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DESERT RESEARCH INSTITUTE
UNIVERSITY OF NEVADA SYSTEM

ASSESSMENT OF FLOOD HAZARD AT THE RADIOACTIVE WASTE MANAGEMENT SITE IN AREA 5 OF THE NEVADA TEST SITE

by

Richard H. French
Walter S. Lombardo

July, 1984

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Dear Dr. French;

Thank you for the publication "Assessment of Flood Hazard at the Radioactive Waste Management Site in Area 5 of the Nevada Test Site." I have circulated it to interested persons on the Research staff here at NRC

Sincerely Donald L Chery Jr.

DOE/NV/10162-15

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CONTENTS

Page

Figures.....iii
Tables.....iv
Executive Summary.....vi

Introduction.....1

Regional Analysis of Streamflow Characteristics:
Background.....5

Alluvial Fans: Background.....9
Introduction.....9
Alluvial Fan Formation.....11
Tectonics and Alluvial Fans.....12
Sediment Transport.....13
Channels and Channel Entrenchment.....15
Lithology, Sediment Characteristics, and Fan
Morphology.....19
Deposition Rates and the Age of Alluvial Fans.....22

Development and Application of Regional Peak Flood
Flow Methods in Nevada and Arizona.....24
Application to Radioactive Waste Management Site...34

Alluvial Fans and the RWMS.....40
Description of Watersheds.....40
Sediment Characteristics, Age, and Deposition
Rates of the Alluvial Fans.....45
Summary.....48

Flooding on Alluvial Fans.....51

Preliminary Assessment of Flood Risk.....71

Conclusions and Comments.....82

Bibliography.....84
Appendix I: Figures 10 - 14.....90
Appendix II: Sieve Analysis for Material
from Sample Sites.....96

FIGURES

Number		Page
1	Location of the Nevada Test Site	2
2	Location of the Radioactive Waste Management Site and Area 5 on the Nevada Test Site	3
3	Generalized Features of a Mountain-Basin System	10
4	Idealized Sketch of Intersection-Point Relationships	17
5	Development of Alluvial Fans	20
6	Maximum Discharge as a Function of Drainage Area	27
7	Arizona Flood Frequency Regions	29
8	Hypothesized Zones of Precipitation in Southern Nevada	33
9	Watersheds and Alluvial Fans Surrounding the RWMS	35
10	Peak Flood Flow Estimates for Watershed 1 Above 3500 Feet	91
11	Peak Flood Flow Estimates for Watershed 2 Above 3500 Feet	92
12	Peak Flood Flow Estimates for Watershed 3 Above 3500 Feet	93
13	Peak Flood Flow Estimates for Watershed 4 Above 3500 Feet	94
14	Peak Flood Flow Estimates for Watershed 5 Above 3500 Feet	95
15	Location of Exploratory Holes on Frenchman Flat in the Vicinity of the RWMS, Showing Depth to Alluvium/Tuff Contact	47
16	Soil Sampling Site Locations	59
17	Definition of Flow Regimes for Fans 2, 3, and 4	70
18	Schematic of an Idealized Alluvial Fan	72
19	Probability of a Channel Deviation from the Medial Position on Fanheads of Alluvial Fans in Parts of Fresno and Merced Counties, California	74

TABLES

Number		Page
1	Independent Variables used in 10 Regional Flood-Frequency Analyses	8
2	Summary of the Regional Peak Flow Equations used by Christensen and Spahr (1980) for Topopah Wash	25
3	Maximun Observed Discharges at Six Selected Sites in Arizona, California, Nevada, New Mexico, and Utah, Christensen and Spahr (1980)	28
4	Summary of the Regional Peak Flow Equations Developed by Roeske (1978)	32
5	Summary of Pertinent Physical Characteristics of Watersheds Above the Radioactive Waste Management Site	36
6	Summary of Peak Flood Flow of Various Return Periods	37
7	Maximum Potential Flood as a Function of Watershed Area	39
8	Summary of Coefficients for the Estimations of Channel Width and Depth	53
9	Estimated Values of y and T for Specified Values of Q	54
10	Estimated Values of y and T for the Maximum Potential Flood	55
11	Summary of Soil Sampling Results	60
12	Summary of Size and Resistance Data Contained in Table 11	65
13	Summary of d_{50} Size Data and Statistics for Watershed 3	68

14 Summary of Average Slope Data for Alluvial Fans Surrounding the Radioactive Waste Management Site.....69

15 Summary of Parameters for Estimating the Probability of a Flood "Hit" on the RWMS by Equation (10) or Equation (11).....75

16 Estimate of the Conditional Probability of a Flood Hitting the Waste Management Site Assuming that the Characteristic Site Length is 2,800 Ft. and using the Channel Top Width Estimates of Christensen and Spahr, (1980).....76

17 Assessment of Risk at the Radioactive Waste Management Site Assuming a Design Life of 100 Years and a Characteristic Length of 2,800 Ft. ..79

18 T_R as a Function of R and N.....81

EXECUTIVE SUMMARY

The purpose of this report is to present the preliminary assessment of flood hazard at the Radioactive Waste Management Site (RWMS) in Area 5 of the Nevada Test Site (NTS).

The RWMS is located at the junction of major alluvial fans, to the east and west, with several smaller fans merging from the north.

[redacted] This conclusion was arrived at by using regional peak flood flow equations developed by the U.S. Geological Survey and various hypotheses regarding flood processes on alluvial fans. It should be noted that the flood hazard at the RWMS is not necessarily greater than it would be for any facility of a similar size and design life located on any alluvial fan in Southern Nevada. Further, the berm on the upslope side of the RWMS may offer some protection; however, the degree of protection provided by this berm was not evaluated.

Although this analysis is subject to a number of limitations, which are noted and discussed within, the conclusion is substantiated by the fact that the RWMS is located on a number of alluvial fans which were formed by erosional processes that are still active. Although protective measures for the site can be developed, the development of such mitigation plans should include not only a careful consideration of the probability that the site will

be hit by a flood event, but also a careful consideration of the consequences of such a hit. This report is a focused analysis of the probability that the RWMS will be hit by a flash flood, but does not address what the consequences of such an event might be.

INTRODUCTION

Hydrologic analyses in general and flood hazard evaluations in particular are difficult to perform in desert and arid regions. In such areas stream gaging records are usually of short length, when they exist, and are usually composed of many low outliers with only a few meaningful values. With these data limitations, the traditional methods of peak flood flow estimation; see for example Anon. (1977), are not applicable and regional peak flood flow regression equations or rainfall runoff models are frequently used.

A second difficulty in evaluating potential flood hazards to facilities in arid regions occurs when the facility is sited on one or more alluvial fans. An alluvial fan is a fan or cone-shaped deposit of sediment which accumulates at the base of some mountain fronts. From a quantitative viewpoint, the formation of these important geological features and the movement of flood flows across them are very poorly understood.

The purpose of this report is to present the preliminary assessment of flood hazard at the Radioactive Waste Management Site (RWMS) in Area 5 of the Nevada Test Site (NTS), Figures 1 and 2. The organization of this report is as follows: In the first two sections, background information of a general nature pertaining to the regional analysis of streamflow characteristics and alluvial fans is presented. In the third section, regional peak flood flow estimation techniques for Nevada and Arizona are summarized and applied to the watersheds surrounding the RWMS in Area 5 of the NTS. In the fourth section of this report, specific

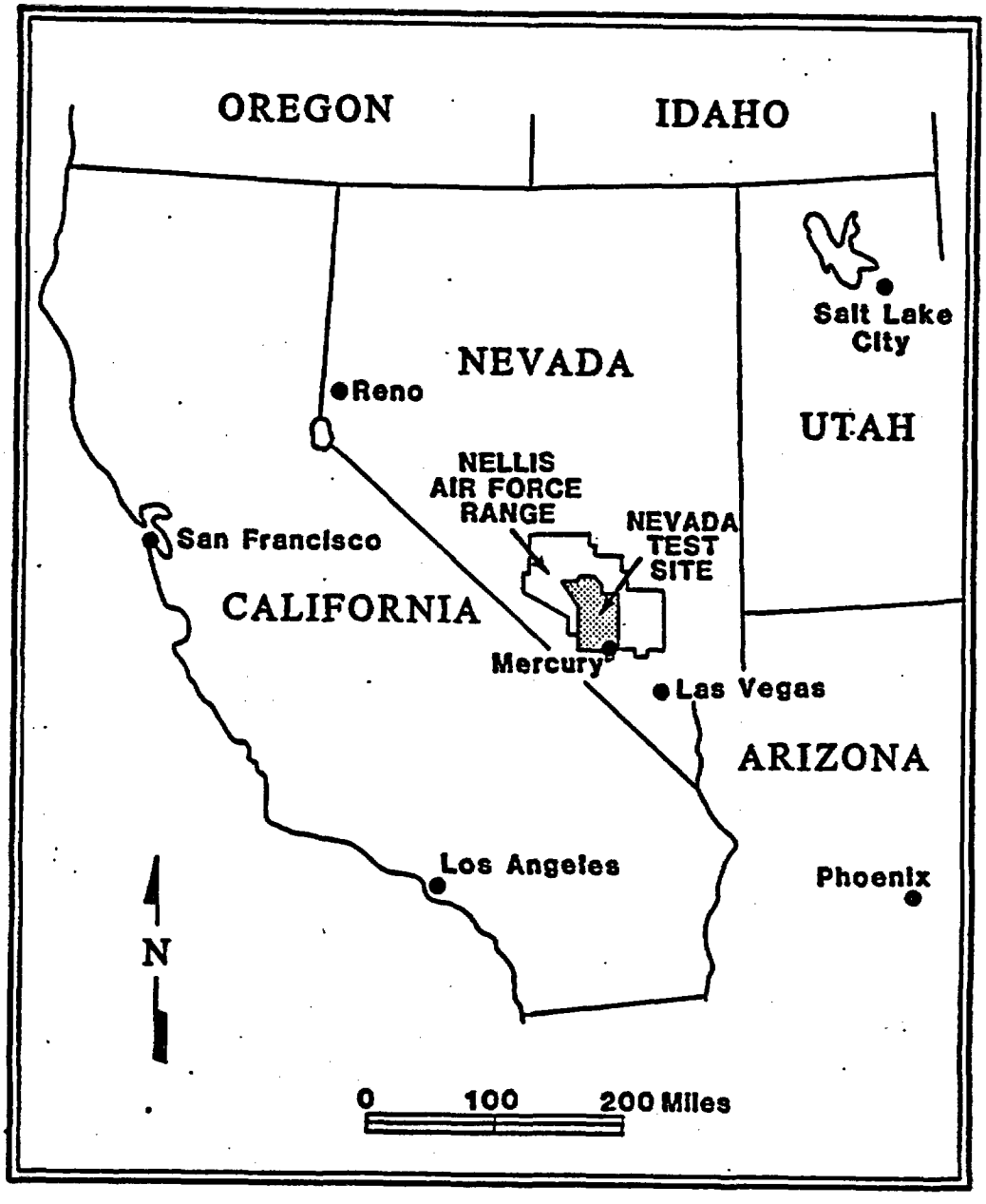

FIGURE 1: Location of the Nevada Test Site

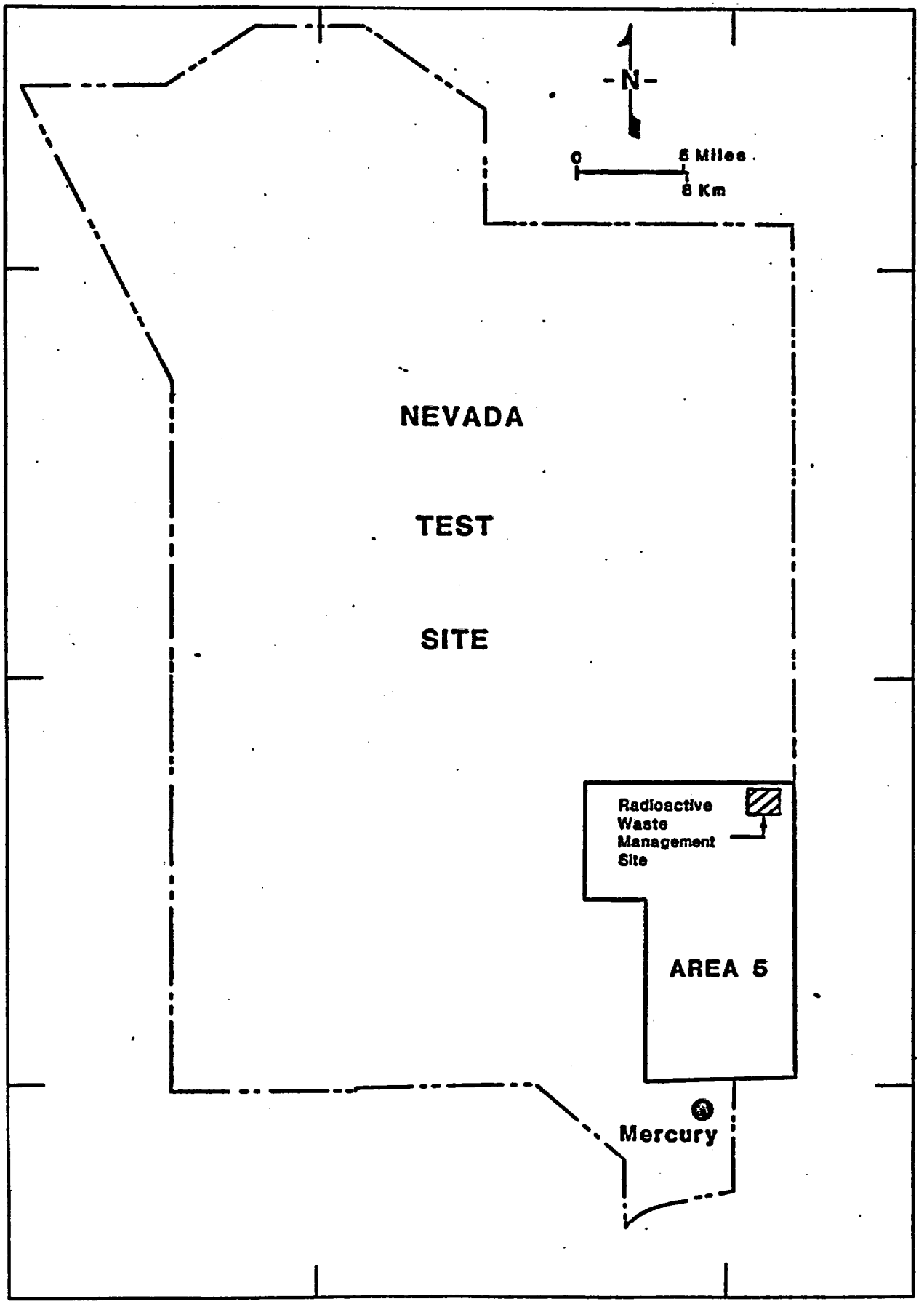

FIGURE 2: Location of the Radioactive Waste Management Site and Area 5 on the Nevada Test Site

observations regarding the alluvial fans on which the RWMS is located are summarized. In the fifth section, the results of the third and fourth sections are used in conjunction with hypotheses regarding flood processes on alluvial fans to assess flood hazard to the RWMS. The final section summarizes the preliminary conclusions and recommendations of the flood hazard assessment study.

REGIONAL ANALYSIS OF STREAMFLOW CHARACTERISTICS:

BACKGROUND

Regional analysis of streamflow characteristics is a methodology for extending stream gaging records in space as opposed to time. Because of the limited resources available - time, money, and manpower - streamflow records are only available at a few of the many sites at which such data are required. Many areas of the arid southwest, for example the Nevada Test Site, lack actual streamflow measurements. Thus, the regional analysis of streamflow characteristics is a technique for analyzing streamflow characteristics on a regional basis using existing data and then synthesizing records for sites where there are no data. Note, this type of analysis tacitly assumes that the region under consideration is homogeneous from the hydrologic viewpoint.

A number of methods are available for developing regional analyses of peak flood discharges for a specified return period. Dalrymple (1960) defines and describes what is termed the index flood method. Riggs (1973) describes a multiple regression method which has the advantage of directly relating the discharge of a specified return period to fundamental basin characteristics and leaving residuals that may be considered due to chance. The regression relationship averages these residuals; and in theory, includes in one set of computations, the effects on discharge of different basin characteristics and averages the variations due to chance, Riggs (1973). In practice, the interpretation of the results of a regional regression analysis is not quite so evident because all of the effects of variability due to basin characteristics are not described by regression. Thus, the residuals have both a component due

to basin variability and a component due to chance variation. The relative magnitudes of these components are not known.

At this point, a paradox regarding the regression method of analysis should be noted. If the data used for the regression analysis are not independent, then the regression relationship developed will likely be biased; but the chance variation will be small; and consequently, the standard error of regression may also be small. However, if the data used are independent, then the regression relationship developed will be unbiased, the chance variation will be large, and the standard error of regression will also be large. Thus, the accuracy of a regional streamflow analysis by the regression method should not be measured in terms of the standard error of estimate alone, Riggs (1973).

The model commonly used in regional regression studies is

$$Q_T = CX_1^{\theta_1} \; X_2^{\theta_2} \; --- \; X_n^{\theta_2} \quad (1)$$

or transforming to a logarithmic coordinate system

$$\text{Log } Q_T = \text{Log } C + \theta_1 \text{ Log } X_1 + \theta_2 \text{ Log } X_2 + --- + \theta_n \text{ Log } X_n \quad (2)$$

where Q_T = peak flood discharge usually in cubic feet per second with a return period of T time units, usually years; $C, \theta_1, \theta_2, ---, \theta_n$ = n regression coefficients, and $X_1, X_2, ---, X_n$ = n hydrologic variables describing the basin. The independent variables; i.e., the X_i are usually determined from either field measurements or from topographic maps. The dependent variables, i.e., the Q_T, result from a flood frequency analysis, see for example Anon. (1977), at a

gaging station with reliable records. The selection of the independent variables X_i is usually done on a statistical basis; i.e., many parameters are initially used, but as the regression procedure proceeds on a step wise regression basis those without statistical significance are discarded. Table 1 summarizes a number of independent variables used in ten regional flood frequency analyses.

The foregoing material is not intended to be a comprehensive treatment of regional regression methods for estimating flood peaks. Rather, it is intended to provide the reader with a brief introduction to the concept, provide some discussion of the problems associated with the methodology, and introduce the subsequent sections of this report. For additional discussion of regional regression methods, the reader is referred to Riggs (1973).

TABLE 1

INDEPENDENT VARIABLES USED IN 10 REGIONAL FLOOD-FREQUENCY ANALYSES, RIGGS (1973)

Variable	1	2	3	4	5	6	7	8	9	10
Drainage area	X	X	X	X	X	X	X	X	X	X
Main-channel slope	X	X	X	X	X					
Percentage of basin covered by lakes and swamps	X		X	X				X	X	
Mean annual precipitation		X					X		X	X
Mean annual runoff								X		
T-year 24-hour rainfall	X		X							
Average degrees below freezing in January	X									
Orographic factor	X									
Elevation		X								X
Number of thunderstorm days		X	X							
Main-channel length			X							
Ratio of runoff to precipitation			X							
Mean annual snowfall				X						
Average number of wet days per year					X					
Shape factor						X				
Geographical factor								X	X	

ALLUVIAL FANS:

BACKGROUND

INTRODUCTION

Frenchman Flat, Area 5 of the NTS, is covered by alluvium in the form of alluvial fans and a playa lake (Frenchman Lake). Alluvial fan material comprises the majority of the surface area of Frenchman Flat. As the dominant landform in the valley, it is necessary to examine alluvial fans from a geological standpoint to understand their role in sediment and surface water transport, especially during flash floods.

An alluvial fan is a fan or cone-shaped deposit of sediment found at the base of some mountain fronts, Figure 3. Many definitions of alluvial fans can be found in literature, see for example: Anstey (1965), Bull (1977), and Rachocki (1981).

In the past 30 years information on alluvial fans has proliferated. Important studies have been made by Bull (1961, 1962, 1964a, 1964b, 1964c, 1977), Beaty (1963, 1970), Denny (1967), Hooke (1965, 1967, 1968), and Rachocki (1981), to name a few. Excellent summaries of studies on alluvial fans can be found in Anstey (1965), Bull (1977), and Rachocki (1981). Anstey, Bull, Denny, and others have devoted much of their attention to the qualitative and quantitative aspects of natural fans. Hooke and Rachocki have tried to simulate natural conditions to create fans in both the field and laboratory.

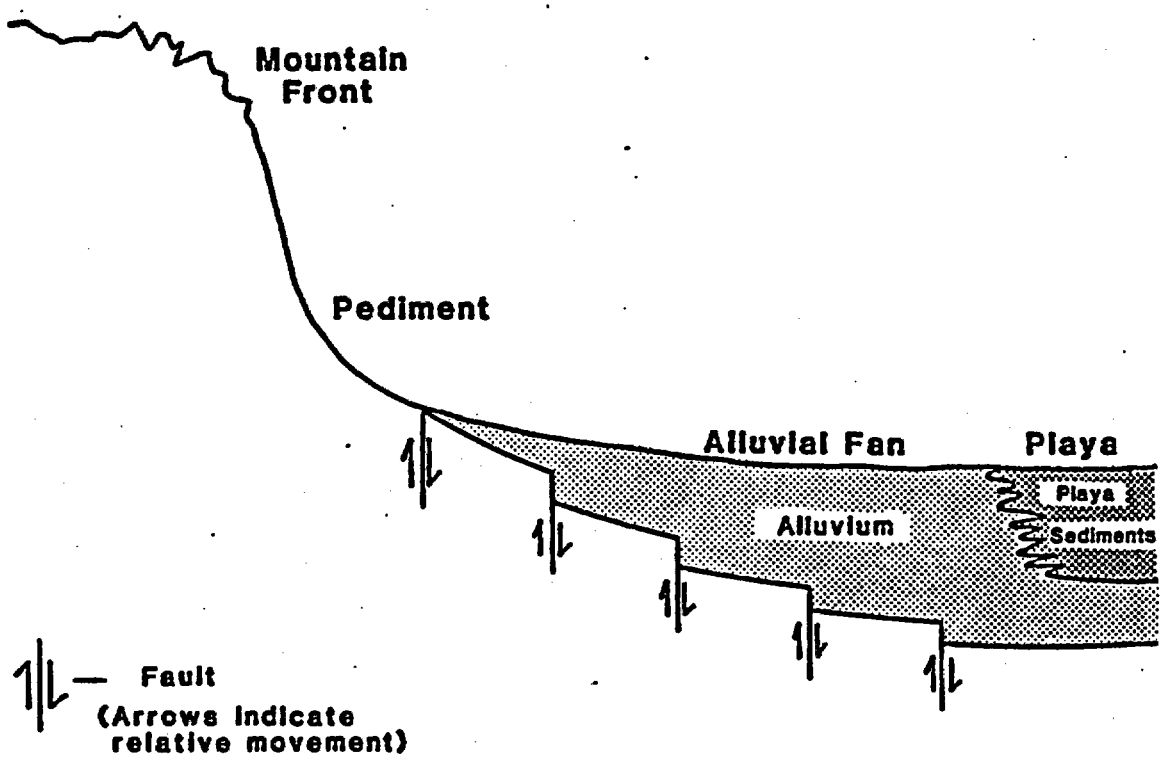

FIGURE 3: Generalized Features of a Mountain-Basin System

ALLUVIAL FAN FORMATION

Alluvial fans are formed by water transporting debris from inter-mountain canyons into adjacent valleys. A scenario for alluvial fan deposition (based on Beaty, 1963) in the desert southwest might be as follows:

> Debris accumulates along the flanks of mountains due to weathering. Accumulation may occur over a period of time, especially where rainfall is not frequent. When an intense rainfall event occurs, such as a summer thunderstorm, debris is transported downslope into an inter-mountain canyon. The water/sediment mixture will travel until it reaches a point where the canyon enters a valley; this point is called the apex. The widening of flow at this point results in a decrease in depth of flow, velocity, and sediment carrying capacity. The sediment is deposited at the apex and downslope from it, usually as debris-flow deposits. Through time, a series of depositional events cause the fan to aggrade and giving it its characteristic shape.

Although alluvial fans are also found in humid areas such as the southeastern United States (Anstey, 1965) and the recently glaciated terrain of Poland (Rachocki, 1981) and Australia (Wasson, 1977), they are primarily features associated with arid climates such as the southwestern United States and West Pakistan (Anstey, 1965). Most researchers attribute alluvial fan formation to climatic and/or geologic features associated with arid regions. Rachocki, however, attributes the abundance of fans in arid regions to excellent preservation rather than unusually favorable conditions for formation. He noted that many of the large fans in the southwestern United States were formed during the more humid (pluvial) conditions of the Pleistocene and that recent aggradation rates have slowed considerably.

Cooke and Warren (1973) discuss factors which they hypothesize may explain alluvial fan formation. These include: geometry and direction of mountain drainage systems related to the receiving lowlands, and small ratio of depositional area to source area.

Characteristics common to alluvial fans worldwide have been described by Bull (1977, p. 225):

> "They occur in areas of decreased confinement of streamflow. Generally, they form as a result of base-level fall of the depositional area relative to the source area. Erosional base-level falls tend to result in temporary thin fans and tectonic base-level falls tend to result in prolonged accumulation of thick fans. Deposition occurs as a result of the stream being unable to transport its load through the reach where the fan accumulates, either because of the decrease of confinement of streamflow or because of changes in the sediment load being supplied to the stream from the hillslopes of the source area."

TECTONICS AND ALLUVIAL FANS

The alluvial fan is a significant landform in the arid regions of the world. Anstey (1965) notes that the Basin and Range region has a large number of alluvial fans. Death Valley and adjacent portions of Nevada (including the NTS) have the highest concentration of fans in the United States. That the Basin and Range is a tectonically active region has much to do with fan formation and growth. Anstey (1965) found alluvial fans were most common in folded or faulted

mountains of low relief. Bull (1977, p. 248) states the following:

> "Thick alluvial fans are orogenic deposits, not only because uplift creates mountainous areas that provide debris and increased stream competence, but also because the loci of deposition on alluvial fans are controlled by the rate and magnitude of uplift of the adjacent mountains."

