if required.) [C]

5 Explore concepts for complete systems, including industry operational guidelines, for ground deicing and establish whether national or site specific systems are more appropriate to Canadian needs. [G]

6 Encourage operators to use alternative means of deicing if warranted (e.g. forced air). [C]

7 Evaluate the impact of ground deicing at a major hub on operations at the rest of the system of airports. [G]

8 Evaluate the economic impacts of ground deicing systems to establish what the industry is prepared to invest. [G]

9 Improve communication between ATS/FSS and aircrew to minimize early starts and deicing. [C]

10 Improve forecasting of types of precipitation. [C]

AIRCRAFT SURFACE CONTAMINATION

11 Develop instrumentation to provide meteorological data to the pilot on precipitation type, accumulation and other features that will affect the holdover times. [P]

12 Continue development of sensors- electronic and optical - for detection of wing contaminants. [C]

13 Improve information regarding holdover times, including effects of meteorological conditions. [C]

14 Conduct further precipitation field tests, instrumented to determine what happens on the test plate. [P]

15 Conduct wind tunnel and flight tests with fluids that have been "contaminated" with ice/slush/snow to establish clearing mechanism. [P]

16 Develop theoretical models for the effects of precipitation on anti-icing fluids. [P]

17 Determine the effects of ground icing and snow adherence on aircraft quantifying all concepts and the variations with aircraft type. [P]

18 Continue aircraft manufacturers research on the effects of de/anti-icing fluids on the operations of their aircraft. [C]

19 Establish the critical locations on aircraft for sensors that can detect breakdown of anti-icing fluid protection. [P]

20 Determine the effect of de/anti-icing fluids on supercritical wing profiles as used on Canadian aircraft. [P]

[C] Cockpit Decision Information Group recommendation

[G] Ground Operations Group recommendation

[P] Physics and Testing Group recommendation