Alluvial fans are generally concave in profile and convex in cross-section. This is due to decreasing slope as sediments are transported and deposited away from the apex, and to the gradual lateral thinning of sediments toward the fan edges.

Bull (1964b) demonstrated that fan slopes may reflect tectonic events. By plotting the slopes of alluvial fans from the San Joaquin Valley, he found that in some areas fans had segmented instead of smooth profiles. The slope of the segments increased towards to the apex, suggesting that periodic uplift of the source area had occurred and at a rate greater than the downcutting of the stream channel.

SEDIMENT TRANSPORT

Sediment transport on alluvial fans takes place as either stream or debris flow. Streamflow appears to be the more important agent in areas where annual precipitation is high (Hooke, 1965). Blissenbach (1954) suggested that the ratio of debris flow to streamflow deposition increases with decreasing rainfall. Both types of flow can be expected to occur on alluvial fans in the Basin and Range province.

Stream transport involves water moving sediment in suspension or traction, depending on the carrying capacity of flow. The sediment load increases with increasing volume and velocity. A decrease in the sediment carrying capacity of a stream results in deposition of sediment to re-establish equilibrium. Likewise, an increase in the sediment carrying capacity of a stream will result in erosion of the stream bed. Typical streamflow features on alluvial fans are channels, rills, and sheetflow. Sediments deposited by stream processes are generally thinly bedded and exhibit graded bedding and sorting of particles downslope.

Debris flows are an intimate mixture of water and sediment. They generally have a matrix of fine particles (clay and silt) and can entrain very large particles, even boulders. Hooke (1965) gives a good summary of the characteristics of debris flows. He distinguishes between debris and streamflow in the following:

> "Whereas streams vary their sediment load readily by deposition or erosion and will continue to flow as long as a slope exists, debris flows cannot selectively deposit any but the coarsest fragments. This means that a debris flow cannot turn into a streamflow by deposition. Both types of flow are formed by water moving over and entraining loose sediment, but at some point sediment entrainment becomes irreversible," (Hooke, 1965, p. 38).

Debris flows are viscous as compared to streamflows and deposit thick, lobate masses of sediment with well-defined edges. Debris flow deposits are poorly graded, sorted, and are easily distinguished from stream deposits. In many alluvial fans, debris and stream deposits are interbedded.

Hooke (1965) attributed the formation of debris flows to intense episodic rainfall, unconsolidated fine material, sparse vegetative cover, and reasonably steep slopes. This view is supported by Bull (1977) and Beaty (1963). Beaty (1974) subsequently noted in his work regarding debris flows in the White Mountains of California and Nevada that debris flows can also be generated by snowmelt.

Some researchers believe that debris flows are the principal mode of transport for coarse alluvium on fans, Beaty (1963, 1970) and Hooke (1965). "Alluvial fans of the White Mountains and by analogy, those of other Great Basin ranges, appear not to have been built by the ordinary processes of stream deposition. Instead, spectacular episodes of debris-flow deposition have been irregularly interspersed with periods of quiescence...," Beaty (1963, p. 535).

Hooke (1967) has suggested that debris flow deposition is generally limited to the upper portion of alluvial fans. This is due to constraints imposed by the volume, yield strength of the flow, the slope of the fan, and "the degree to which existing channels prevent lateral spreading at the fan head." The less viscous the flow, the farther downslope it will travel. Beaty (1963, 1974) provides excellent examples of recent and old debris flows, including eyewitness accounts.

CHANNELS AND CHANNEL ENTRENCHMENT

Packard (1974) found the following sequence of stream characteristics on an alluvial fan in Southern Arizona: flow in braided channels, complex channel flow, sheetflow, and rillflow entering headcut channels at the toe of the fan (from Bull, 1977).

The point where channel flow changes to sheetflow is known as the intersection point (Hooke, 1965). This point of intersection occurs where the slope of the channel merges with the slope surface of the fan, Figure 4. Water and sediment continue downslope as surface flow.

A common characteristic of alluvial fans is the entrenchment of a channel near the fan apex (fanhead trench). Channel entrenchment occurs when erosion rather than deposition occurs near the apex. This can happen in several ways:

1) Uplift of the source area in relation to the fan promotes active erosion of the apex, Bull (1977), and Denny (1967).

2) Climatic changes such as "...increasing storm frequency, increasing storm intensity, increasing total precipitation, and decline of total precipitation with increased storm intensity ..." (Cooke and Warren, 1973, pp. 185) may result in the erosion of a channel at the apex.

3) Temporary events such as a large-scale flood may cause the scouring of a channel, Beaty (1963, 1970) and Denny (1967).

4) An "alternation of debris flows and water flows" may cause entrenchment early in the development of a fan, so that fans in a sense are "born incised" (Hooke, 1967, pp. 457).

Bull (1964a) presented convincing evidence that channel entrenchment in alluvial fans in Fresno County, California, occurred during periods of increased rainfall. Bluck (1964)

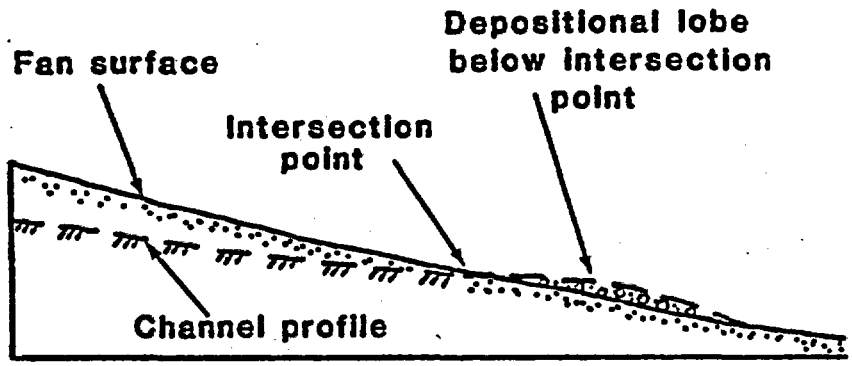

FIGURE 4: Idealized Sketch of Intersection-Point Relationships (Hooke, 1967)

hypothesized that channel entrenchment in Arrow Canyon, Clark County, Nevada, occurred when debris-flow deposition changed to stream type deposition, although an explanation for this change was not offered. Hooke's (1967, pp. 457) simulations of alluvial fan growth in the laboratory give evidence that channel entrenchment may occur when water flow succeed debris flows, a condition noted by others (Beaty, 1963 and Anstey, 1965) in eyewitness accounts of debris flows and floods.

Although erosional processes are evident in the formation of a fanhead trench, this is balanced by re-deposition of the channel material further downslope. Coarse material originally deposited near the apex is scoured during channel entrenchment and transported downslope where it is deposited on finer sediments. Fanhead trenches act as conduits for material entering the fan from the apex. The result: coarse sediment deposition is shifted downslope.

A fanhead trench is not always a permanent feature. In many cases channels may shift and backfill older trenches. Bull (1977, p. 233) distinguishes between a "temporary" and a "permanently" entrenched stream:

> "Some streams are permanently entrenched, and may have channel bottoms that are as much as 50 m (160 ft.) below a fan surface with an old soil profile. Other fanhead trenches appear to be temporary, being less than 15 m (50 ft.) below a fan surface having no visible soil profile; and having been entrenched and backfilled one or more times before the present channel down-cutting."

The balance between erosion and deposition on an alluvial fan affects its shape significantly. The tendency

for sediment laden streamflow, or a debris flow, is to spread out when it passes the apex or fanhead trench. On small fans, a flood may completely cover the fan surface causing aggradation downslope and outward in a uniform manner. On large fans, flow may not cover the entire fan surface; and therefore, fan aggradation will not be uniform.

On the upper fan, flow direction is determined by the channels, or fanhead trench, which also influence the direction of downslope movement. If the sediment load of a stream or debris flow is dropped abruptly in the channel, the channel may be blocked and subsequent flow diverted around it. In this manner, a channel or fanhead trench may be backfilled and a new channel created. A slight change in flow direction on the upper fan may dramatically change the direction of flow and deposition downslope.

The diversion of flow by sediment blockage is a common phenomena on alluvial fans. This process causes a fan to grow in a haphazard manner, Figure 5. The random pattern of aggradation gives an alluvial fan its fan-like appearance. It also means that flow can occur in any direction on the fan downslope from the apex or intersection point, making predictions of flash-flood paths difficult.

LITHOLOGY, SEDIMENT CHARACTERISTICS, AND FAN MORPHOLOGY

Physical characteristics of sediments play an important role in determining the size and shape of alluvial fans. Bull (1962, p. 51) stated:

> "... on average, fans derived from drainage basins characterized mainly by mudstone and shale are roughly

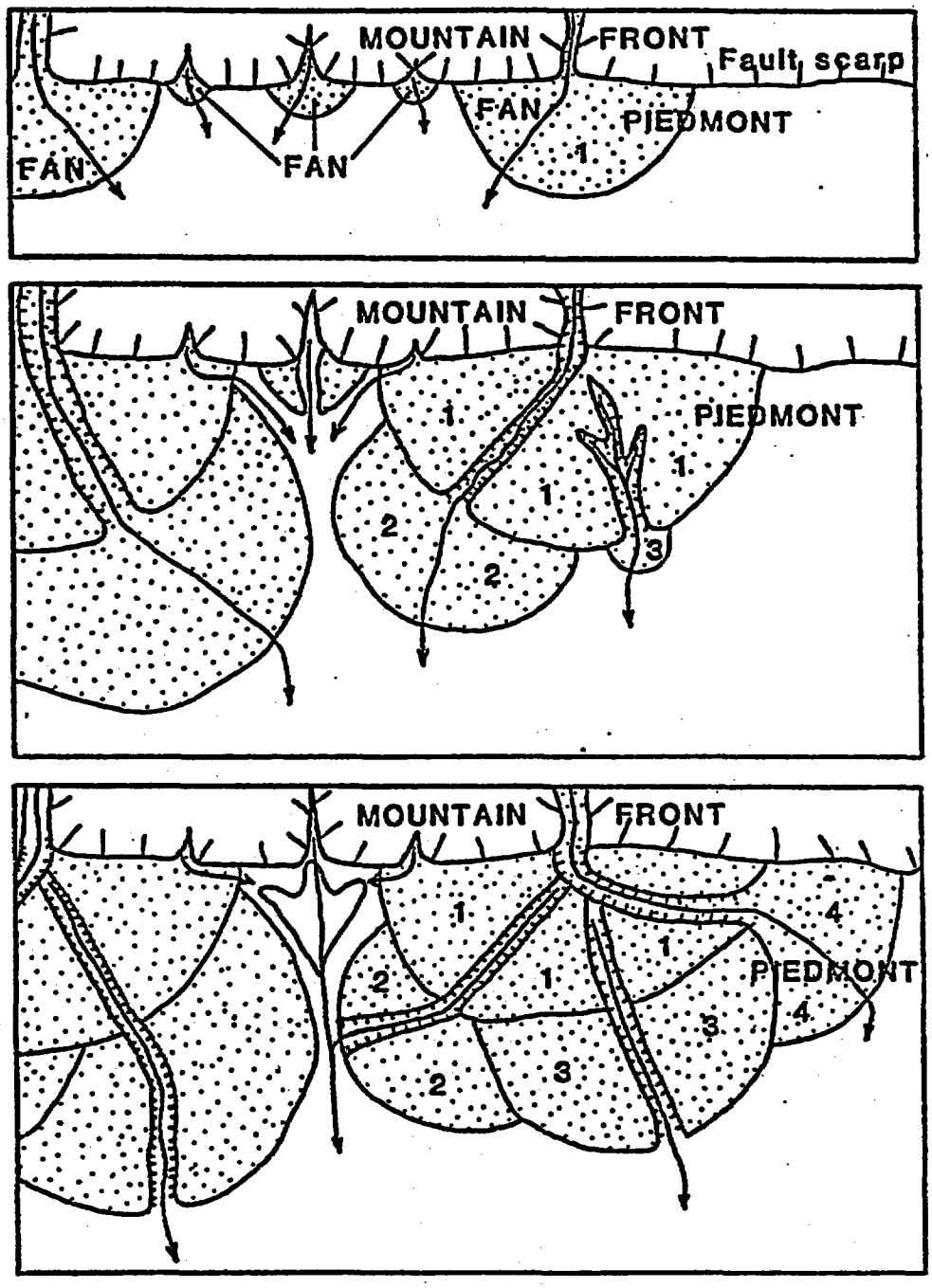

FIGURE 5: Development of Alluvial Fans (Denny, 1967)

twice as large as the fans derived from drainage basins of comparable size characterized mainly by sandstone."

Bull also found that fan deposits derived from mudstone and shale were thicker and had steeper slopes. He attributed this difference to the susceptibility of mudstone and shale to erosion.

Fans composed of sedimentary and volcanic alluvium have lower slopes than those of metamorphic origin (Hooke, 1965). Hooke suggested this difference was due to particle size of the various rock types. Alluvium from metamorphic rocks is generally coarser than that of volcanic and sedimentary origin. Larger particles have a higher angle of repose, resulting in fans with steeper slopes.

The roughness of a fan surface is determined by particle size distribution of the alluvium. According to Anstey (1965) alluvium of granitic origin tends to be coarser than that of sedimentary or metamorphic origin. An increase in surface roughness changes the flow hydraulics and results in a decrease of channel scouring.

As was mentioned earlier, particle size plays a role in the type of flow regime which occurs on an alluvial fan. Hooke's (1965) studies showed an abundance of silt and clay is necessary for debris flows. During fieldwork on alluvial fans in eastern California, Hooke found fans with source areas composed of rocks like quartzite and dolomite showed little evidence of debris flows. On fans composed of granitic rocks (containing feldspars which decompose to form clays) and easily erodible sedimentary rocks such as shale or sandstone, debris flows appeared to be responsible for much of the deposition.

Unfortunately, little work has been done on fans in volcanic terrains. However, since volcanic rocks generally contain feldspar, it can be assumed that they will provide sufficient clay (due to weathering) to promote debris flows.

DEPOSITION RATES AND THE AGE OF ALLUVIAL FANS

Alluvial fans are depositional features which can be active for long periods of time. The rates of aggradation on large fans may seem very slow when averaged over the entire fan surface. Major depositional events, however, may affect only a portion of a fan during any one event, so the amount of material deposited during an event may be many times the average rate for the fan as a whole.

Many of the large alluvial fans in the southwestern United States are thought to be of Pleistocene age. Bull (1964c) put a tentative age of 600,000 years on the Arroyo Ciervo Fan in the San Joaquin Valley and Beaty (1970) dated the Milner Creek Fan in the White Mountains at 700,000 years.

The Milner Creek Fan contains an estimated 2.9 x 10^{10} cubic feet of sediment and is still growing at the rate of 3 to 6 inches per thousand years. Bull believes the Arroyo Ciervo Fan to be 700 to 900 feet thick with calculated average accretion rates of 0.11 to 0.7 feet per decade for different parts of the fan.

Blissenbach (1954) and Bull (1964b) measured debris flows with apex to toe thicknesses of 20 feet to 1 foot and 1.6 to 0.3 feet respectively. Alluvium deposited by streamflow may range from a fraction of an inch to several feet.

In many cases erosion occurs with deposition during a flood event. Anstey (1965) reported on the destructive nature of an alluvial fan flash flood in Death Valley which deposited 4 feet of alluvium in some areas and scoured deep (6 to 8 feet) channels in other parts of the fan. Boulders up to 6 feet in diameter were moved in one channel. Hooke (1965) related a similar story for a flash flood near the Wasatch Range in Utah. Beaty (1963) described a flash flood in the White Mountains which consisted of a debris flow lasting approximately one hour, followed by up to 48 hours of high streamflow.

Fans which have not had new material deposited on their surfaces for 1,000 to 1,000,000 years may have established soil profiles and a veneer of desert varnish (Bull, 1977). Most often the upper fan surfaces adjacent to a fanhead trench will be old as new deposition occurs below the channel. Old fan surfaces may be dissected by dendritic erosional channels which coalesce into headcuts near the toe of the fan. Abandoned fanhead trenches may be partially filled by material eroding from the edges of the channel.

DEVELOPMENT AND APPLICATION OF REGIONAL PEAK FLOOD FLOW METHODS IN NEVADA AND ARIZONA

Christensen and Spahr (1980) evaluated the flood potential of Topopah Wash and its tributaries in the eastern part of Jackass Flats, on the Nevada Test Site, using a regional peak flood flow analysis. The equations used in this study are summarized in Table 2 where Q_T = peak flood flow in cubic feet per second with a return period of T years, A = drainage area in square miles, E = mean basin elevation in thousands of feet, and L = latitude of the basin minus 35° latitude. With regard to these equations, Christensen and Spahr (1980) made the following comments:

1. The equations in this table were developed by U.S. Geological Survey personnel in Carson City, Nevada, for use in Nevada.

2. These equations were developed from a data base composed of 71 gaged basins.

3. Of the 71 basins used in the analysis, only 19 basins were located in Southern Nevada and none were in the vicinity of Topopah Wash.

Since a regional regression relationship for the peak flood flow with a return period of 500 years was not available, Christensen and Spahr (1980) estimated this flow by plotting the computed 10, 25, 50 and 100 year discharges on a log-probability graph and extrapolating to estimate the five hundred year flood.

Christensen and Spahr (1980) estimated the maximum potential flood for the Topopah Wash area from the envelope

TABLE 2

SUMMARY OF THE REGIONAL PEAK FLOW EQUATIONS
USED BY CHRISTENSEN AND SPAHR (1980) FOR TOPOPAH WASH

Equation	Standard Error of Estimate in Percent (derived from log units)*	Limits of Applicability
$Q_{10} = 392\ A^{0.66}\ E^{-1.02}\ L^{-0.33}$	120	$0.2<A<100$
$Q_{25} = 1810\ A^{0.61}\ E^{-1.14}\ L^{-0.70}$	120	$2<E<10$ $1<L<7$
$Q_{50} = 4860\ A^{0.58}\ E^{-1.21}\ L^{-0.94}$	140	
$Q_{100} = 11900\ A^{0.55}\ E^{-1.28}\ L^{-1.16}$	160	

* Note, in the Christensen and Spahr report these numbers were reported in log units. These numbers have been converted for comparison with corresponding numbers in Table 4 using the methodology given by Riggs (1968).

curve developed by Crippen and Bue (1977) or Crippen (1982) for this area. The envelope curve, Figure 6, hypothesizes a relationship between maximum flood flow and drainage basin area. The curve in Figure 6 is based on six discharges in Nevada, Utah, Arizona, and New Mexico, Table 3. With regard to the envelope curve in Figure 6, the following observations are noted:

1. With the passage of time, floods may occur which will be above the envelope curve shown.

2. From the relation plotted, it is clear that the discharge per square mile decreases as the drainage area increases. Christensen and Spahr (1980) assert this is due to the fact that there is a limit to storm size and the proportion of storm size to drainage area decreases as the size of the drainage area increases.

3. The maximum potential flood has no reference to recurrence interval.

Note: Some authors have suggested techniques for associating return periods with discharges predicted by Figure 6; see for example, Mimikou (1984), but in this report no attempt to do this will be made.

Roeske (1978) developed regression equations for estimating flood magnitudes at ungaged sites for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years for six flood frequency regions in Arizona, Figure 7. These equations were based on annual peak discharge data collected at 221 gaging stations having 10 or more years of record. Roeske (1978) specifically noted that the equations presented

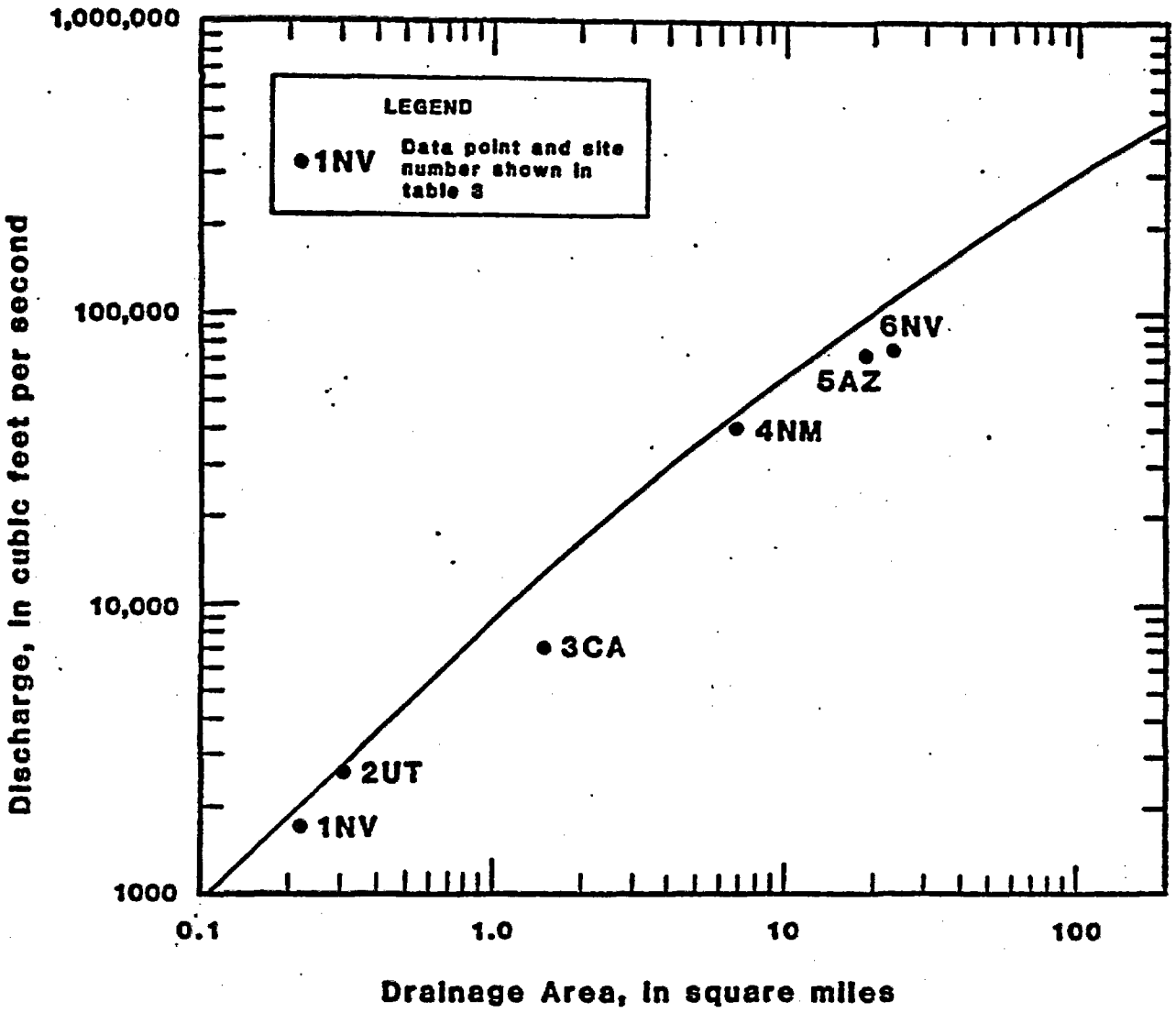

FIGURE 6: Maximum Discharge as a Function of Drainage Area (Christensen and Spahr, 1980)

TABLE 3

MAXIMUM OBSERVED DISCHARGES AT SIX SELECTED SITES IN ARIZONA, CALIFORNIA, NEVADA, NEW MEXICO, AND UTAH, CHRISTENSEN AND SPAHR (1980)

Site no. in Figure 6	Location	Drainage area (mi^2)	Date	Discharge Peak (ft^3/s)	Discharge Unit [$(ft^3/s)/mi^2$]
1NV	Lahontan Reservoir Tributary no. 3 near Silver Springs, Nevada	0.22	7-20-71	1,680	7,640
2UT	Little Pinto Creek tributary near Newcastle, Utah	.30	8-11-64	2,630	8,770
3CA	Arch Creek near Earp, California	1.52	8-19-71	7,160	4,710
	Pojoaque, New Mexico	6.70	8-22-52	44,000	6,570
5AZ	Bronco Creek near Wikieup,				

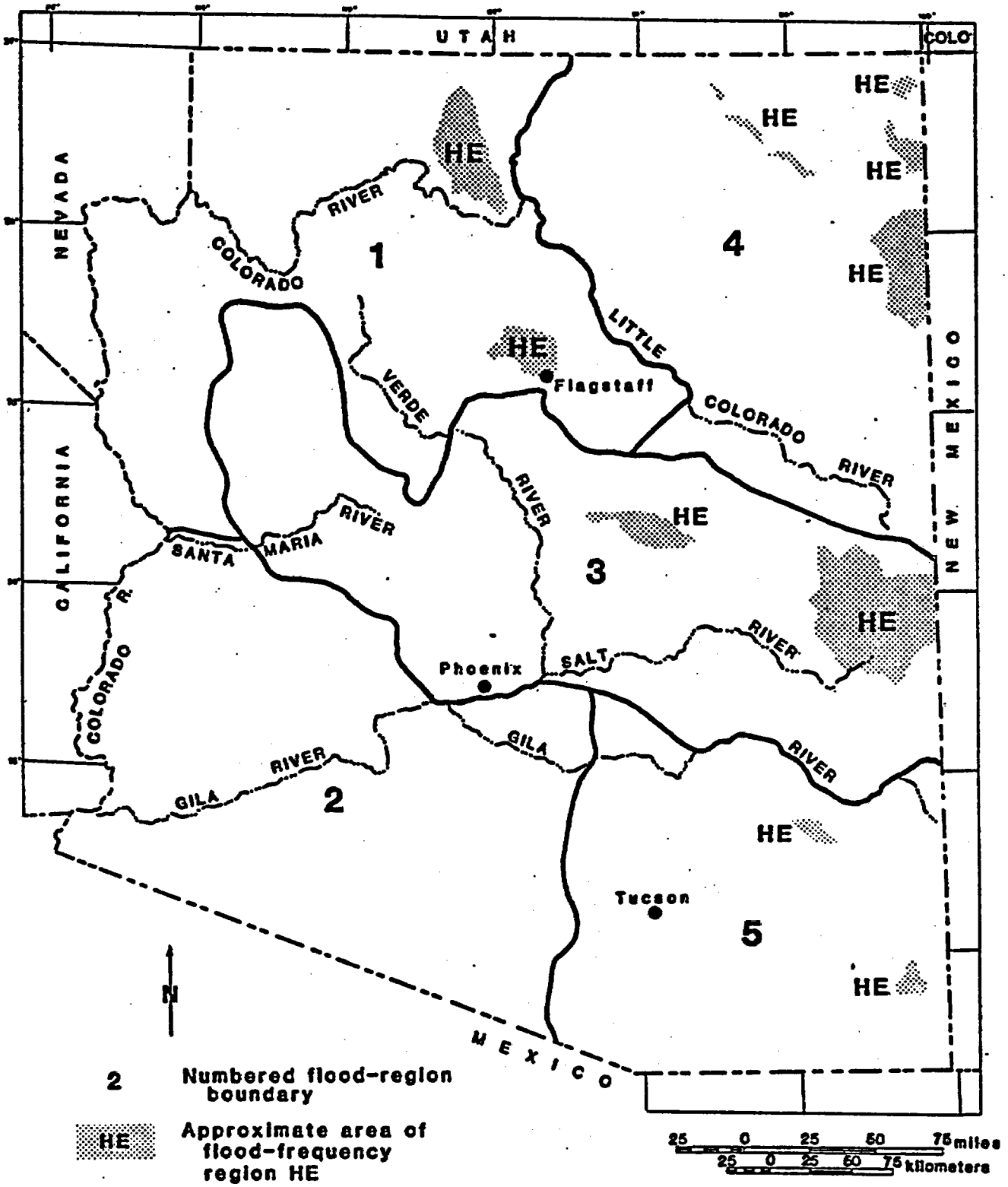

FIGURE 7: Arizona Flood Frequency Regions (Roeske, 1978)

in his analysis applied only to streams not significantly affected by regulation, diversion, or urbanization.

Of the equations developed by Roeske (1978), two sets may be relevant to flood studies on the Nevada Test Site: Region 1, Figure 7, which is conterminous with Southern Nevada, and Region 2, which although it is geographically removed from Southern Nevada in many ways, more closely resembles the Nevada Test Site than Region 1. For example:

1. The average annual precipitation in Region 2 (Arizona) ranges from 3 to 12 inches and in Region 1 (Arizona) ranges from 6 to 25 inches. The average annual precipitation at the Well 5B and Cane Spring stations, both of which are in the vicinity of the RWMS is 4.6 and 7.8 inches respectively.

2. Elevations in Region 2 (Arizona) are on the order of 500 to 3,000 feet while those in Region 1 (Arizona) are on the order of 3,000 to 10,000 feet. Frenchman Flat, on the Nevada Test Site, is at an approximate elevation of 3,100 feet while the surrounding mountains rise to 5,000 feet.

3. The surficial geology of Region 2 (Arizona) consists primarily of Quaternary sedimentary deposits with some exposed volcanic flows, tuffs, and intrusives. Region 1 (Arizona) is characterized primarily by Permian limestone deposits. The surficial geology of the area in the vicinity of the RWMS and in the valley, is typified by Quaternary sediments, Tertiary volcanic tuffs and ash flows, and Paleozoic carbonates and quartzites.

The regression equations for peak flood flows with a specified return period developed by Roeske (1978), for Arizona Regions 1 and 2, are summarized in Table 4.

With regard to the regional peak flood flow studies of Christensen and Spahr (1980), and Roeske (1978), the following comments should be considered:

1. French (1983) hypothesized that the portion of Nevada south of latitude 38.5 degrees can be divided into zones of excess and deficit precipitation, separated by a rather indefinite transition region, Figure 8. If it is assumed that annual average precipitation is correlated with peak flood flow, then it follows from the hypothesis of French (1983) that some areas of Nevada will experience more severe flooding than others. Further, it would then be inappropriate to treat Southern Nevada as a single hydrologic unit from the perspective of flood hazard. It may also be inappropriate to assume that Southern Nevada is hydrologically similar to Arizona.

2. The Christensen and Spahr (1980) report does not enumerate the stations which composed the data base from which their regression equations were derived. Since these equations are said to apply to Nevada, it must be assumed that all stream flow records in Nevada were used. Given the distribution in both space and time of the Nevada stream flow data, this would suggest that the regression equations in Table 2 are biased by the large number of perennial rivers in Northern Nevada. This possible bias is not discussed by Christensen and Spahr (1980).

TABLE 4

SUMMARY OF THE REGIONAL PEAK FLOW EQUATIONS
DEVELOPED BY ROESKE (1978)

Arizona, Region I		Arizona, Region II	
Equation (based on 17 stations)	Standard Error of Estimate in Percent (derived from log units)	Equation (based on 26 stations)	Standard Error of Estimate in Percent (derived from log units)
$Q_2 = 19.0\ A^{0.660}$	93	$Q_2 = 87.0\ A^{0.433}$	76
$Q_5 = 66.3\ A^{0.600}$	81	$Q_5 = 218\ A^{0.462}$	53
$Q_{10} = 127\ A^{0.566}$	80	$Q_{10} = 352\ A^{0.475}$	53
$Q_{25} = 252\ A^{0.532}$	83	$Q_{25} = 586\ A^{0.487}$	62
$Q_{50} = 393\ A^{0.510}$	86	$Q_{50} = 815\ A^{0.494}$	72
$Q_{100} = 584\ A^{0.490}$	91	$Q_{100} = 1100\ A^{0.499}$	83
$Q_{500} = 1300\ A^{0.451}$	105	$Q_{500} = 2000\ A^{0.509}$	111

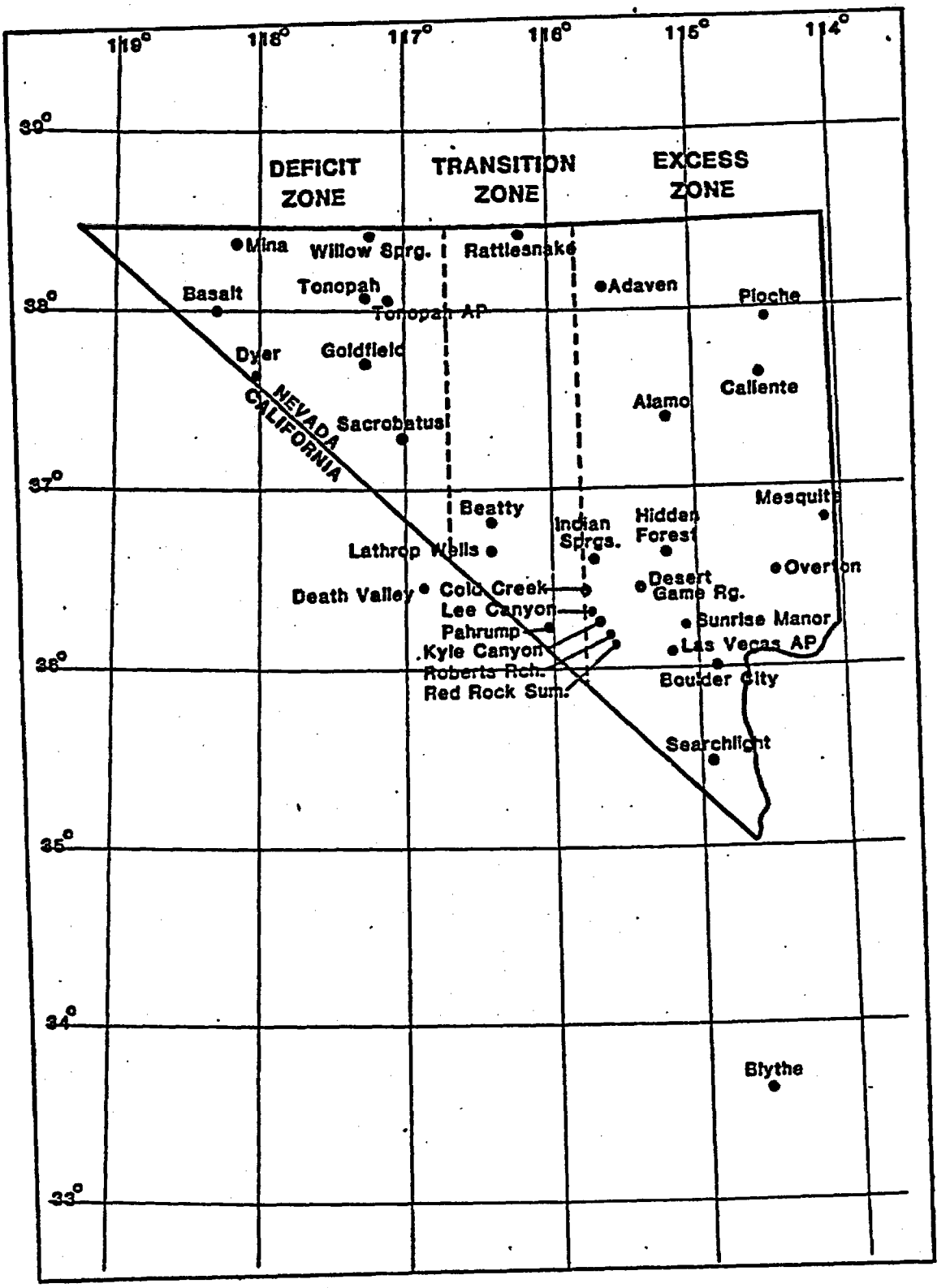

FIGURE 8: Hypothesized Zones of Precipitation in Southern Nevada (French, 1983)

3. Stream flow data for Southern Nevada can generally be characterized as being sparse, poorly distributed, and of short duration. Thus, it is not likely that regression equations developed for only Southern Nevada would be more accurate than those presented by Christensen and Spahr (1980).

APPLICATION TO RADIOACTIVE WASTE MANAGEMENT SITE

With reference to Figure 9, it is asserted that five watersheds present a possible flood hazard risk to the RWMS in Area 5 of the NTS. The pertinent physical characteristics of these watersheds, above elevation 3,500 feet, are summarized in Table 5. With regard to drainage area, three of the watersheds are relatively small while two are relatively large. There is only a slight variation in the average elevation of these watersheds and essentially no variation in their latitude.

In Table 6, the peak flood flow of a specified return period associated with each of the watersheds is estimated by the equations stated by Christensen and Spahr (1980) and developed by Roeske (1978). The data summarized in Table 6 are plotted in Figures 10, 11, 12, 13, and 14 which are in Appendix I. With regard to these figures the following observations are noted:

1. In all cases the Roeske (1978) Arizona Region 2 equations predict the largest peak flood flows.

2. Except for short return periods, $\leq$ 25 years, the Roeske (1978) Arizona Region 1 equations predict the smallest peak flood flows.

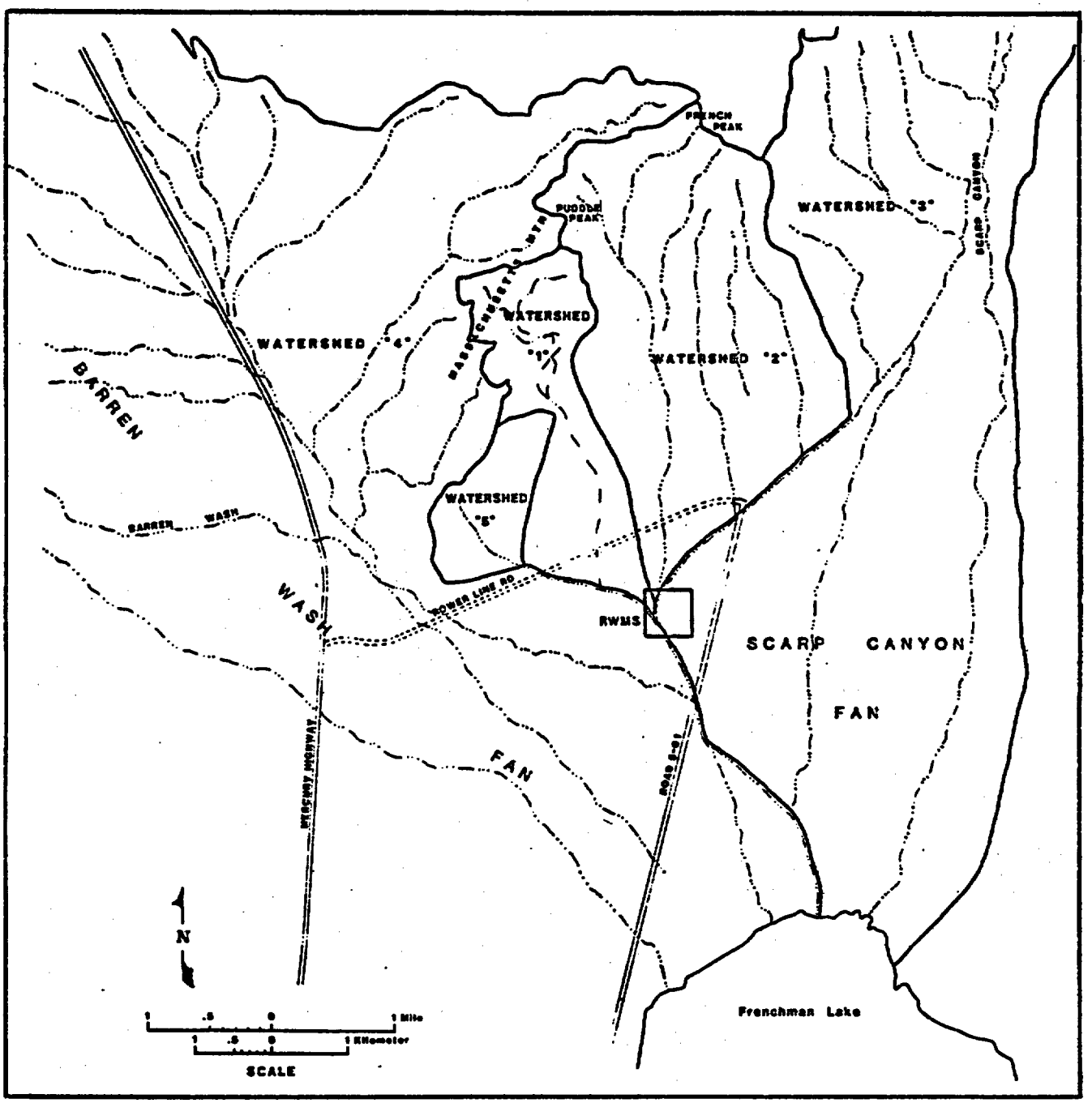

FIGURE 9: Watersheds and Alluvial Fans Surrounding the RWMS

TABLE 5

SUMMARY OF PERTINENT PHYSICAL CHARACTERISTICS OF WATERSHEDS ABOVE THE RADIOACTIVE WASTE MANAGEMENT SITE

All data apply to the portion of the watershed above the 3,500 ft. contour.

Watershed	Area mi^2	Average Elevation ft	Latitude degrees
1	1.23	3,840	36.9
2	3.45	4,030	36.9
3	42.1	4,510	37.0
4	90.7	4,750	36.9
5	0.38	3,665	36.9

TABLE 6

SUMMARY OF PEAK FLOOD FLOWS OF VARIOUS RETURN PERIODS

	Peak Flood Flow by Nevada Equations					Peak Flood Flow by Arizona Region 1 Equations					Peak Flood Flow by Arizona Region 2 Equations				
	Watershed					Watershed					Watershed				
Return Period	1	2	3	4	5	1*	2	3	4	5*	1	2	3	4	5
10	92	173	792	1268	45	—	256	1055	1629	—	388	634	2080	2995	222
25	285	502	1959	3058	147	—	487	1843	2773	—	648	1071	3621	5264	366
50	594	1010	3582	5512	320	—	739	2647	3916	—	903	1503	5170	7555	509
100	1146	1876	6058	9179	641	—	1071	3650	5317	—	1220	2041	7110	10430	679
500	3020	5300	15800	23800	1860	—	2272	7022	9928	—	2222	3756	13420	19838	1222

* Region 1 equations cannot be used because the drainage area is less than 1.84 square miles.

3. Except for short return periods, $\leq$ 25 years, the equations used by Christensen and Spahr (1980) predict peak flood flows greater than those predicted by the Roeske Arizona Region 1 equations and less those predicted by the Roeske Arizona Region 2 equations.

4. For short return periods the equations used by Christensen and Spahr (1980) often predict peak flows greater than those predicted by the Roeske Arizona Region 1 equations.

The maximum potential flood event for each watershed, estimated from Figure 6, is given in Table 7.

TABLE 7

MAXIMUM POTENTIAL FLOOD
AS A FUNCTION OF WATERSHED AREA

Watershed	Area mi^2	Maximum Potential Flood ft^3/s
1	1.23	10,000
2	3.45	27,000
3	42.1	180,000
4	90.7	290,000
5	0.38	3,500

ALLUVIAL FANS AND THE RWMS

DESCRIPTION OF WATERSHEDS

The watersheds described in this report are those which drain toward Frenchman Lake and at some point pass through or come in close proximity to the RWMS, Figure 9. The summaries presented here are based on field work, soil sampling, and analysis of topographic and geologic maps and aerial photographs.

Watershed 1 is a small watershed (approximately 1.2 square miles) situated northwest of the RWMS, along the eastern flank of Massachusetts Mountain south of Puddle Peak. A fanhead valley cuts through rhyolitic tuffs and opens into an alluvial fan where the valley enters Frenchman Flat. Prominent low terraces of unconsolidated and caliche-cemented alluvium are found on portions of the fan (Poole, 1965). These terraces are covered with desert varnish and signify that deposition has not occurred on much of the fan for a long period of time. The terraces are discernable on aerial photographs, as are the areas of more recent deposition.

The southernmost part of the alluvial fan abuts Barren Wash Fan. An alluvial fan of Watershed 2 bounds it to the east. As flow reaches the lower portion of the fan, it is routed to the southeast by Barren Wash Fan and toward the RWMS.

Watershed 2 is north of the RWMS, located along the east flank of Puddle Peak and south of French Peak. A pediment is the dominant landform on the upper slope of the watershed, especially to the northwest. Note: a pediment is a gently

inclined planate erosion surface carved in bedrock and veneered with fluvial gravel, Anon. (1962). Tuffaceous rocks outcrop through a thin alluvial cover. Several alluvial fans are found below the pediment, eventually coalescing to form a bajada. Note: a bajada is a relatively smooth surface formed by the coalescing of alluvial fans along a mountain front. Areas which have not received recent sediment form alluvial terraces. Terraces are most prevalent in the north-central portion of the watershed. Much of the watershed shows evidence of recent flow, both in the field and on aerial photographs. Recent deposition has occurred in the western and eastern parts of the watershed. For example, the powerline road just north of the RWMS has sustained recent minor damage by flow in channels crossing the dirt road.

Like Watersheds 1 and 5, Watershed 2 is bounded by a large alluvial fan. Scarp Canyon Fan, having a large drainage area and source of alluvium, is encroaching on Watershed 2 from the east, and acts as a barrier to flow from the west. Scarp Canyon Fan directs all flow from the eastern portion of Watershed 2 southwestward toward the RWMS.

There is evidence of debris flows in the northern part of the watershed. In several small canyons south of Puddle Peak debris is found where the canyons open into larger channels. The debris consists of jumbled pebble to boulder-sized material, with little sand or finer sediment present. There is no apparent grading or sorting of particles. In one canyon a trench is found just upstream from the pile of debris. This trench appears to have been excavated by a debris flow, in a manner similar to that described by Beaty (1963). It should be noted however that without further study the possibility of a debris slide (rather than flow) cannot be ruled out.

Although debris flows may have occurred in the upper portions of the watershed, fluvial deposition is dominant. This is especially true in the southern portions of the watershed, near the RWMS.

Watershed 3 is a large watershed located east and northeast of the RWMS. The most prominent features are Scarp Canyon and Scarp Canyon Fan. The drainage area for Scarp Canyon extends as far north as Carbonate Ridge. In addition, this watershed encompasses the eastern flank of French Peak which drains toward Scarp Canyon Fan.

Bedrock in the Scarp Canyon area is primarily Tertiary rhyolitic-tuffs, with some Palezoic sedimentary rocks, especially to the north. French Peak is composed of rhyolitic tuffs.

The Scarp Canyon Fan is dissected by a large fanhead trench, which in places has cut 30 to 40 feet into alluvium and bedrock. Above the 3700 foot elevation (approximate) the channel cuts through bedrock and a thin veneer of alluvium. Below the 3700 foot elevation the channel is entrenched in unconsolidated and caliche-cemented alluvium. The alluvium consists of poorly sorted and crudely graded sediments ranging up to boulder-sized particles. In some areas of the channel the walls are well-cemented, suggesting that the channel is cutting through old fan material.

Within Scarp Canyon several streambeds may be found, splitting and rejoining as they wind toward the fan. Between the streambeds, or between the streambed and the canyon wall, levee-like deposits are found. These deposits generally vary from 1 to 5 feet above the streambed and have smooth, flat surfaces. The sediments are much finer than what is found in the streambed or in the canyon walls. Rocks to one foot or

larger are scarce but ubiquitous in these deposits. It is quite possible these sediments were deposited when water overflowed the channel banks of the streambed, and dropped fine material. Another possibility which cannot be discounted is that these are aeolian deposits, the scattered larger particles having washed down from the canyon walls. That these sediments were deposited by fluvial processes is supported by the finding of similar deposits in an area of aggradation below the mouth of Scarp Canyon.

Recent flow in Watershed 3 has occurred in two areas. The first is below the mouth of Scarp Canyon (intersection point) where the bulk of aggradation occurs on the fan. The second area is on the west side of the fan, where runoff from the east flank of the French Peak area of Massachusetts Mountain combines with runoff from the west side of Scarp Canyon Fan, and that of Watershed 2. This area is typified by numerous small dendritic channels, many of which have evidence of recent flow. Approximately 60% of the area of the RWMS lies within this area.

Watershed 4 is located in the northwestern portion of Frenchman Basin, northwest of the RWMS. This was the largest watershed (90 square miles) studied for this project. Barren Wash Fan is the dominant landform in the watershed. Barren Wash drains a large area, from Mid Valley, which is outside the Frenchman Basin, to Frenchman Lake. Also included in this watershed is the area bordered by Massachusetts Mountain on the east, CP Hogback on the north, and CP Hills to the west. The majority of rocks in this area are Tertiary tuffs, with some Palezoic sedimentary rocks found in the CP Hills and around Mid Valley (Orkild, 1968, McKeown, et al. 1976).

Barren Wash Fan appears to be a complex fan as described by Denny (1967), Figure 5. The upper portion of the fan

(primary fan) is deeply entrenched and has dissecting stream channels across the fan surface. Most of the surface is covered with desert pavement and desert varnish. The edges of the fanhead trench are scalloped indicating significant erosion. It is apparent that deposition has not occurred on the upper portion of the fan for a long period of time, measured in hundreds and perhaps thousands of years.

The formation of the fanhead trench has shifted deposition to its present position near the southern end of Massachusetts Mountain. At this point Barren Wash has captured the stream channel draining the northeastern portion of Watershed 4 (bordered by CP Hills, CP Hogback, and Massachusetts Mountain). From this point a newer (secondary) fan is being built, probably on the alluvium of the primary fan.

From the aerial photographs there does not appear to have been much recent deposition on Barren Wash Fan. Most of the deposition has occurred in a corridor between the intersection point and Frenchman Lake. The portion of the secondary fan of Barren Wash nearest the RWMS has had little deposition in recent years, although there are numerous channels in this area.

Recent streamflow and deposition have occurred on the western flank of Massachusetts Mountain. This is evident from aerial photographs and examination in the field. Streamflow travels southwest until it encounters the eastern edge of the Barren Wash Fan. It is then diverted southward where it enters Barren Wash near the southern edge of Massachusetts Mountain. From this point it follows the same pattern as flow from Barren Wash.

Poole (1965) has mapped prominent low alluvial terraces south of Massachusetts Mountain and Barren Wash. The

surfaces are slightly dissected, suggesting that deposition has not occurred on these terraces for some time. These terraces represent previous depositional areas on the fan and signify a shift in deposition to the southeast.

Watershed 5 is located along the extreme southeastern portion of Massachusetts Mountain, northwest of the RWMS. It is a very small watershed, approximately 0.4 square miles, and is characterized by a pediment rather than alluvial fan surface. Tertiary volcanic rocks form talus deposits adjacent to bedrock, consisting of boulder to sand-sized particles (Poole, 1965). Alluvium similar to that of most of Frenchman Flat is found adjacent to the talus deposits. The alluvium of Watershed 5 is bordered and being encroached by alluvium from Barren Wash Fan and the fan from Watershed 1. This has resulted in a "funneling" of flow toward the southeast, directly toward the RWMS. Although there is evidence of recent flow and channeling in Waterbed 5, impact on the RWMS should be negligable because of its small drainage area.

SEDIMENT CHARACTERISTICS, AGE, AND DEPOSITION RATES OF THE ALLUVIAL FANS

Alluvial fan researchers have devoted much of their attention to determining the age and rates of deposition of alluvial fans. Evidence used to make such estimates has been based on information gleaned from rare drill logs, road and channel cuts, and measurements made on recent depositional events. The drilling of exploratory holes in Frenchman Flat has produced valuable information which would have been impossible to obtain otherwise. Data on alluvial thickness and to some extent the lithologic characteristics of the alluvium was obtained from 12 drill holes in Watersheds 2, 3,

and 4. The thickness of alluvium in these holes is given in Figure 15.

A tentative age of 7 million years is given to the fans of northern Frenchman Flat, based on the occurrence of the Spearhead member of the Thirsty Canyon Tuff near the alluvium/tuff contact (Carr, et al., 1975). This unit is 500 to 1000 feet thick and has a very distinctive seismic profile. This alluvium is derived from the Tertiary tuffs and Paleozoic sedimentary rocks. Basaltic lava flows were encountered in some drill holes.

Above the cemented alluvium is a poorly sorted and generally unconsolidated alluvium of more recent age. This unit has an average thickness of 600 feet and consists primarily of tuffaceous alluvium. Some zones of caliche are present in this unit.

Bluck (1964) described an alluvial fan with a unit of cemented alluvium underlying unconsolidated alluvium in the Arrow Canyon Range, located approximately 65 miles east of Frenchman Flat. Based on the distributions of particle size, sphericity, and shape, Bluck suggested that the older, cemented alluvium was of mudflow origin, and that the more recent, unconsolidated alluvium was of streamflow origin. The initiation of the fanhead trench was attributed to the change in the depositional environment and fan profile.

There is no evidence at present to suggest that the units of cemented and unconsolidated alluvium in Frenchman Flat and the Arrow Canyon Range area were formed contemporaneously and/or in response to the same environmental factors. The possibility does exist however, and deserves attention.

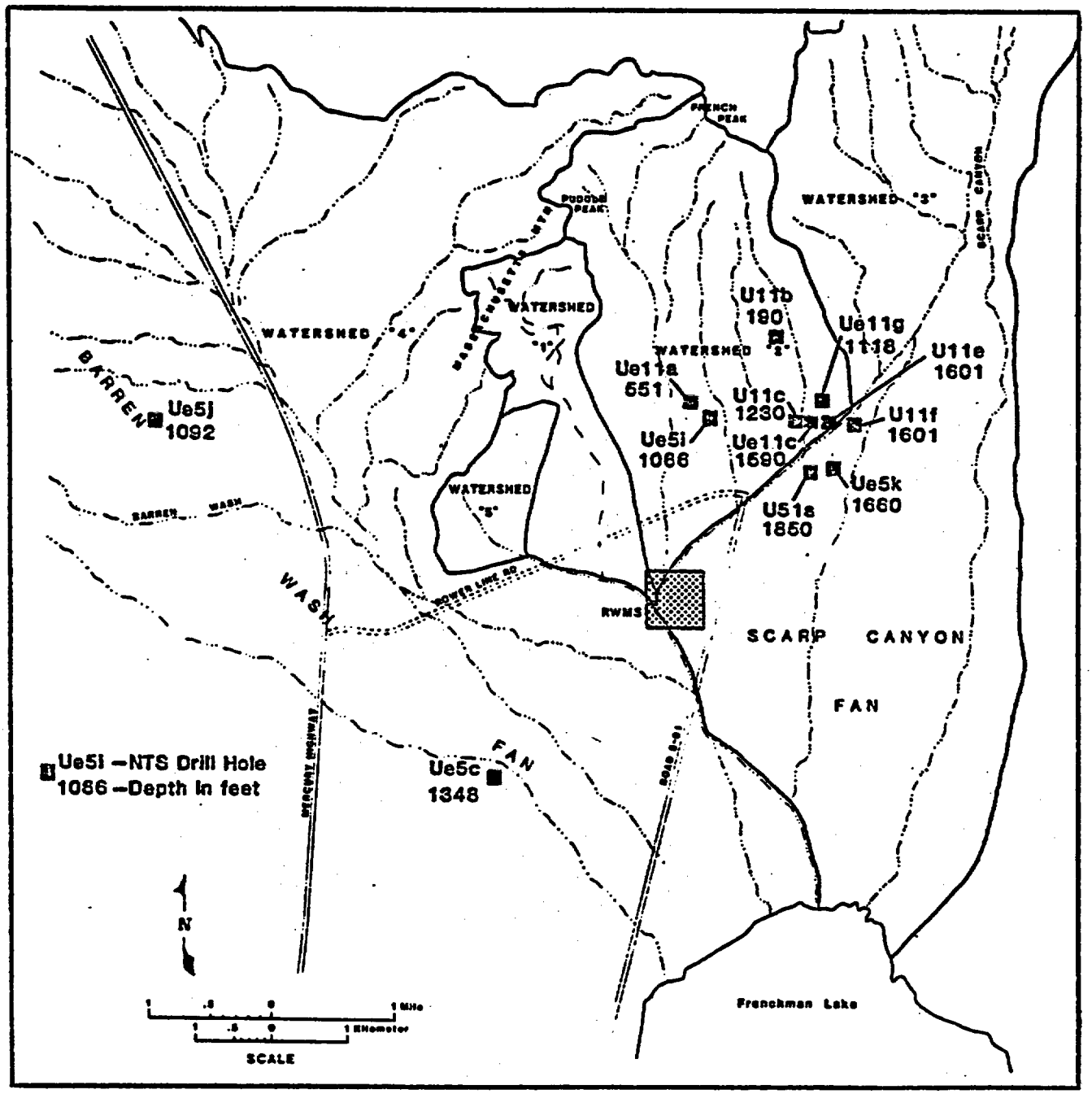

FIGURE 15: Location of Exploratory Holes on Frenchman Flat in the Vicinity of the RWMS, Showing Depth to Alluvium/Tuff Contact (Howard and Bell, 1984)

In attempting to determine the rate of deposition on the alluvial fans of Frenchman Flat, one must keep in mind the variables which affect deposition. First, deposition rarely occurs on the entire surface of an alluvial fan. Generally only a small portion of the fan receives sediment in an event. Second, changes in climate can change the depositional rate significantly. This is especially true when considering the age of these fans. Third, erosion does occur on alluvial fans, and may remove sediment from an inactive part of the fan.

Using an age of 7 million years for the alluvial fans, and an average thickness of 1600 feet for northern Frenchmen Flat, a deposition rate of 2.8 inches per 1000 years is arrived at. The most serious problem with this value is not knowing if any major unconformities exist in the 7 million year record since the deposition of the Thirsty Canyon Tuff layer. An erosional surface may exist on the surface of the tuff, between the cemented and unconsolidated alluvium, or somewhere else in the stratigraphic sequence. A hiatus in deposition would affect the long-term deposition rate considerably. It is reasonable to assume that deposition was not constant, but fluctuated greatly with climatic changes and other factors.

SUMMARY

The RWMS is sited at the junction of aggrading alluvial fans from Scarp Canyon, Barren Wash, and those of Massachusetts Mountain and French Peak, Figure 9. The Scarp Canyon and Barren Wash fans are large and probably have minimum ages of 2.5 million years and may be as old as 7 million years. These fans appear to be overrunning the fan

material from French Peak and Massachusetts Mountain which have smaller drainage areas and sediment supply.

The rocks of the source areas of these fans are primarily Tertiary volcanics with some Paleozoic sedimentary rocks. These rocks erode relatively easily and provide sufficient material for alluvial fan growth. The low annual precipitation and the abundance of clay supplied by the decomposition of feldspars in the volcanic rocks are conducive to debris flow formation. Although, debris flows are unlikely to reach the RWMS, they may occur in the upper reaches of the watersheds.

Tectonic features, such as the Cane Spring Fault Zone, the Frenchman Flexure and a series of northeast trending faults occurring directly north of the RWMS, are partly responsible for the deep basin which Frenchman Flat occupies and the alluvial fan material which fills it.

Recent aerial photographs indicate that much of the Scarp Canyon Fan has relatively recent deposition. From the photographs there is little evidence to suggest an established soil profile on much of the fan. Recent flow on Scarp Canyon Fan has occurred primarily below the fanhead trench which is east of the RWMS. Although the upper portion of Scarp Canyon appears to be permanently entrenched, the lower portion does not appear to be. Therefore, a large-scale flood could possibly modify or radically alter the present flowpath and direct floodwaters toward the RWMS. Of greater immediate concern is the channeling along the western edge of Scarp Canyon Fan. Scarp Canyon Fan acts as a barrier to flow from the drainage basins to the north and west of the fan. From aerial photographs it is evident that flow from Watersheds 1, 2, 5, and a portion of Watershed 3,

is routed along the western edge of Scarp Canyon Fan with a portion of it passing through the RWMS.

The upper flanks of Barren Wash Fan are dissected by erosional channels, indicating that there has been little if any deposition on this part of the fan for quite some time. Recent deposition has occurred principally below the intersection point of the entrenched channel which is located just south of the southern tip of Massachusetts Mountain. In this area, drainage from the western flank of Massachusetts Mountain merges with Barren Wash. A portion of the flow below the intersection point is directed eastward toward the RWMS. Aggradation of Barren Wash Fan to the northeast has also directed the flow of Watershed 5 toward the RWMS.

The RWMS is apparently situated at the junction of major alluvial fans, to the east and west, with several smaller fans merging from the north. At least a portion of recent flow has passed through the site which the waste depository now occupies. One should expect the processes which have created these alluvial fans will continue into the forseeable future with potentially serious consequences for the RWMS.

FLOODING ON ALLUVIAL FANS

The nature and characteristics of flooding on alluvial fans are such that traditional methods of hydraulic engineering cannot be used to assess the extent and seriousness of flooding. Among the characteristics of flooding on alluvial fans noted [redacted]non. (1982), and previously in this report are:

1. Flows only rarely spread evenly across the surface of a fan. In general, a flood flow will initially be concentrated in an identifiable temporary channel or will be confined to a specific portion of the fan. These initial flows are prone to lateral migration and sudden relocation to almost any other portion of the fan during a single extreme flow event. Thus, Dawdy (1979) asserted that all portions of a fan are at risk during a flood event.

2. For a majority of fans, critical slope; and hence, critical flow is the norm.

3. Channels formed on the face of a fan are shaped by the flow itself. If supercritical flow occurs, the channel banks will erode so that a wider channel is formed and the flow will return to a critical state of flow.

4. Given the hypothesis that a channel on an alluvial fan passing a flood event is subject to migration, Dawdy (1979) asserted that the potential hazard of a flood is approximately equal for all points that are radially equidistant from the fan apex.

The assumptions and assertions of Dawdy (1979) regarding flooding on alluvial fans are admittedly open to discussion, see for example, McGinn (1980) and Dawdy (1981). However, they do provide a framework within by which the potential flood hazard to the RWMS can be evaluated.

The implementation of the Dawdy (1979) analysis technique requires a method of estimating the width and depth of the channel formed by the flood event. Leopold and Maddock (1953) hypothesized from riverine field data that

$$u = C_1 Q^m \quad (3)$$

$$y = C_2 Q^f \quad (4)$$

and

$$T = C_3 Q^b \quad (5)$$

where u = average velocity of flow (ft/s), T = channel top width (feet), Q = flow rate (ft^3/s), y = channel depth (feet), and C_1, C_2, C_3, m, f, b = coefficients. Using field data, Leopold and Maddock (1953) estimated values of m, f, and b; Table 8, Columns (2) and (3). Leopold and Langbein (1962) subsequently developed theoretical values for m, f, and b; Table 8, Column (4). Dawdy (1979) also estimated values of m, f, and b; Table 8, Column (5). The equations used by Dawdy (1979) to estimate width and depth of a stable channel on an alluvial fan are

$$T = 9.5Q^{0.4} \quad (6)$$

and

$$y = 0.07Q^{0.4} \quad (7).$$

If Equations (6) and (7) are used in conjunction with the flow rates in Tables 6 and 7, then the estimates of T and y for Tables 9 and 10 result.

TABLE 8

SUMMARY OF COEFFICIENTS
FOR THE
ESTIMATIONS OF CHANNEL WIDTH AND DEPTH

Coefficient (1)	Field Data Leopold and Maddock (1953) Midwest (2)	Field Data Leopold and Maddock (1953) Semi-Arid (3)	Theoretical Leopold and Langbein (1962) (4)	Dawdy (1979) (5)
f (depth)	0.40	0.3	0.36	0.4
b (width)	0.50	0.5	0.55	0.4
m (velocity)	0.10	0.20	0.09	0.2

TABLE 9

ESTIMATED VALUES OF y AND T FOR SPECIFIED VALUES OF Q

Return Period	Parameter	Peak Flood Flow by Nevada Equations					Peak Flood Flow by Arizona Region 1 Equations					Peak Flood Flow by Arizona Region 2 Equations				
		Watershed					Watershed					Watershed				
		1	2	3	4	5	1*	2	3	4	5*	1	2	3	4	5
10	Q (ft^3/s)	92	173	792	1268	45	—	256	1055	1629	—	388	634	2080	2995	222
	T (ft)+	60	80	110	170	40	—	90	120	180	—	100	130	200	230	80
	y (ft)	0.4	0.6	1.0	1.2	0.3	—	0.6	1.1	1.3	—	0.8	0.9	1.5	1.7	0.6
25	Q (ft^3/s)	285	502	1959	3058	147	—	487	1843	2773	—	648	1071	3621	5264	366
	T (ft)+	90	110	200	240	70	—	110	190	230	—	130	150	250	290	100
	y (ft)	0.7	0.8	1.5	1.7	0.5	—	0.8	1.4	1.7	—	0.9	1.1	1.9	2.2	0.7
50	Q (ft^3/s)	594	1010	3582	5512	320	—	739	2647	3916	—	903	1503	5170	7555	509
	T (ft)+	120	150	250	300	100	—	130	220	260	—	140	180	290	340	110
	y (ft)	0.9	1.1	1.8	2.2	0.7	—	1.0	1.6	1.9	—	1.1	1.3	2.1	2.5	0.8
100	Q (ft^3/s)	1146	1876	6058	9179	641	—	1071	3650	5317	—	1220	2041	7110	10430	679
	T (ft)+	160	190	310	370	130	—	150	250	290	—	160	200	330	380	130
	y (ft)	1.2	1.4	2.3	2.7	0.9	—	1.1	1.9	2.2	—	1.2	1.5	2.4	2.8	1.0
500	Q (ft^3/s)	3020	5300	15800	23800	1860	—	2272	7022	9928	—	2222	3756	13420	19838	1222
	T (ft)+	230	290	450	540	190	—	210	330	380	—	210	260	420	500	160
	y (ft)	1.7	2.2	3.3	3.9	1.4	—	1.5	2.4	2.8	—	1.5	1.9	3.1	3.7	1.2

* Equation cannot be used for these watersheds because A < 1.84 sq. mi.
\+ Rounded to nearest 10 feet

TABLE 10

ESTIMATED VALUES OF y and T
FOR THE MAXIMUM POTENTIAL FLOOD

Parameter	Watershed				
	1	2	3	4	5
Q (ft^3/s)	10,000	27,000	180,000	290,000	3,500
T (ft)+	380	560	1200	1450	250
y (ft)	2.8	4.1	8.9	11.	1.8

+ Rounded to nearest 10. ft. (3.05 m)

With regard to the data summarized in Tables 9 and 10 it is noted that the channels formed by the flood events are wide but shallow. In the case of the maximum potential flood, Table 7, the channels are still very wide, but the depth of flow is also greater.

The assumption of critical flow on the fans can be examined by defining the critical slope and then comparing the fan slope with this parameter. By definition, the critical slope is one on which uniform flow occurs at critical depth. The normal velocity of flow is given by the Manning equation or in the English system of units

$$u = \frac{1.49}{n} \quad R^{2/3}\sqrt{S} \qquad (8)$$

where u = average velocity, n = Manning's resistance coefficient, R = hydraulic radius, and S = longitudinal slope of the channel. By definition, when critical flow occurs

$$u_c = \sqrt{gy_c} \qquad (9)$$

where u_c = critical velocity and y_c = critical depth. In addition, under critical flow conditions in a rectangular channel

$$y_c = \sqrt[3]{\frac{q^2}{g}} \qquad (10)$$

where q = flow per unit width and g = acceleration of gravity. Substitution of Equations (9) and (10) in Equation (8) yields an equation for the critical slope or

$$S_c = \frac{21.3\ n^2}{q^{2/9}} \qquad (11)$$

where S_c = critical slope. Then when $S > S_c$ supercritical flow occurs and when $S < S_c$ subcritical flow occurs.

There are a number of methods available for estimating the Manning resistance coefficient in Equation (11). Strickler, see for example Simons and Senturk (1976), defined n in terms of the size of the material composing the bed of the channel or

$$n = \frac{d^{1/6}}{21.1} \qquad (12)$$

where d = diameter in millimeters of the uniform sand used in the experiments. Since the experiments used to derive the functional relationship specified by Equation (12) were performed with a uniform sand, this equation cannot be used to estimate n in an alluvial channel. Meyer-Peter and Muller (1948) used a sand mixture in their experiments and developed the following equation:

$$n = \frac{d_{90}^{1/6}}{26} \qquad (13)$$

where d_{90} = diameter of the bed material in meters such that 90% of the material, by weight, is smaller. Note, Equation (13) is not applicable when the bed of the channel is paved with cobbles. Lane and Carlson (1953) using field data suggested:

$$n = \frac{d_{75}^{1/6}}{39} \qquad (14)$$

where d_{75} = diameter of the bed material in inches such that 75% of the material, by weight, is smaller. Note, Equation (14) is applicable to channels whose beds are paved with cobbles.

A number of surface and subsurface soil samples were obtained from the watersheds and alluvial fans surrounding the RWMS. In Figure 16, the approximate locations of the sample sites are shown, and in Table 11 the results of the sieve analyses of the soil samples are summarized. Graphs showing the size distribution for each sample are contained in Appendix II.

Table 11 is divided into two parts. In the first part, the data for samples obtained from the bottom of streambeds are summarized. In the second part, data obtained from non-channel parts of the watersheds and fans are summarized. In Columns 2 and 4 of this table, the d_{90} (in meters) and d_{75} (in inches) characteristic sizes are specified. From these characteristic sizes, values of n are estimated by Equations (13) and (14).

In Table 12, the average values and standard deviations of d_{75} and n, by Equation (14), are summarized for Watersheds 2, 3, and 4. Although at this time there is not a sufficient number of samples for a statistical analysis of the results, Table 12 demonstrates, at least qualitatively, that the watersheds and fans surrounding the RWMS appear to be composed of similar sized materials and would therefore have similar hydraulic resistance coefficients.

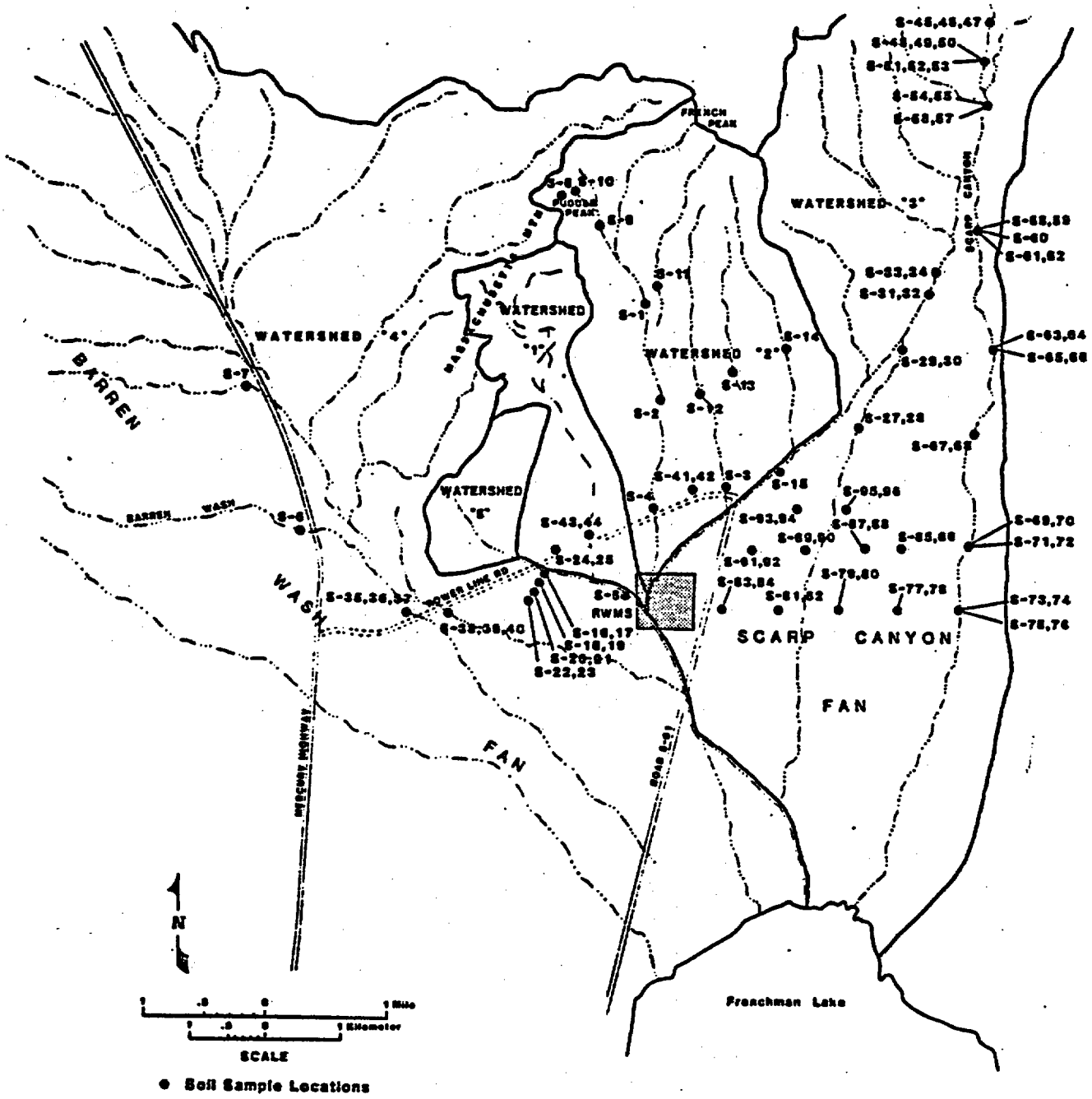

FIGURE 16: Soil Sampling Site Locations

TABLE 11

SUMMARY OF SOIL SAMPLING RESULTS

	SITE	d_{90} m	n by Eq. 13	d_{75} in	n by Eq. 14	COMMENTS
From streambeds:	(1)	(2)	(3)	(4)	(5)	(6)
Watershed 1:	S-24	0.014	0.019	0.35	0.022	Surface sample from bottom of streambed in southwestern portion of Watershed 1 just north of PL-DIK Road.
	S-25	0.011	0.018	0.24	0.020	One-foot sample from same locality as S-24.
	S-43	0.020	0.020	0.43	0.022	Surface sample from bottom of streambed in south-central portion of Watershed 1, just nort of PL-DIK Road.
	S-44	>0.030	>0.021	>1.2	>0.026	One-foot sample from same locality as S-43.
Watershed 2:	S-1	0.0085	0.017	0.24	0.020	Surface sample from bottom of streambed in north-central portion of Watershed 2.
	S-2	0.0080	0.017	0.20	0.020	Surface sample from bottom of streambed in northwestern portion of Watershed 2; downstream from S-1.
	S-3	0.0090	0.018	0.28	0.021	Surface sample from bottom of streambed in south-central portion of Watershed 2; downstream from S-12.
	S-4	0.0085	0.017	0.24	0.020	Surface sample from bottom of streambed in southwestern portion of Watershed 2; downstream from S-4.
	S-5	0.0062	0.016	0.16	0.019	Surface sample from bottom of streambed near the intersection of Watershed 2, Barren Wash Fan, and Scarp Ojn Fan.
	S-8	0.012	0.018	0.25	0.020	Surface sample from bottom of streambed along north-east flank of Puddle Peak in Watershed 2.
	S-9	0.028	0.021	0.37	0.022	Surface sample from bottom of streambed east of Puddle Peak in Watershed 2.
	S-10	0.0060	0.016	0.14	0.018	Surface sample from bottom of streambed adjacent to the saddle between Puddle Peak and French Peak in Watershed 2.
	S-11	0.024	0.021	0.47	0.023	Surface sample from bottom of streambed in central portion of Watershed 2.
	S-12	0.020	0.020	0.47	0.023	Surface sample from bottom of streambed in central portion of Watershed 2; east of S-12.
	S-13	0.013	0.019	0.26	0.020	Surface sample from bottom of streambed in east-central portion of Watershed 2.
	S-14	L O S T				Surface sample from bottom of streambed in central-eastern portion of Watershed 2, east of S-13.
	S-41	0.032	0.022	0.47	0.023	Surface sample of bottom of streambed in south-central portion of Watershed 2, off PL-DIK Road and north of NMS.
	S-42	0.0090	0.018	0.16	0.019	One-foot sample from same locality as S-41.

	SITE	d_{90} m	n by Eq. 13	d_{75} in	n by Eq. 14	COMMENTS
	(1)	(2)	(3)	(4)	(5)	(6)
From streambeds: (continued)						
Watershed 3:	S-15	0.0080	0.017	0.13	0.018	Surface sample from bottom of streambed along west edge of Scarp Cyn Fan in Watershed 3.
	S-27	0.0059	0.016	0.11	0.018	Surface sample from bottom of streambed along west edge of Watershed 3, downstream from S-29.
	S-28	0.013	0.019	0.26	0.020	One-foot sample from same locality as S-27.
	S-29	0.012	0.018	0.18	0.019	Surface sample from bottom of streambed along west edge of Watershed 3, downstream from S-31.
	S-30	0.0095	0.018	0.13	0.018	One-foot sample from same locality as S-29.
	S-31	0.022	0.020	0.45	0.022	Surface sample from bottom of streambed along west edge of Watershed 3, downstream from S-33.
	S-32	0.024	0.021	0.53	0.023	One-foot sample from same locality as S-31.
	S-33	0.014	0.019	0.35	0.022	Surface sample from bottom of streambed along west edge of Watershed 3, near apex of Scarp Cyn Fan.
	S-34	0.013	0.019	0.20	0.020	One-foot sample from same locality as S-33.
	S-45	>0.030	>0.021	>1.2	>0.026	Surface sample from bottom of streambed in Scarp Cyn of Watershed 3, just south of Gate 5-4P.
	S-46	0.012	0.018	0.20	0.020	One-foot sample from same locality as S-45.
	S-47	0.011	0.018	0.20	0.020	Two-foot sample from same locality as S-45.
	S-48	0.0051	0.016	0.11	0.018	Surface sample from bottom of streambed in Scarp Cyn downstream from S-45 in Watershed 3.
	S-49	0.0039	0.015	0.09	0.017	One-foot sample from same locality as S-48.
	S-50	0.021	0.020	0.31	0.021	Two-foot sample from same locality as S-48.
	S-54	0.0068	0.017	0.19	0.019	Surface sample of bottom of streambed in Scarp Cyn downstream from S-48, in Watershed 3.
	S-55	0.0088	0.017	0.16	0.019	One-foot sample from same locality as S-54.
	S-58	0.0095	0.018	0.24	0.020	Surface sample from bottom of streambed in Scarp Cyn downstream from S-54, near apex of alluvial fan, in Watershed 3.
	S-59	0.032	0.022	0.67	0.024	One-foot sample from same location as S-58.
	S-63	0.010	0.018	0.23	0.020	Surface sample from bottom of streambed in Scarp Cyn, downstream from S-58 in Watershed 3.
	S-64	0.020	0.020	0.43	0.022	One-foot sample from same location as S-63.
	S-67	0.012	0.018	0.17	0.019	Surface sample from bottom of streambed in Scarp Cyn, downstream from S-63, 100 yards north of Nye Cyn Road, on Scarp Cyn Trail, in Watershed 3.
	S-68	0.0048	0.016	0.091	0.017	One-foot sample from same location as S-67.
	S-69	0.017	0.020	0.20	0.020	Surface sample from bottom of streambed downstream of S-67, in Watershed 3, just south of Scarp Cyn.
	S-70	0.0060	0.016	0.055	0.016	One-foot sample from same location as S-69.
	S-75	0.0080	0.017	0.10	0.017	Surface sample from bottom of streambed downstream from Scarp Cyn in Watershed 3 west of S-73.
	S-76	0.0042	0.015	0.039	0.015	One-foot sample from same location as S-75.

	SITE	d_{90} m	n by Eq. 13	d_{75} in	n by Eq. 14	COMMENTS
	(1)	(2)	(3)	(4)	(5)	(6)
From streambeds: (continued)						
Watershed 4:	S-6	0.0080	0.017	0.19	0.019	Surface sample from Barren Wash Fan near the culvert under the Mercury Highway in Watershed 4.
	S-7	0.012	0.018	0.26	0.020	Surface sample from bottom of streambed along north edge of Barren Wash Fan in Watershed 4.
	S-16	0.011	0.018	0.24	0.020	Surface sample from bottom of streambed along Watershed 1-4 boundary, west of RMS, just off FL-DIX Road.
	S-17	0.073	0.025	1.2	0.026	One-foot sample from same locality as S-16.
	S-18	>0.030	>0.021	0.59	0.023	Surface sample from bottom of streambed approximately 50 yards south of S-16 along northeastern edge of Watershed 4.
	S-19	0.032	0.022	0.39	0.022	One-foot sample from same locality as S-18.
	S-22	0.013	0.019	0.30	0.021	Surface sample from bottom of streambed approximately 50 yards south of S-20 on northeastern edge of Watershed 4.
	S-23		L O S T			One-foot sample from same locality as S-22.
	S-35	0.014	0.019	0.32	0.021	Surface sample from bottom of Barren Wash (in Watershed 4) just south of Massachusetts Mountain.
	S-36	0.0066	0.017	0.19	0.019	One-foot sample from same locality as S-35.
	S-37	0.015	0.019	0.23	0.020	Two-foot sample from same locality as S-35.
	S-38	0.013	0.019	0.24	0.020	Surface sample from bottom of streambed originating in southernmost portion of Massachusetts Mtn, in Watershed 4, east of S-35.
	S-39	0.0068	0.017	0.12	0.018	One-foot sample from same locality as S-38.
	S-40	0.0057	0.016	0.16	0.019	Two-foot sample from same locality as S-38.

	SITE	d_{90} m	n by Eq. 13	d_{75} in	n by Eq. 14	COMMENTS
	(1)	(2)	(3)	(4)	(5)	(6)
From non-channel parts of watersheds:						
Watershed 3:	S-51	0.004	0.015	0.04	0.015	Surface sample from levee approximately 30 feet east of S-48 in Scarp Cyn of Watershed 3.
	S-52	0.0017	0.013	0.03	0.014	One-foot sample from same locality as S-51.
	S-53	0.0022	0.014	0.03	0.014	Two-foot sample from same locality as S-51.
	S-56	0.022	0.020	0.28	0.021	Surface sample from Cyn wall approximately 40 feet east of S-54 in Scarp Cyn in Watershed 3.
	S-57	0.021	0.020	0.20	0.020	One-foot sample from same location as S-56.
	S-60	>0.030	>0.021	>1.2	>0.026	Surface sample from Scarp Cyn wall west of streambed, west of S-58.
	S-61	0.0042	0.015	0.047	0.015	Surface sample from levee in Scarp Cyn in area between S-58 and S-60.
	S-62	0.0032	0.015	0.032	0.014	One-foot sample from same location as S-61.
	S-65	0.0085	0.017	0.098	0.017	Surface sample from levee deposit in Scarp Cyn, west of S-63.
	S-66	0.0070	0.017	0.051	0.016	One-foot sample from same location as S-65.
	S-71	>0.030	>0.021	0.79	0.025	Surface sample from levee deposit approximately 30 yards east of S-69 in Watershed 3.
	S-72	>0.030	>0.021	0.28	0.021	One-foot sample from same location of S-71.
	S-73	0.0072	0.017	0.079	0.017	Surface sample from levee deposit adjacent to streambed, downstream from Scarp Cyn Watershed 3, downstream from S-69.
	S-74	>0.030	>0.021	0.14	0.018	One-foot sample from same location as S-73.
	S-77	0.010	0.018	0.071	0.016	Surface sample from Scarp Cyn. Fan, in Watershed 3, 1/2 mile west of S-75.
	S-78	0.0075	0.017	0.079	0.017	One foot sample from same location as S-77.
	S-79	0.0009	0.012	0.016	0.013	Surface sample from Scarp Cyn. Fan, in Watershed 3, 1/2 mile west of S-77.
	S-80	0.0010	0.012	0.017	0.013	One foot sample from same location as S-79.
	S-81	0.015	0.019	0.20	0.020	Surface sample from Scarp Cyn. Fan 1/2 mile west of S-79.

	SITE	d_{90} m	n by Eq. 13	d_{75} in	n by Eq. 14	COMMENTS
	(1)	(2)	(3)	(4)	(5)	(6)
From non-channel parts of watersheds: (continued)						
Watershed 3:	S-82	0.0090	0.018	0.13	0.018	One foot sample from same location as S-81.
	S-83	0.0052	0.016	0.030	0.014	Surface sample from Scarp Cyn. Fan 1/2 mile west of S-81 near Road 5-01.
	S-84	0.0041	0.015	0.027	0.014	One foot sample from same location as S-83.
	S-85	0.011	0.018	0.034	0.015	Surface sample from Scarp Cyn. Fan 1/2 mile north of S-77.
	S-86	0.019	0.020	0.13	0.018	One foot sample from same location as S-85.
	S-87	0.0020	0.014	0.020	0.013	Surface sample from Scarp Cyn. Fan, in Watershed 3, 3/10 of a mile west of S-85.
	S-88	0.0029	0.014	0.024	0.014	One foot sample from same location as S-87.
	S-89	0.0080	0.017	0.026	0.014	Surface sample from Scarp Cyn. Fan 1/2 mile west of S-87.
	S-90	0.0034	0.015	0.024	0.014	One foot sample from same location as S-89.
	S-91	0.0048	0.016	0.027	0.014	Surface sample from Scarp Cyn. Fan 4/10 of a mile west of S-89, 2/10 mile east of Road 5-01.
	S-92	0.0058	0.016	0.033	0.014	One foot sample from same location as S-91.
	S-93	0.020	0.020	0.24	0.020	Surface sample from Scarp Cyn. Fan 1/2 mile east of Road 5-01 near road that is approximately 1/10 mile south of intersection of Powerline Road and Road 5-01.
	S-94	>0.030	>0.021	0.26	0.021	One foot sample from same location as S-93.
	S-95	0.0030	0.015	0.032	0.014	Surface sample from Scarp Cyn. Fan 4/10 of a mile east of S-93.
	S-96	0.0020	0.014	0.030	0.014	One foot sample from same location as S-95.
Watershed 4:	S-20	0.0095	0.018	0.13	0.018	Surface sample from site approximately 50 yards south of S-18 along northeastern edge of Watershed 4.
	S-21	0.0095	0.018	0.11	0.018	One-foot sample from same locality as S-20.

TABLE 12

SUMMARY OF SIZE AND RESISTANCE
DATA CONTAINED IN TABLE 11

Watershed	Streambed				Off-Channel			
	$\bar{d}_{75}$ (in)	σ (in)	$\bar{n}$	σ	$\bar{d}_{75}$ (in)	σ (in)	$\bar{n}$	σ
2	0.28	0.12	0.021	0.002	----	----	-----	-----
3	0.22	0.15	0.019	0.002	0.11	0.15	0.016	0.003
4	0.34	0.28	0.021	0.002	0.12	0.014	0.018	0

In Table 13, d_{50} size data and the corresponding average values and standard deviations are summarized. In this table data from the streambeds and non-channel areas are separated and these data are further separated into surface and subsurface data. Although there are not sufficient data for absolute conclusions to be reached, the following comments are supported by the data. First, there is not a significant value of $\bar{d}_{50}$ for the surface and subsurface data. Second, there is a significant difference between the $\bar{d}_{50}$ values for streambeds and non-channel areas. Third, a comparison of d_{50} sizes across the fan (specifically S-85, S-87, S-89 and S-91 and S-77, S-79, S-81 and S-83) does not demonstrate any obvious trends. This last comment indicates that while the surface and near surface material varies in size it tends to exhibit no significant variation in size across the fan.

In Table 14, the average slopes of the alluvial fans, below elevation 3800 feet, surrounding the RWMS are summarized. In examining the data in this table, it should be noted that these slopes were estimated by connecting what was judged to be the apex of the fan with the lowest point in the basin with a straight line. The slopes were then estimated by estimating changes in elevation along with the corresponding longitudinal distances on this line.

In Figure 17, the critical slope, S_c, is plotted as a function of the flow per unit width, q, and the estimated value of n for the fans below Watersheds 2, 3 and 4. Also plotted in this figure are the extreme combinations of estimated flow per unit width, Tables 9 and 10, and estimated fan slope, Table 14. From this figure, it can be concluded that for most flood flow discharges the resultant flow on the alluvial fans surrounding the RWMS will be either critical or supercritical; i.e., high velocities and low depths of flow.

Thus, one of the basic assumptions of the flood risk analysis is substantiated.

In conclusion it should be noted that the nature and characteristics of flooding on alluvial fans is receiving increasing attention. For example, Price (1974) developed a random walk model to simulate alluvial fan deposition on a geologic time scale. In Anon. (1981) basic physical hydraulic model studies sponsered by FEMA are discussed. Although both of these studies are significant, they do not provide a methodology for hazard evaluation that is demonstrably superior to that presented in this chapter.

TABLE 13

SUMMARY OF d_{50} SIZE DATA
AND STATISTICS FOR WATERSHED 3

Streambed (Surface)

Site	d_{50} mm
S-15	0.90
S-27	0.98
S-29	1.0
S-31	2.4
S-33	5.8
S-45	10.
S-48	1.3
S-54	2.7
S-58	3.0
S-63	2.2
S-67	1.1
S-69	0.56
S-75	0.42

N = 13
$\bar{d}_{50}$ = 2.5 mm
σ_{50} = 2.68 mm

Streambed (Subsurface)

Site	d_{50} mm
S-28	3.0
S-30	1.0
S-32	7.0
S-34	1.8
S-46	1.9
S-47	1.2
S-49	1.3
S-50	2.1
S-55	1.8
S-59	4.8
S-64	5.2
S-68	1.0
S-70	0.32
S-76	0.42

N = 14
$\bar{d}_{50}$ = 2.3 mm
σ_{50} = 1.98 mm

N = 27
$\bar{d}_{50}$ = 2.4 mm
σ_{50} = 2.30 mm

Non-channel Samples

Site	d_{50} mm
S-51	0.35
S-56	1.7
S-61	0.32
S-65	0.68
S-71	6.1
S-73	0.38
S-77	0.29
S-79	0.24
S-81	0.62
S-83	0.20
S-85	0.22
S-87	0.27
S-89	0.22
S-91	0.19
S-93	0.78
S-95	0.40

N = 16
$\bar{d}_{50}$ = 0.81 mm
σ_{50} = 1.46 mm

Non-channel Samples

Site	d_{50} mm
S-52	0.31
S-53	0.37
S-57	1.5
S-62	0.29
S-66	0.35
S-72	2.2
S-74	0.40
S-78	0.36
S-80	0.24
S-82	0.72
S-84	0.22
S-86	0.31
S-88	0.28
S-90	0.25
S-92	0.19
S-94	0.62
S-96	0.42

N = 17
$\bar{d}$ = 0.53 mm
σ_{50} = 0.529 mm

N = 33
$\bar{d}_{50}$ = 0.67 mm
σ_{50} = 1.08 mm

TABLE 14

SUMMARY OF AVERAGE SLOPE DATA FOR ALLUVIAL FANS SURROUNDING THE RADIOACTIVE WASTE MANAGEMENT SITE

Elevation ft	Watershed 1 x ft	Watershed 1 S	Watershed 2 x ft	Watershed 2 S	Watershed 3 x ft	Watershed 3 S	Watershed 4 x ft	Watershed 4 S	Watershed 5 x ft	Watershed 5 S
3800										
			1300	0.0769						
3700										
	1200	0.0833	1300	0.0769	6950	0.0144	5250	0.0190		
3600										
	1900	0.0526	1725	0.0580	4300	0.0233	5300	0.0189		
3500										
	2200	0.0455	2050	0.0488	4150	0.0241	4600	0.0217		
3400										
	2700	0.0370	2375	0.0421	4500	0.0222	6650	0.0150	1200	0.0833
3300										
	3650	0.0274	6000	0.0167	5200	0.0192	6050	0.0165	8500	0.0118
3200										
	11600	0.0086	8200	0.0122	7400	0.0135	7375	0.0136	8500	0.0118
3100										
	3850	0.0052	4400	0.0045	3300	0.0061	1800	0.0111	3200	0.0063
3080										

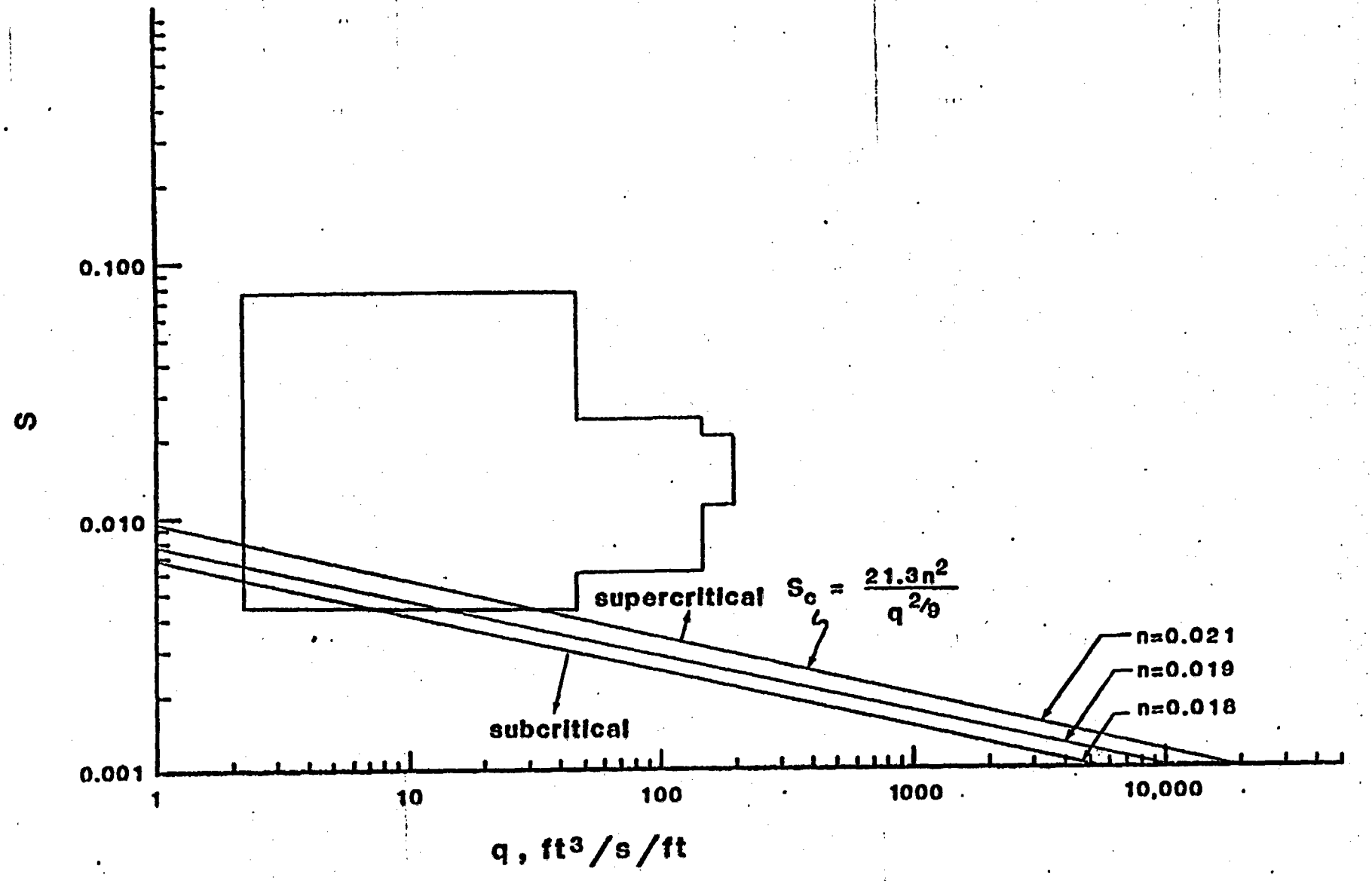

FIGURE 17: Definition of Flow Regimes for Fans 2, 3, and 4

PRELIMINARY ASSESSMENT OF FLOOD RISK

At this point, reasonable hypotheses for estimating the probability of a point on an alluvial fan being "hit" by a flood event must be developed. Dawdy (1979) assumed that a channel caused by a flood event was equally likely to cross a contour at any point or

$$p(x|f) = \frac{T}{W_c} \qquad (13)$$

where $p(x|f)$ = probability that the point x on a specified contour will be hit given that the flood event occurs, T = channel top width, and W_c = contour width.

The Dawdy hypothesis, Equation (13), yields what would seem to be conservative estimates of the probability of a point on a specified contour being hit given that a flood event occurs. An alternative hypothesis can be derived by considering the geometry of the idealized alluvial fan shown schematically in Figure 18. In this idealized case, the fan is assumed to spread out in a conical shape between two boundaries which cannot be crossed by a flood event. It is assumed the points on line AB, connecting the apex of the fan and the lowest point in the watershed, are the most likely to be hit by a flood event. Points lying off line AB are less likely to be hit depending on their position with respect to AB. Quantifying these assumptions,

$$p(x|f) = \frac{T}{W_c} \left(1 - \frac{\theta}{\Gamma}\right) \qquad (14)$$

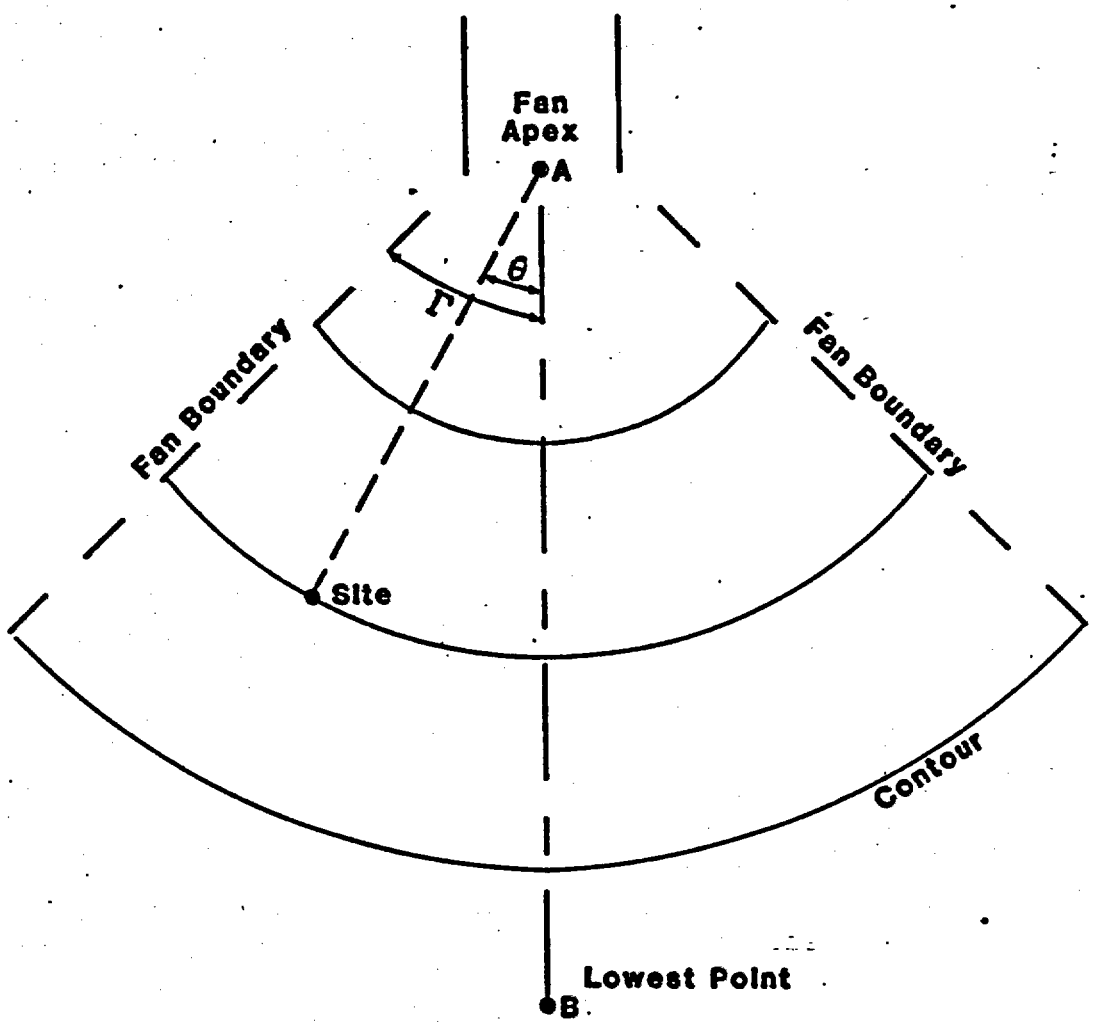

FIGURE 18: Schematic of an Idealized Alluvial Fan

where θ and Γ are angles defined in Figure 18. The observations of Bull (1962) seem to lend qualitative support to the type of hypothesis expressed by Equation (14). In examining present-day channel deviation from the medial radial line of seventy-five fans, Bull (1962) found that about two-thirds of the channels were within thirty degrees of the medial position and only three channels had a deviation of more than fifty degrees. These observations are summarized in Figure 19. Note, the medial radial line on an alluvial fan is by definition the straight line from the fan apex to the toe positioned so that the fan is split into approximately two equal areas, Bull (pers. commun., 1984).

Equations (13) and (14) provide functional relationships for estimating the conditional probability that, given a flood event occurs, the point x located on specified contour will be hit. With these point relationships defined, the probability of a flood hit on a feature of finite size can be estimated. If Equation (13) is used, then the conditional probability of a flood hit on a feature having a characteristic dimension W is

$$p(x|f) = \frac{2T + W}{W_c} \qquad (15)$$

In the case of Equation (14), the corresponding equation is

$$p(x|f) = \frac{2T + W}{W_c} \left(1 - \frac{\theta}{\Gamma}\right) \qquad (16)$$

Table 15 summarizes the pertinent geometric data for the alluvial fans surrounding the RWMS. The conditional probabilities of a flood event in a specified return period hitting the RWMS are summarized and estimated by Equations (15) and (16) in Table 16. In preparing Table 16, it was assumed that the appropriate characteristic length was the

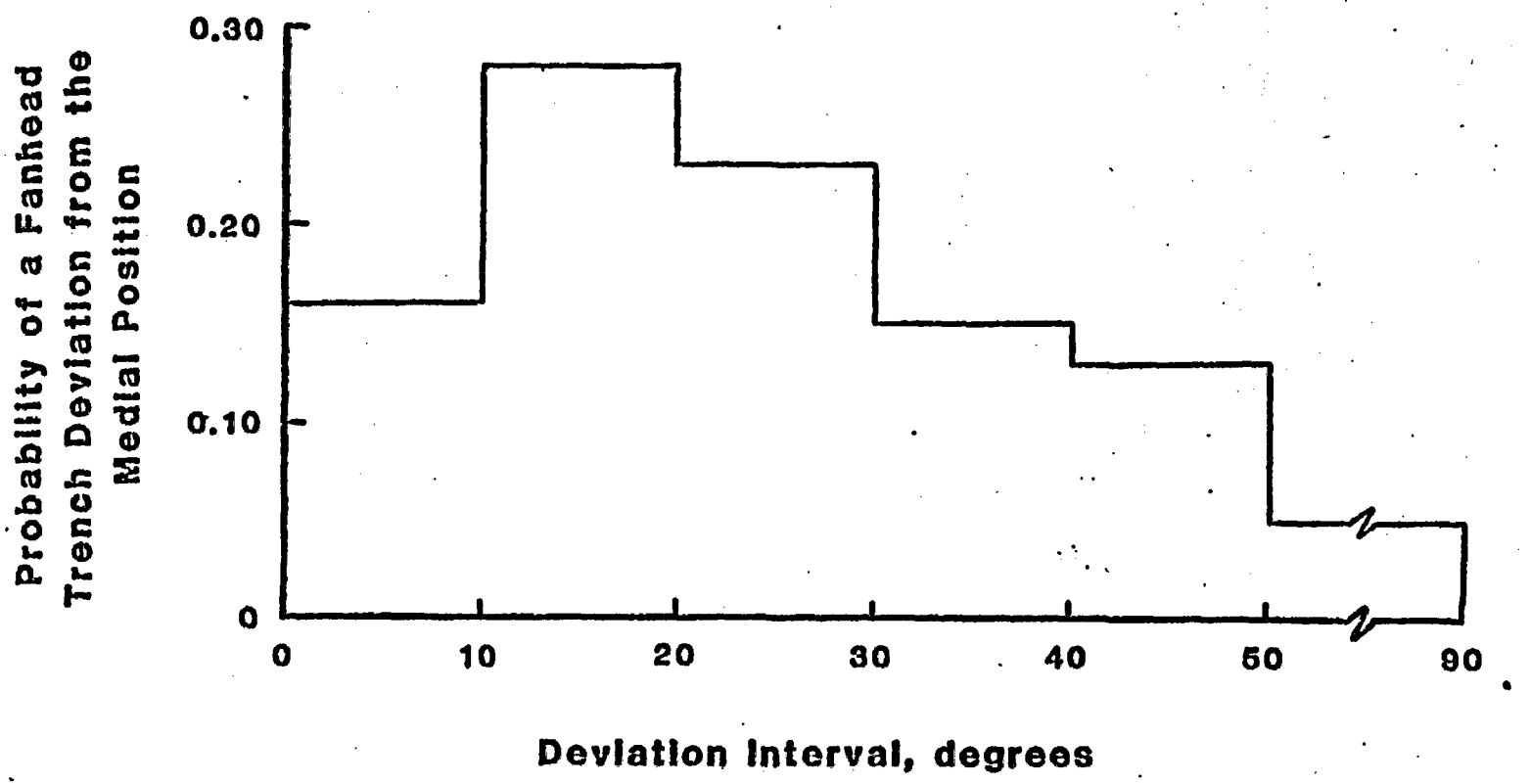

FIGURE 19: Probability of a Channel Deviation from the Medial Position on Fanheads of Alluvial Fans in Parts of Fresno and Merced Counties, California

TABLE 15

SUMMARY OF PARAMETERS FOR ESTIMATING THE PROBABILITY OF A FLOOD "HIT" ON THE RWMS BY EQUATION (15) OR EQUATION (16)

Watershed	W_c ft	θ degrees	Γ degrees
1	3,500	5.	30.
2	3,700	12.	30.5
3	9,300	21.	44.
4	11,100	18.	36.
5	1,200	2.	14.

TABLE 16

ESTIMATE OF THE CONDITIONAL PROBABILITY OF A FLOOD HITTING THE WASTE MANAGEMENT SITE ASSUMING THAT THE CHARACTERISTIC SITE LENGTH IS 2,800 FT AND USING THE CHANNEL TOP WIDTH ESTIMATES OF CHRISTENSEN AND SPAHR, (1980)

Return Period yrs	Watershed 1 p(x|f) by		Watershed 2 p(x|f) by		Watershed 3 p(x|f) by		Watershed 4 p(x|f) by		Watershed 5 p(x|f) by	
	Eq(15)	Eq(16)	Eq(15)	Eq(16)	Eq(15)	Eq(16)	Eq(15)	Eq(16)	Eq(15)	Eq(16)
10	0.83	0.69	0.80	0.49	0.32	0.10	0.28	0.14	1.0	1.0
25	0.85	0.71	0.82	0.50	0.34	0.11	0.30	0.15	1.0	1.0
50	0.87	0.72	0.84	0.51	0.35	0.11	0.31	0.15	1.0	1.0
100	0.89	0.74	0.86	0.52	0.37	0.11	0.32	0.16	1.0	1.0
500	0.93	0.78	0.91	0.55	0.40	0.12	0.35	0.17	1.0	1.0
Maximum Potential Flood	1.0	0.83	1.0	0.61	0.56	0.29	0.51	0.26	1.0	1.0

diagonal of the RWMS or 2,800 feet. Since this characteristic length is larger than the width of the alluvial fan below Watershed 5 at the RWMS, the probability of a flood originating in this watershed hitting the RWMS is one. In all cases, the probability of a flood event hitting the site is rather high, but recall that the probabilities summarized in this table are conditional probabilities.

The data summarized in Table 16 provide the basis for the assessment of the risk or probability that an event will occur at least once in a design life of N years. By definition,

$$R = 1 - [1 - p(x)]^N \qquad (17),$$

where R = risk and p(x) = probability that event x will occur, (Viessman et al. 1972). For example, if the design life of the RWMS is 100 years, what is the probability that a flood event with a return period of ten years and originating from Watershed 1 will hit the site at least once in 100 years? By definition, the probability of a flood event with a return period of ten years occurring is:

$$p(f) = \frac{1}{10} = 0.10$$

From Table 16, the probability of a flood with a ten year return period and generated in Watershed 1 hitting the site is:

$$p(x|f) = 0.83,$$

where Equation (15) was used to estimate p(x|f). Based on the definition of conditional probability:

$$p(x) = p(x|f)\ p(f) = 0.83(0.1) = 0.083 \qquad (18)$$

then the risk of the site being hit at least once in its design life, by a flood event originating at Watershed 1 with a return period of ten years, is by Equation (17):

$$R = 1 - [1 - p(x)]^N = [1.0 - 0.083]^{100} = 1.00.$$

In Table 17, the risk that the RWMS will be hit at least once in its design life by a flood event of a given return period and originating in a specified watershed is summarized. Since risk is a probability, it cannot, by definition, be greater than one or less than zero. In the first two columns of this table the watershed and return period are identified. In the next four columns the flood corresponding to the return period is described. In the last two columns the risk of the flood described in the preceding columns hitting the RWMS at least once during its design life is estimated. An example of the correct interpretation of the information in this table is given at the bottom of the table.

A careful examination of Table 17 demonstrates that the risk the RWMS will be hit at least once during its design life by a flood event whose return period is one hundred years or less is very high. The risk that the RWMS will be hit at least once during its design life by a flood event whose return period is greater than one hundred years but less than or equal to five hundred years ranges from a low of 0.02 (Watershed 3) to a high of 0.42 (Watershed 2).

An alternative technique for determining the design event, which results in a specified risk to a facility, is to first define the risk which is acceptable and then determine p(x) in Equation (17) where the design life of the facility

TABLE 17

ASSESSMENT OF RISK* AT THE RADIOACTIVE WASTE MANAGEMENT SITE ASSUMING A DESIGN LIFE OF 100 YEARS AND CHARACTERISTIC LENGTH OF 2800 FEET.

		Estimated Flood Parameters				Risk	
Watershed/ Alluvial Fan (1)	Return Period Years (2)	Flow Rate ft^3/s (3)	Channel Width ft (4)	Depth of Flow ft (5)	Velocity of Flow ft/s (6)	$p(x\|f)$ by Eq (15) (7)	$p(x\|f)$ by Eq (16) (8)
1	10	92	60	0.4	4	1.0	1.0
	25	285	90	0.7	5	0.97	0.94
	50	594	120	0.9	6	0.83	0.77
	100	1146	160	1.2	6	0.59	0.52
	500	3020	230	1.7	8	0.17	0.14
2	10	173	80	0.6	4	1.0	0.99
	25	502	110	0.8	6	0.96	0.87
	50	1010	150	1.1	6	0.82	0.64
	100	1876	190	1.4	7	0.58	0.41
	500	5300	290	2.2	8	0.17	0.42
3**	10	792	110	1.0	7	0.96	0.63
	25	1959	200	1.5	7	0.75	0.36
	50	3582	250	1.8	8	0.50	0.20
	100	6058	310	2.3	8	0.31	0.10
	500	15800	450	3.3	11	0.08	0.02
4	10	1268	170	1.2	6	0.94	0.76
	25	3058	240	1.7	7	0.70	0.45
	50	5512	300	2.2	8	0.46	0.26
	100	9179	370	2.7	9	0.27	0.15
	500	23800	540	3.9	11	0.07	0.03
5	10	45	40	0.3	4	1.0	1.0
	25	147	70	0.5	4	0.98	0.98
	50	320	100	0.7	5	0.87	0.87
	100	641	130	0.9	5	0.63	0.63
	500	1860	190	1.4	7	0.18	0.18

*Note: Risk is the probability of the site being hit at least once during its design life by a flood whose magnitude is expressed in terms of return period.

This series of lines summarizes the risk to the RWMS from floods originating in Watershed 3. For example, the event which on the average occurs once every ten years (column 2), has an estimated magnitude of 792 ft^3/s (column 3); will form a channel 110 ft wide (column 4) with a depth of 1.0 ft (column 5); the velocity of flow will be 7 ft/s (column 6); and the risk that this event will hit the RWMS ranges from 0.63 to 0.96 (columns 7 and 8).

is known. In many cases of interest once p(x) is known, the return period of the design event can be determined from the definition of return period or

$$T_R = \frac{1}{p(x)} \qquad (19)$$

where T_R = return period. However, in this case, p(x) is the product of p(x|f) and p(f), Equation (18). In addition, p(x|f) is a function of p(f). Therefore, in this case, an explicit solution of Equation (17) for the return period of the design event is not possible.

It is, however, instructive to combine Equation (17) and (19), then solve them for T_R, ignoring for a moment the value of T_R, which does not have its traditional meaning given by this analysis. If this is done, then

$$T_R = \frac{1}{1 - (1-R)^{1/N}} \qquad (20).$$

The results of this analysis for various values of R and N are summarized in Table 18. The interpretation of this table is: if $R \leq 10\%$, then the maximum probable flood event, Table 7, should be used as the design event.

TABLE 18
T_R AS A FUNCTION OF R AND N

Risk %	Return Period, T_R, in Years for Design Life of, Yrs. 100	150	200
50	144	217	289
40	196	294	392
30	281	421	561
20	448	673	897
15	615	923	1,230
10	950	1,420	1,900
5	1,950	2,920	3,900
2	4,950	7,420	9,990
1	9,950	14,900	19,900
0.1	100,000	150,000	200,000

CONCLUSIONS AND COMMENTS

The preliminary assessment of flood hazard at the Radioactive Waste Management Site indicates that the risk is high. The site will be hit at least once during its design life by a flood event of significant size, and the potential for the site to be hit several times during its design life is also high. It should be noted and emphasized that the flood hazard at the RWMS is not higher than it would be for any facility of a similar size and design life located on any alluvial fan in Southern Nevada. Further, the berm on the upslope side of the RWMS may offer some protection from flooding; however, the degree of protection provided by this berm was not evaluated.

The validity of the above conclusion depends on the following:

1. The validity and accuracy of both the methodology and equations used to estimate peak flood flows.

2. The validity and accuracy of both the methodology and equations used to estimate the width of the channel formed by a flood flow across an alluvial fan.

3. The validity and accuracy of the equations used to estimate the probability of a flood event either hitting a point or a structure of finite size.

4. The accuracy with which the alluvial fans on which the site is located were defined.

The accuracy and validity of the method and equations used to estimate the peak flood flows are questionable. The

primary problem with this type of analysis, in an arid or semi-arid region such as Southern Nevada, is the paucity and possible skew of the data on which the analysis is based. In contrast, estimates for the magnitude of the maximum potential flood in Southern Nevada are perhaps better.

The accuracy and validity of the methods used to estimate channel width are open to quesiton. The probability of a flood event hitting either a point or structure on the alluvial fan is also open to question. Very little is known about the passage of a flood event across a fan.

The accuracy with which the alluvial fans on which the RWMS is located were defined is high compared with the other assumptions inherent in the analysis.

Even given the noted limitations of the analysis, it can be logically and rationally concluded that there is a significant flood hazard at this site and the potential for relatively severe damage to the site during its design life is very real. Recall that the RWMS is apparently situated at the junction of major alluvial fans, to the east and west, with several smaller fans merging from the north. One should expect that the processes which have created these fans will continue into the forseeable future.

In conclusion, it should be noted that although protective measures for the site can be developed, the development of such mitigation plans should include not only a careful consideration of the probability that the site will be hit by a flood event, but also a careful consideration of the consequences of such a hit. This report is a focused analysis of the probability that the RWMS will be hit by a flash flood, but does not address what the consequences of such an event might be.

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APPENDIX I

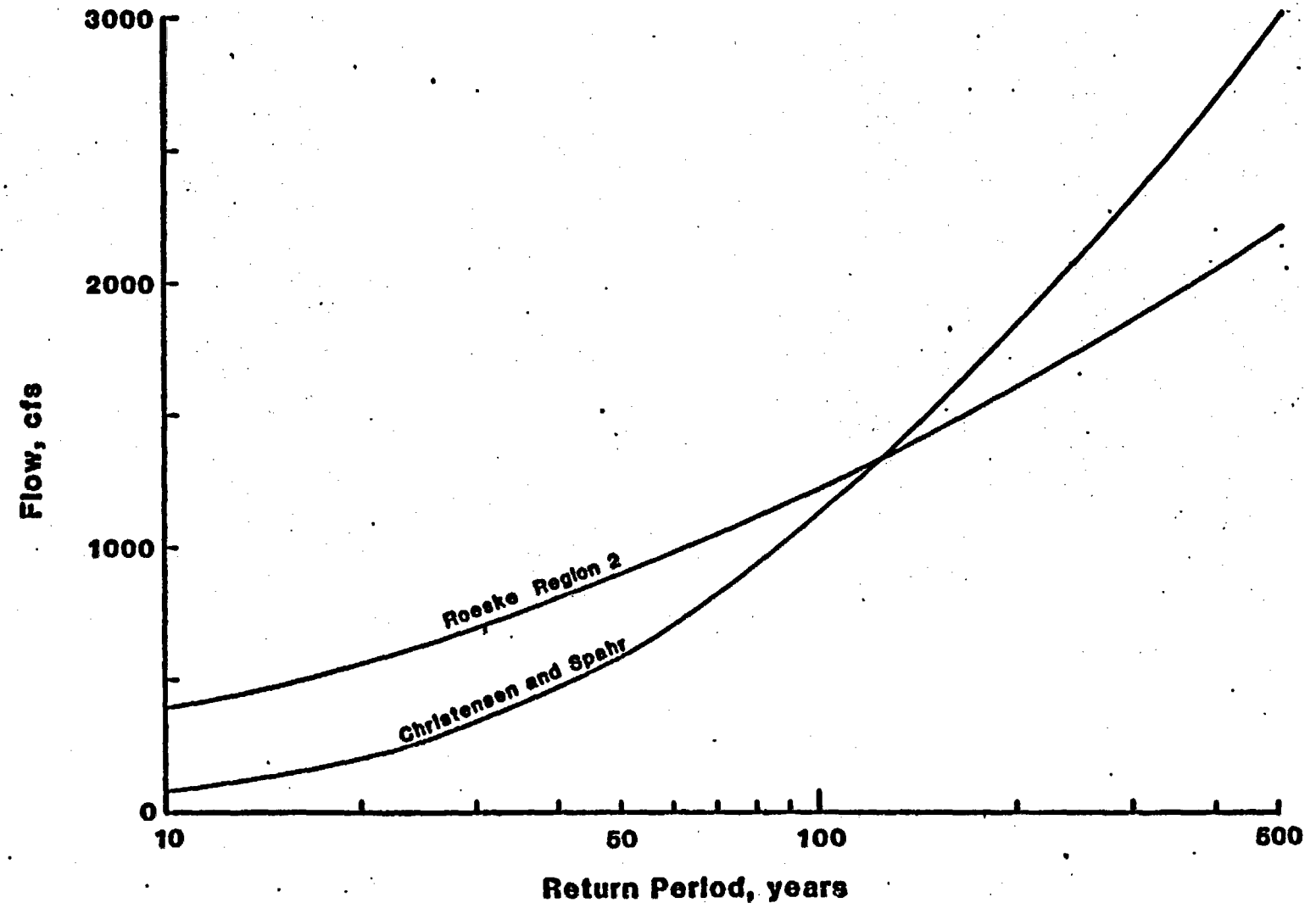


FIGURE 10: Peak Flood Flow Estimates for Watershed 1 Above 3500 Feet

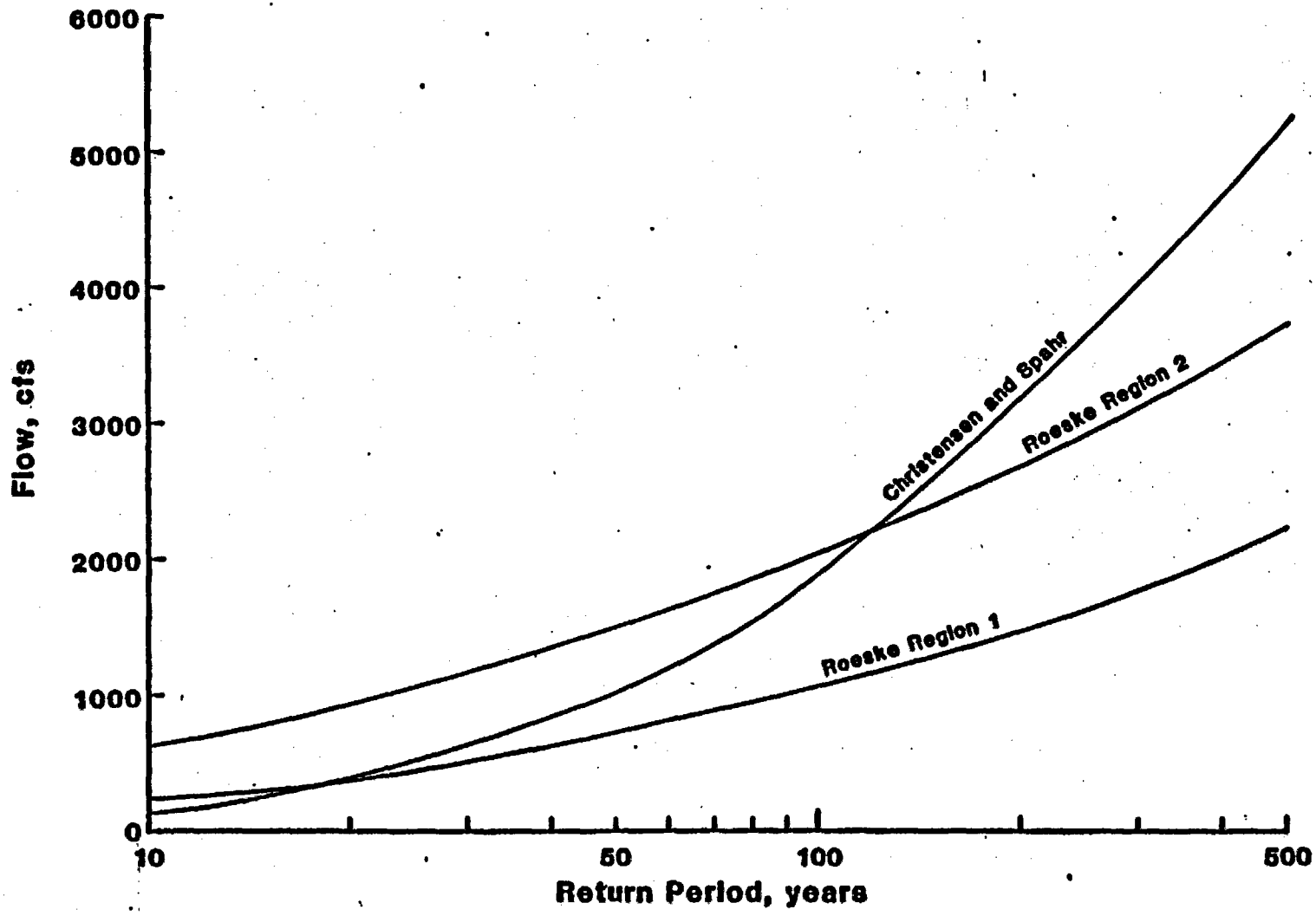


FIGURE 11: Peak Flood Flow Estimates for Watershed 2 Above 3500 Feet

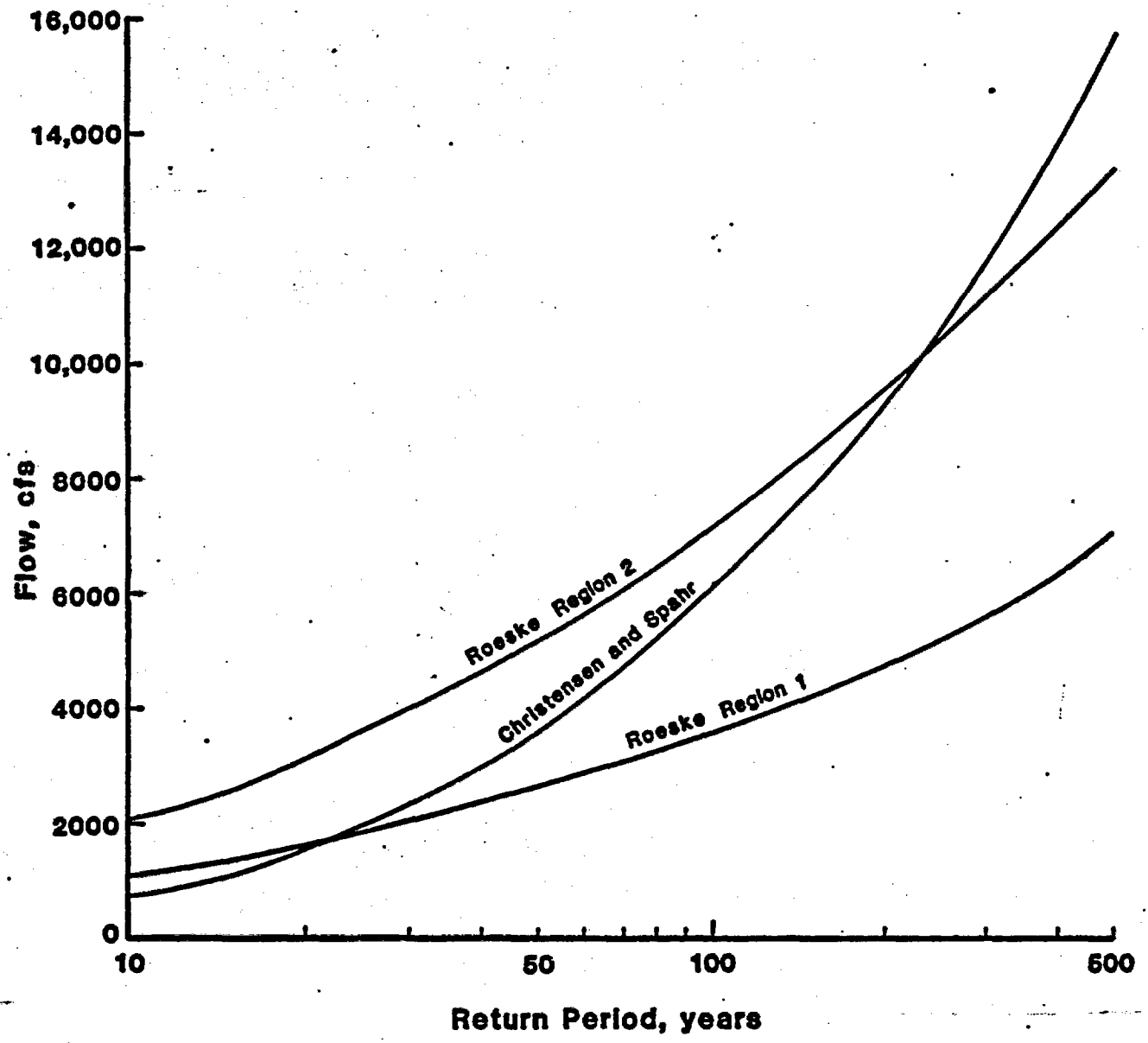


FIGURE 12: Peak Flood Flow Estimates for Watershed 3 Above 3500 Fe

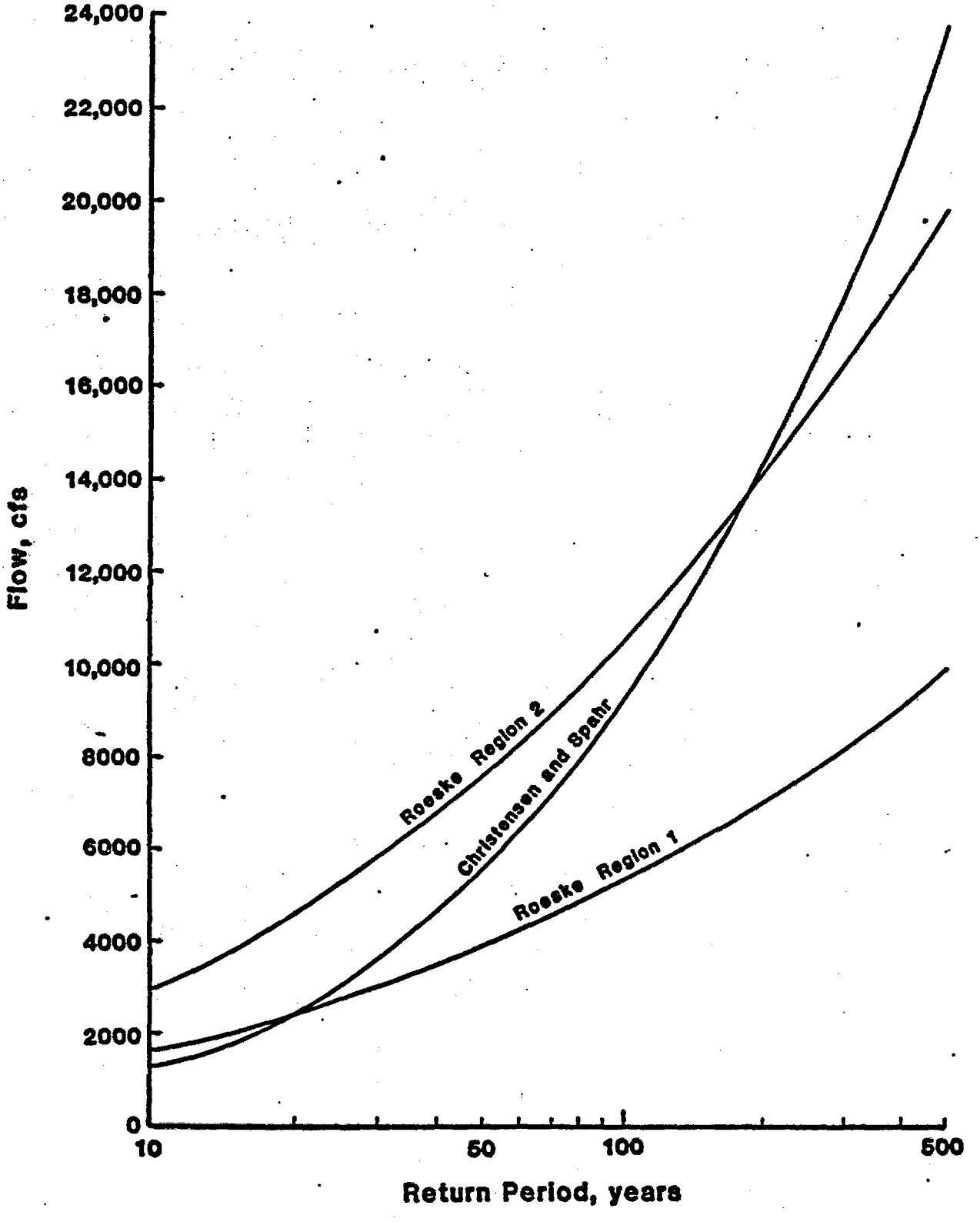


FIGURE 13: Peak Flood Flow Estimates for Watershed 4 Above 3500 Feet

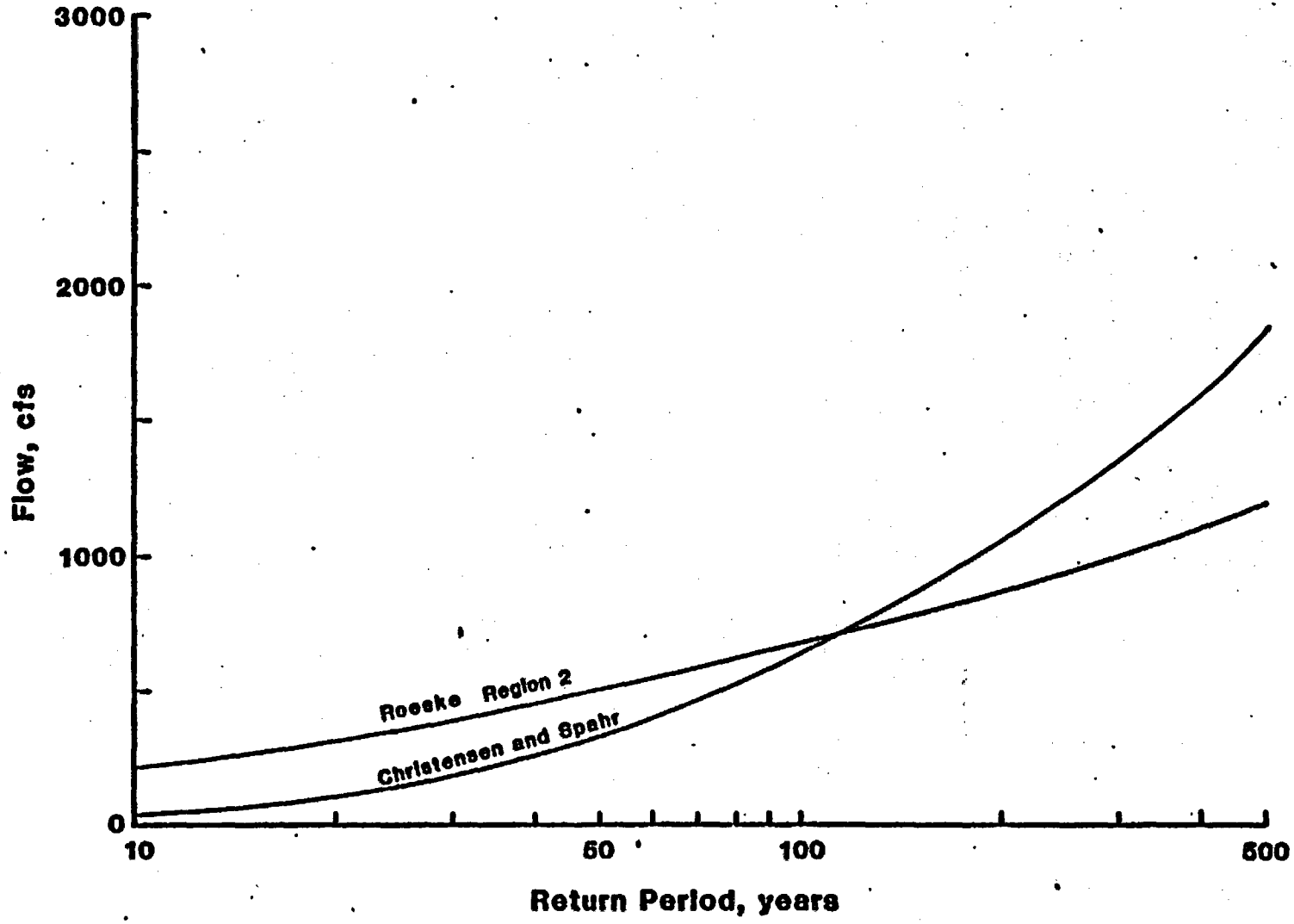
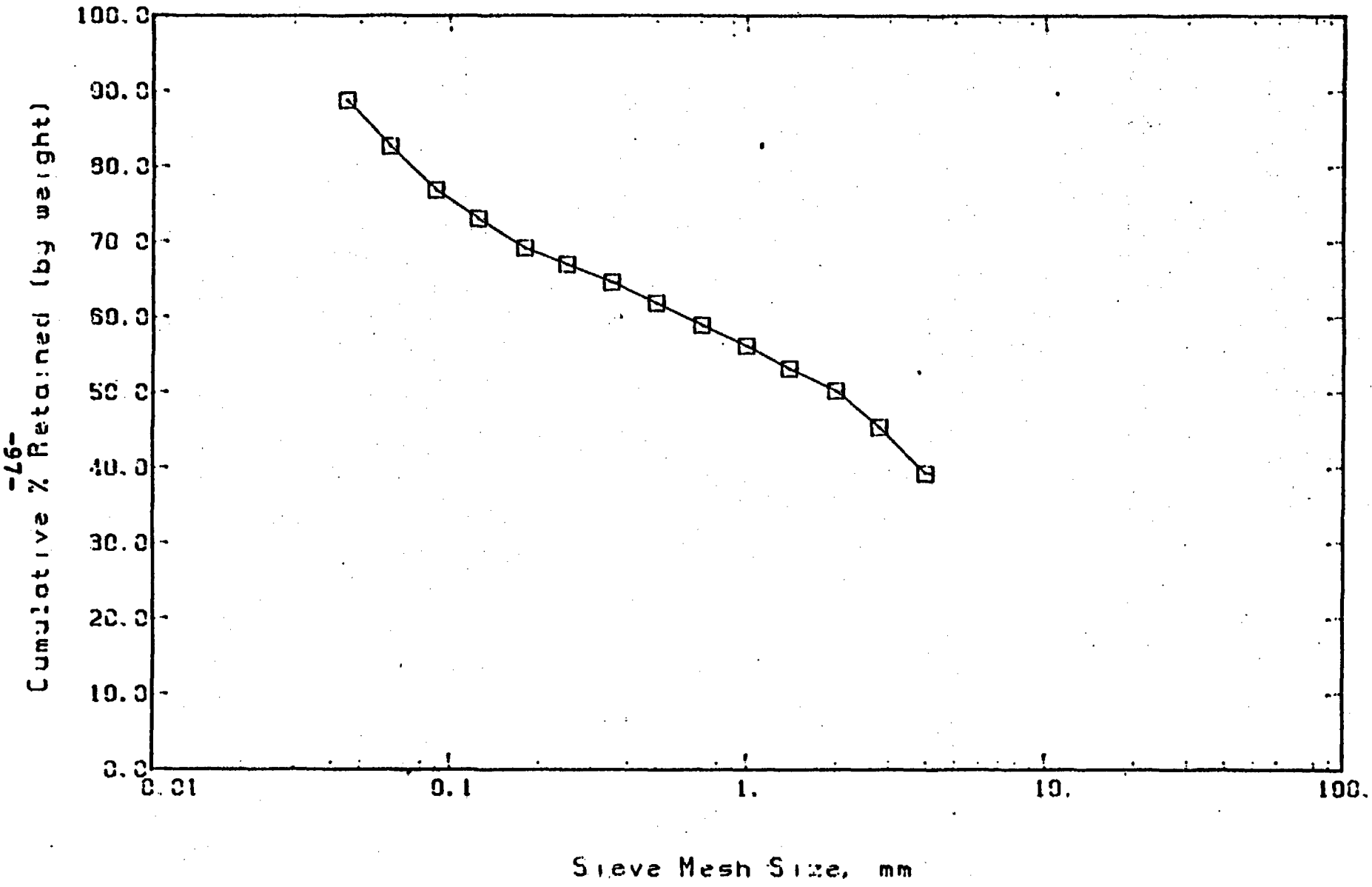
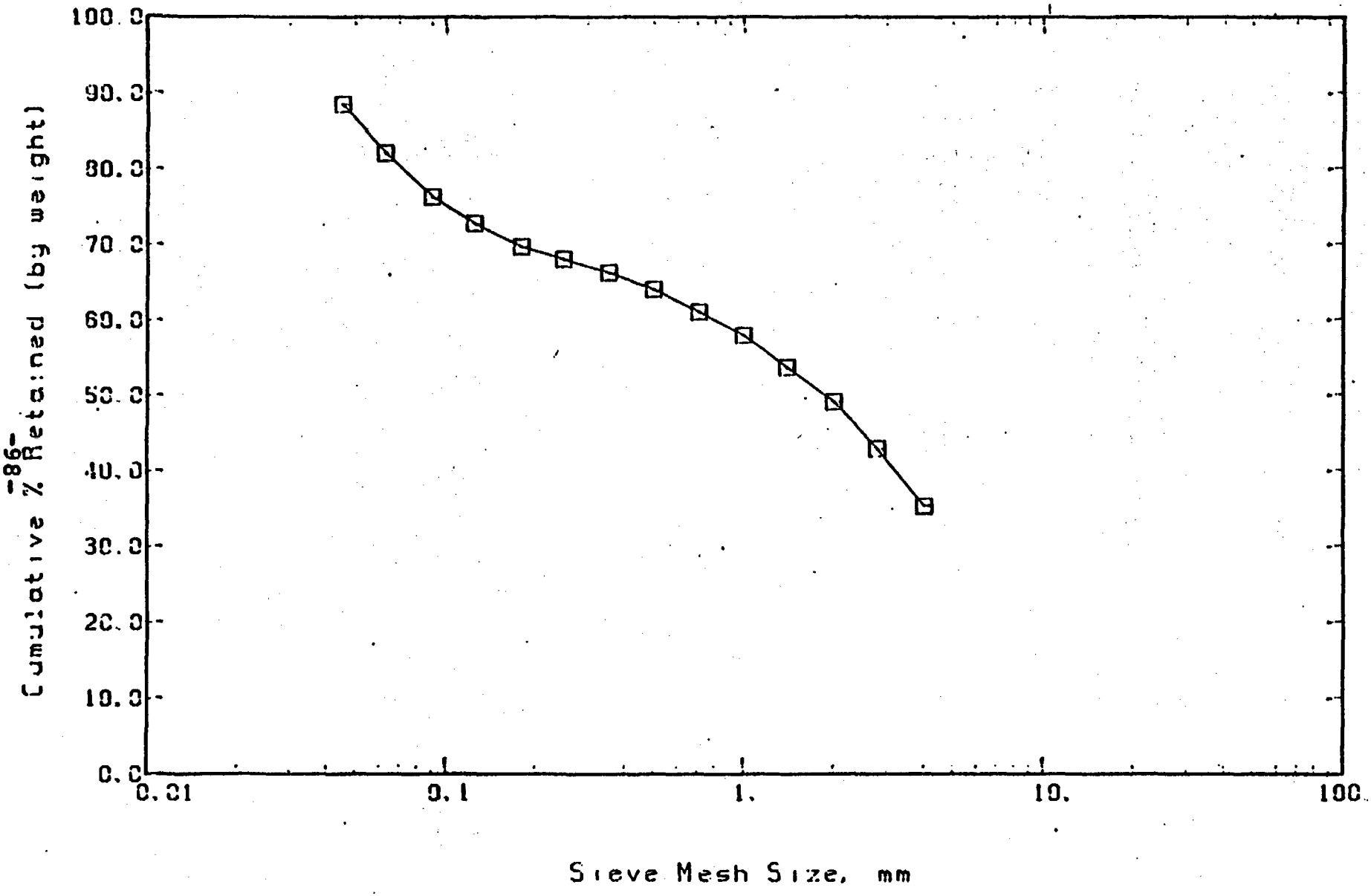


FIGURE 14: Peak Flood Flow Estimates for Watershed 5 Above 3500 Feet

APPENDIX II



Sieve Analysis for Material from Sample Site S-1



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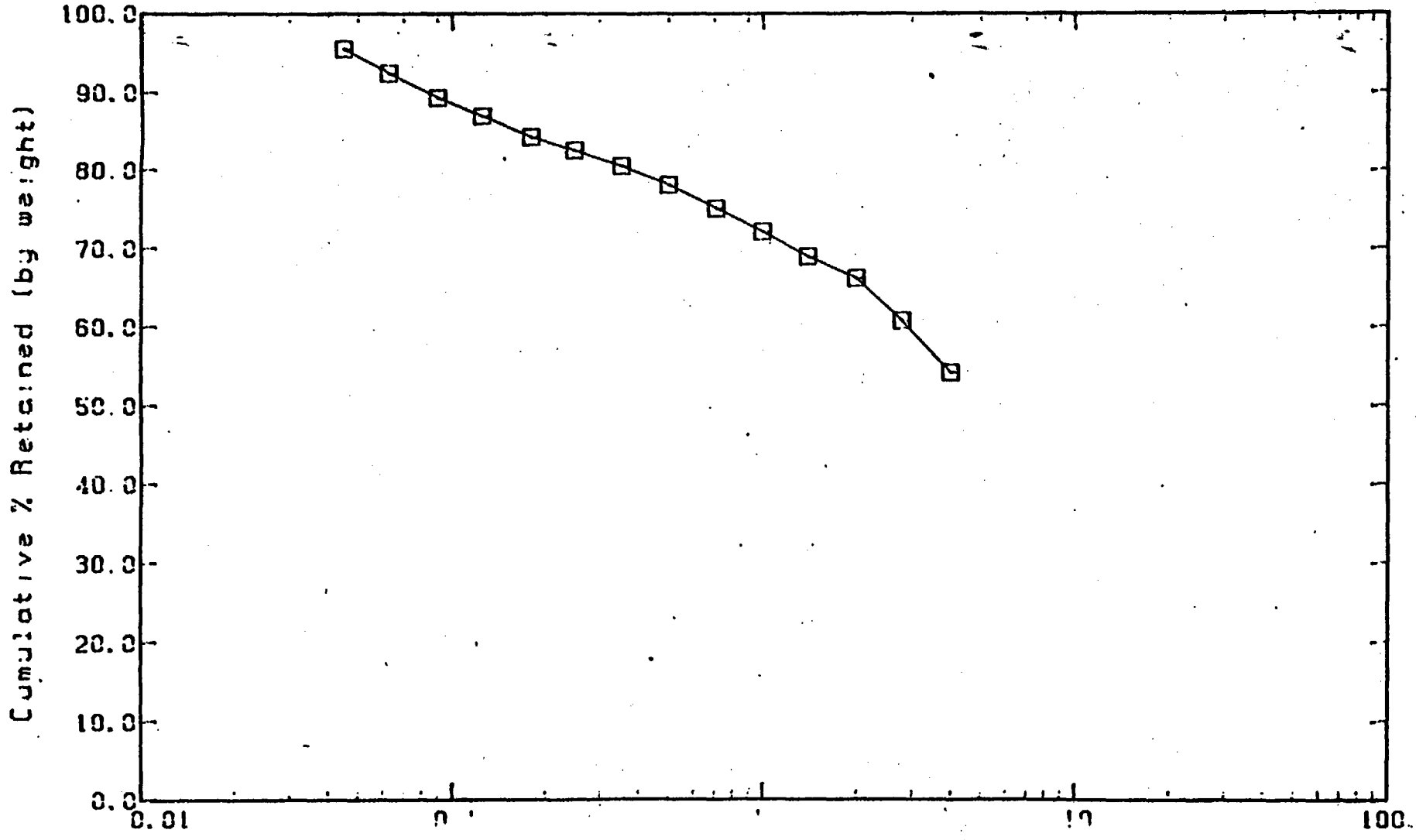

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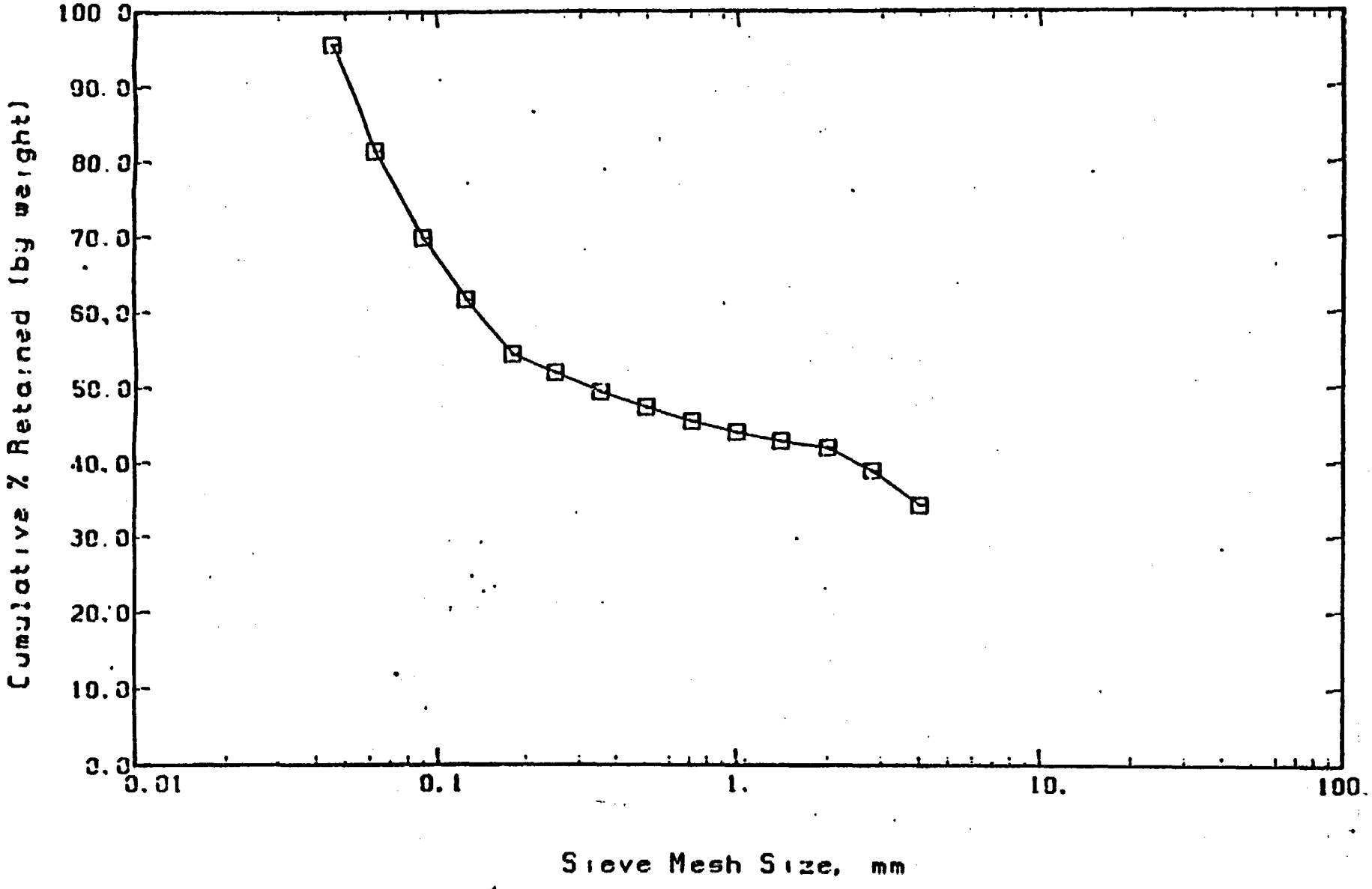
Sieve Mesh Size, mm



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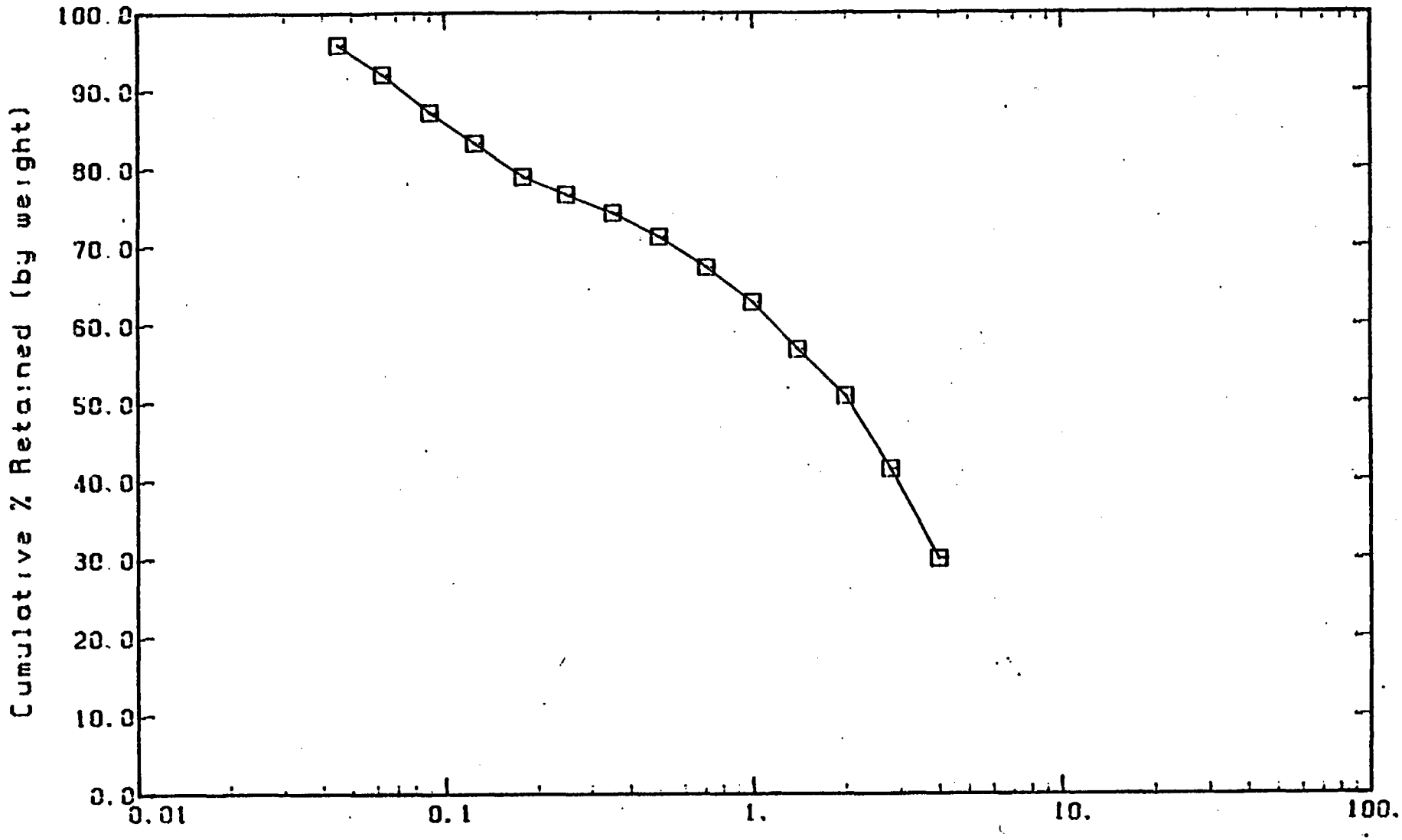

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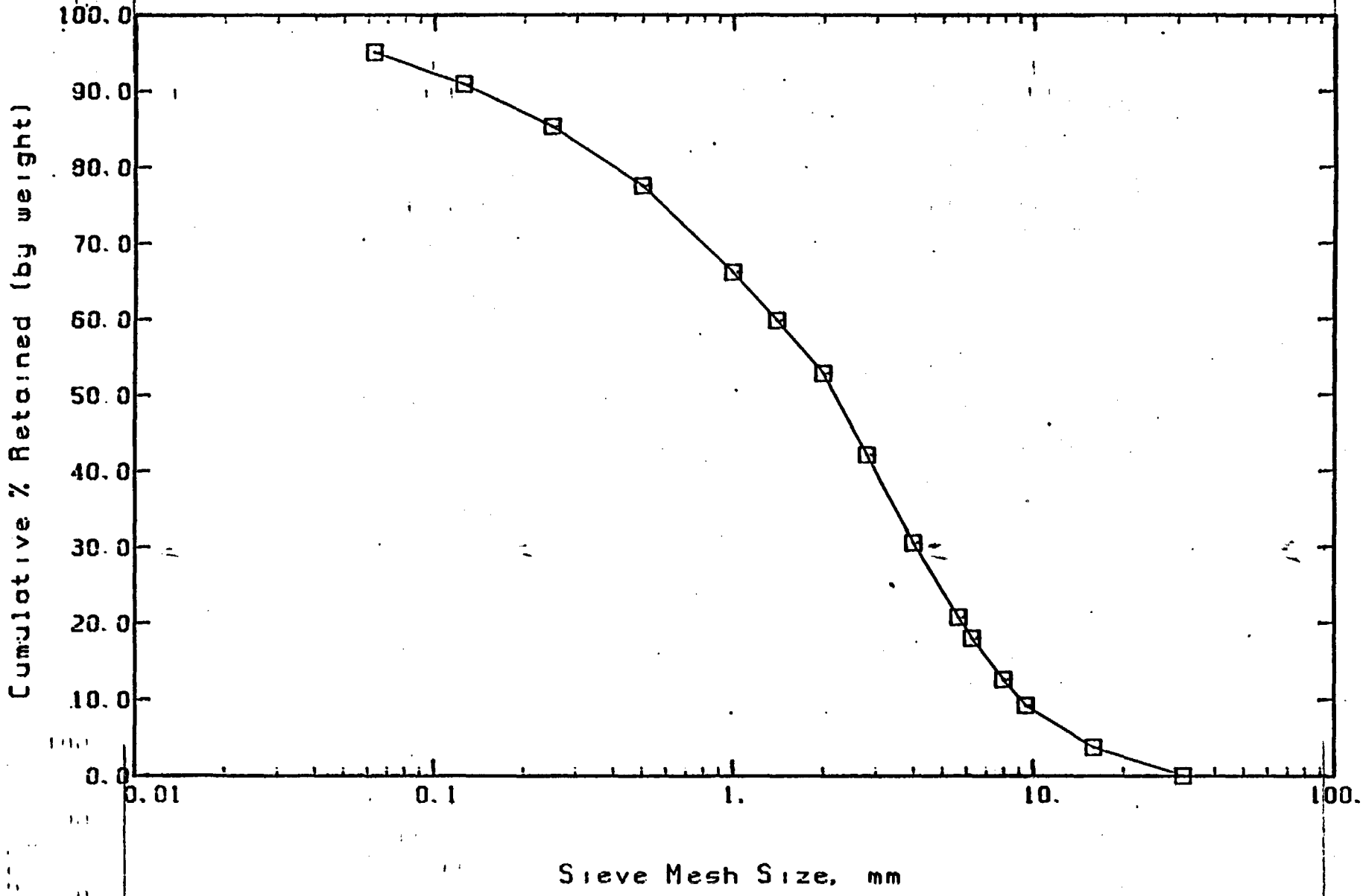

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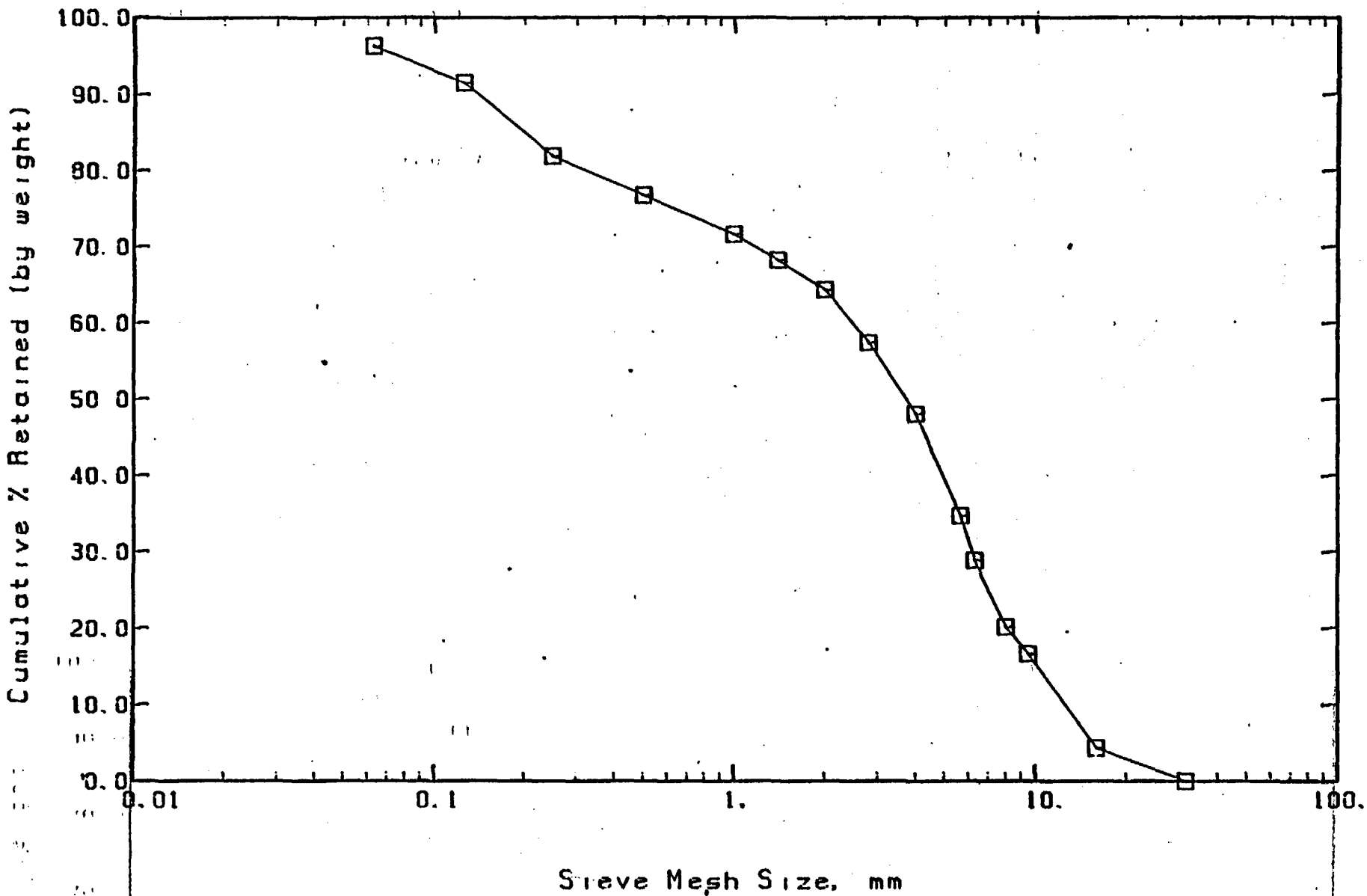

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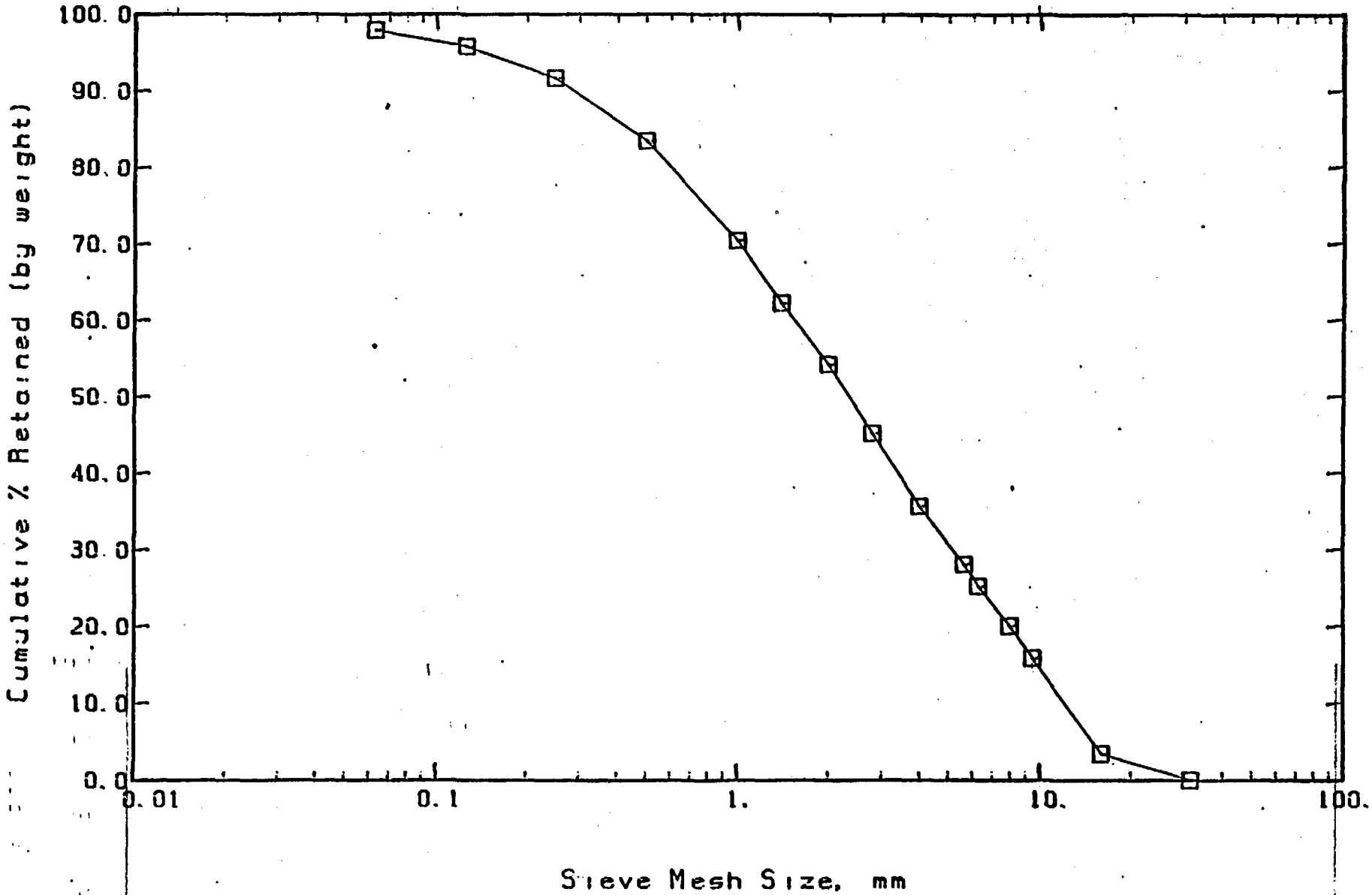

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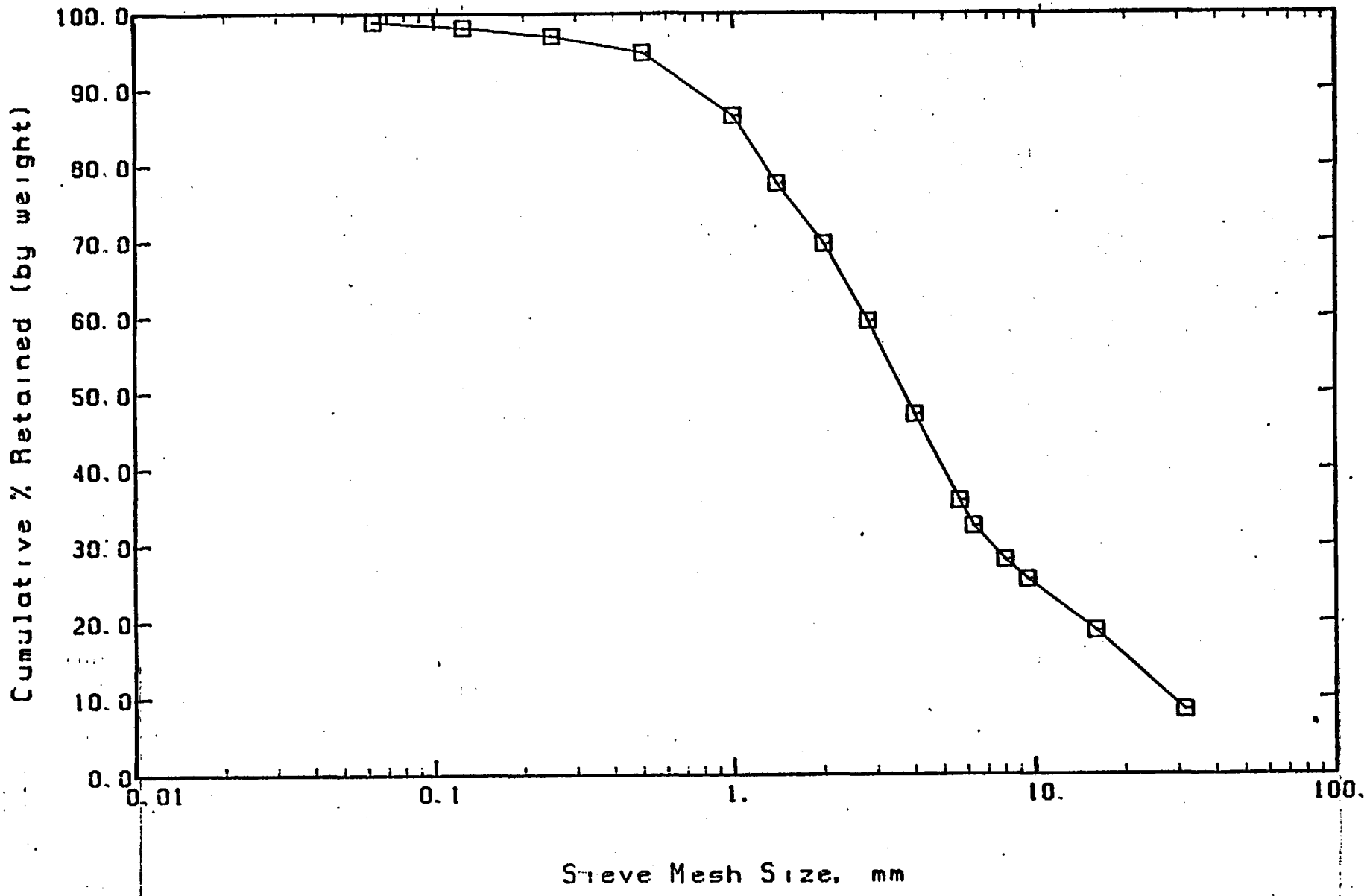

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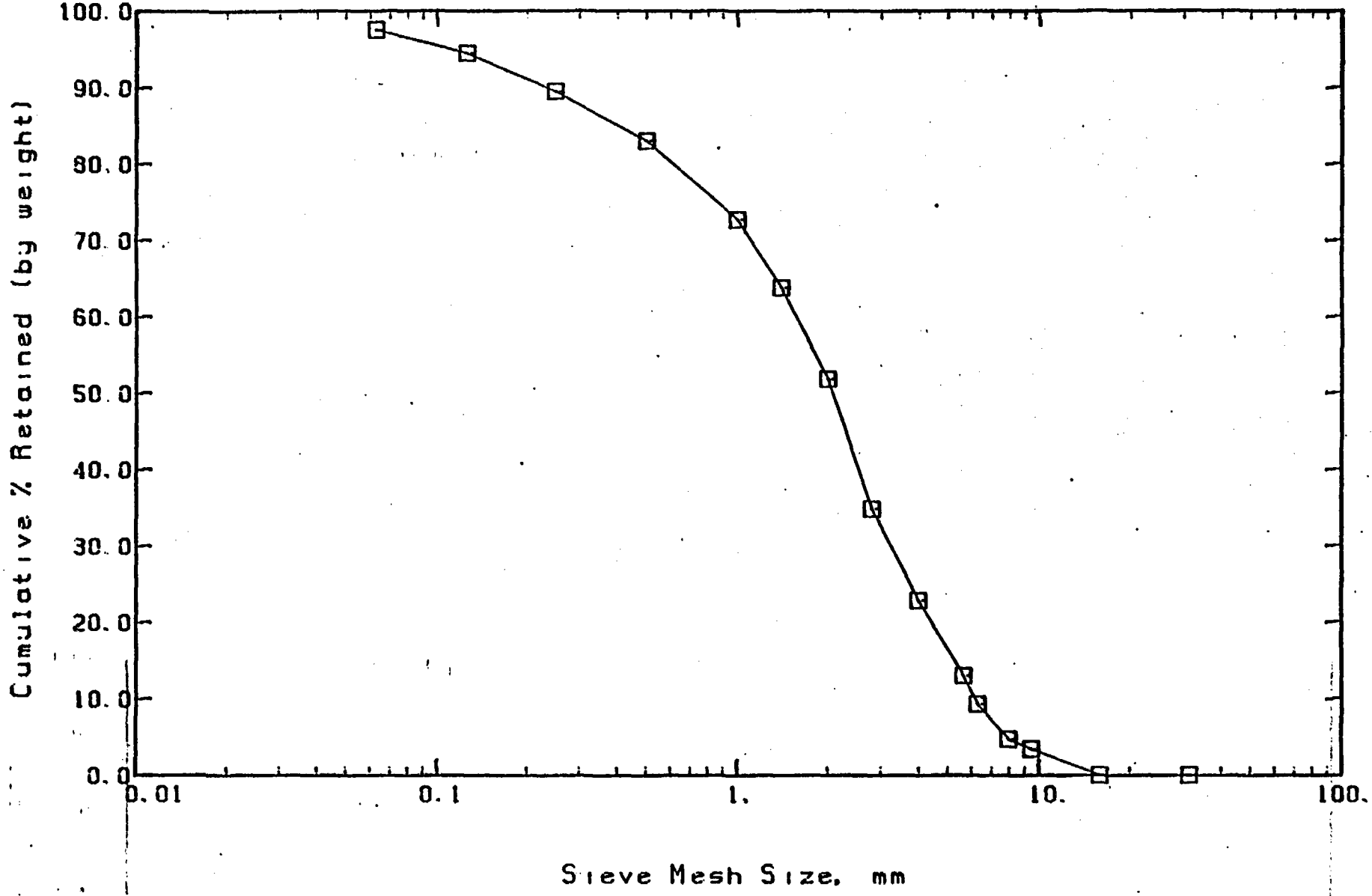

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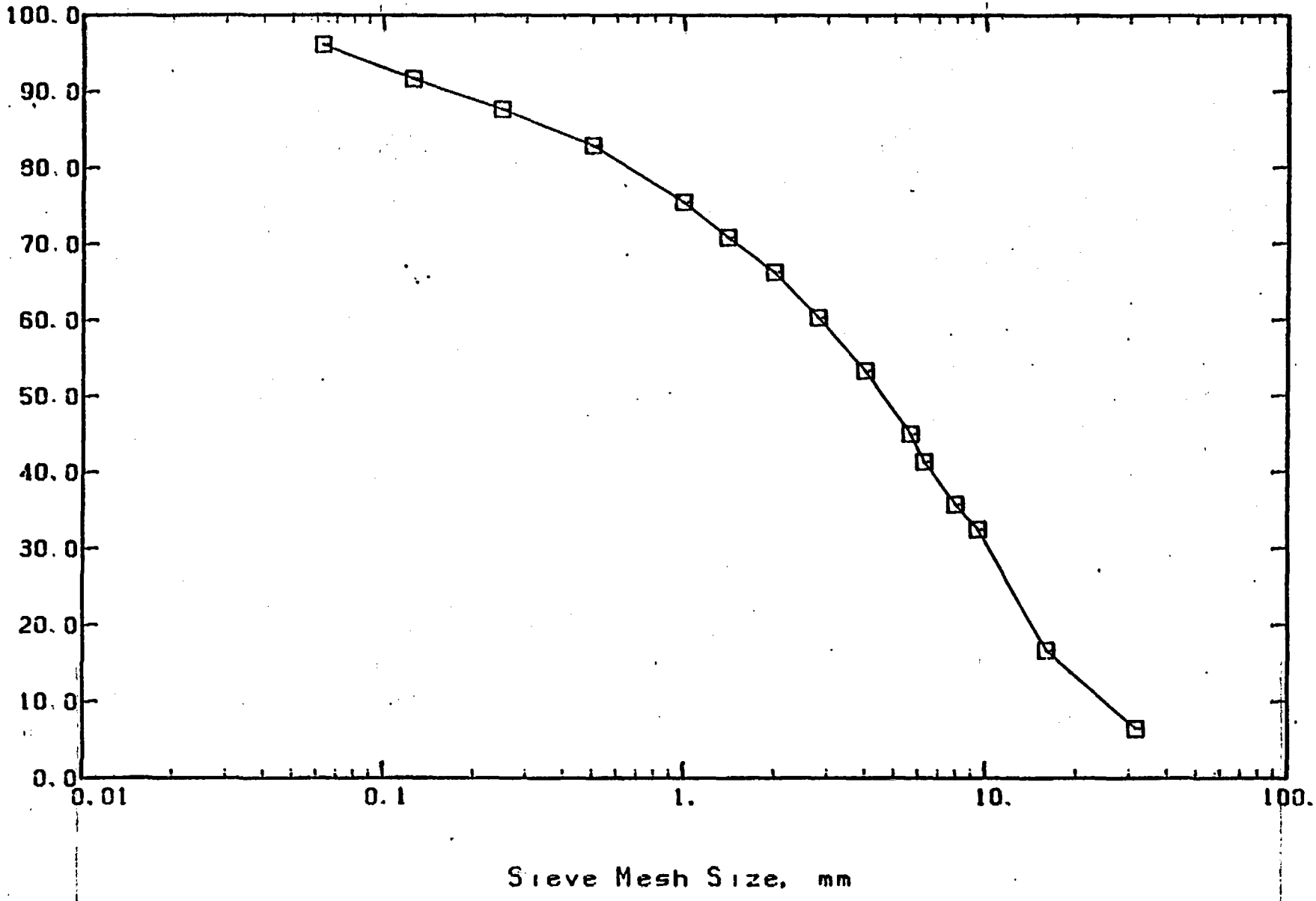

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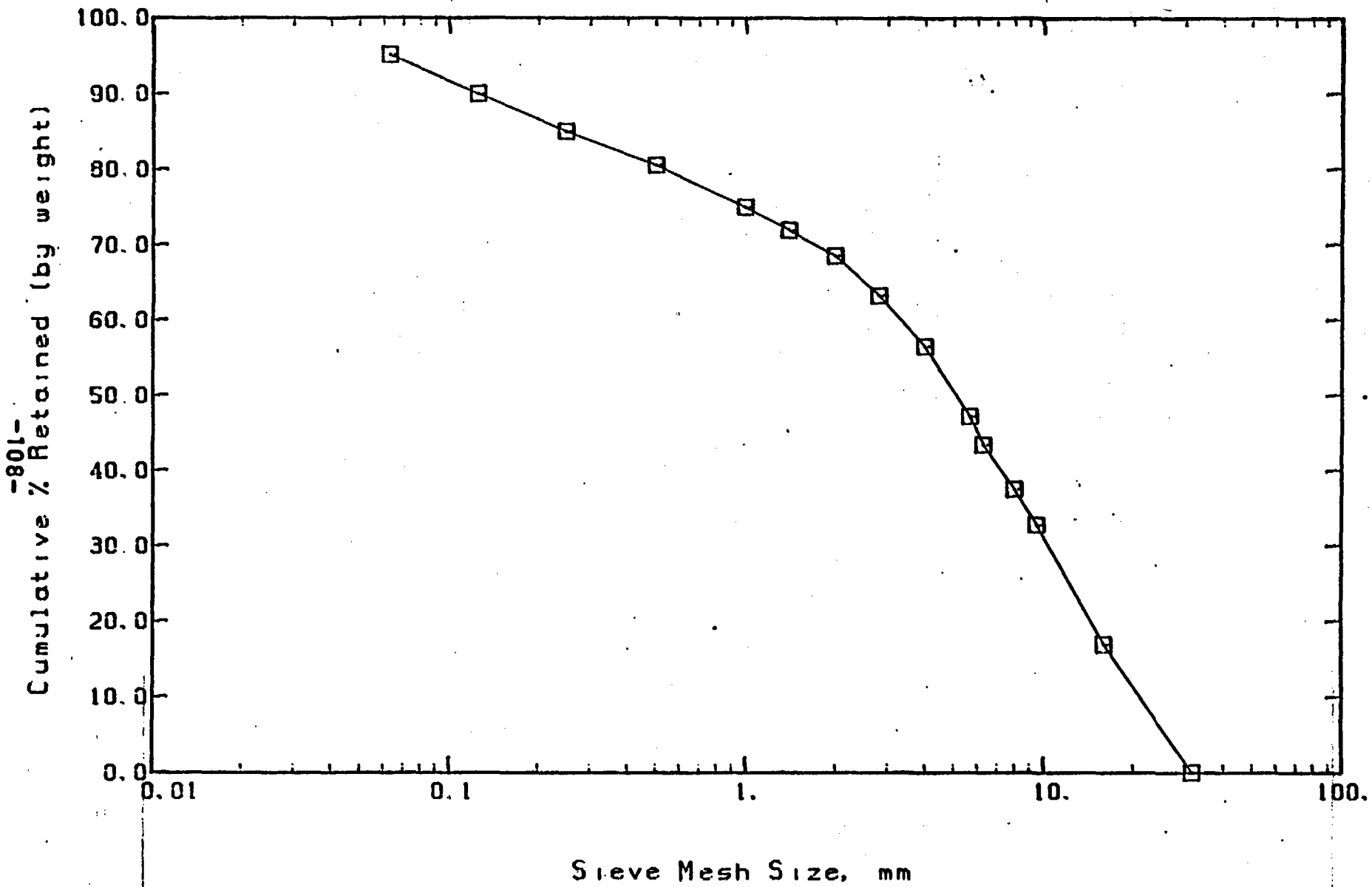

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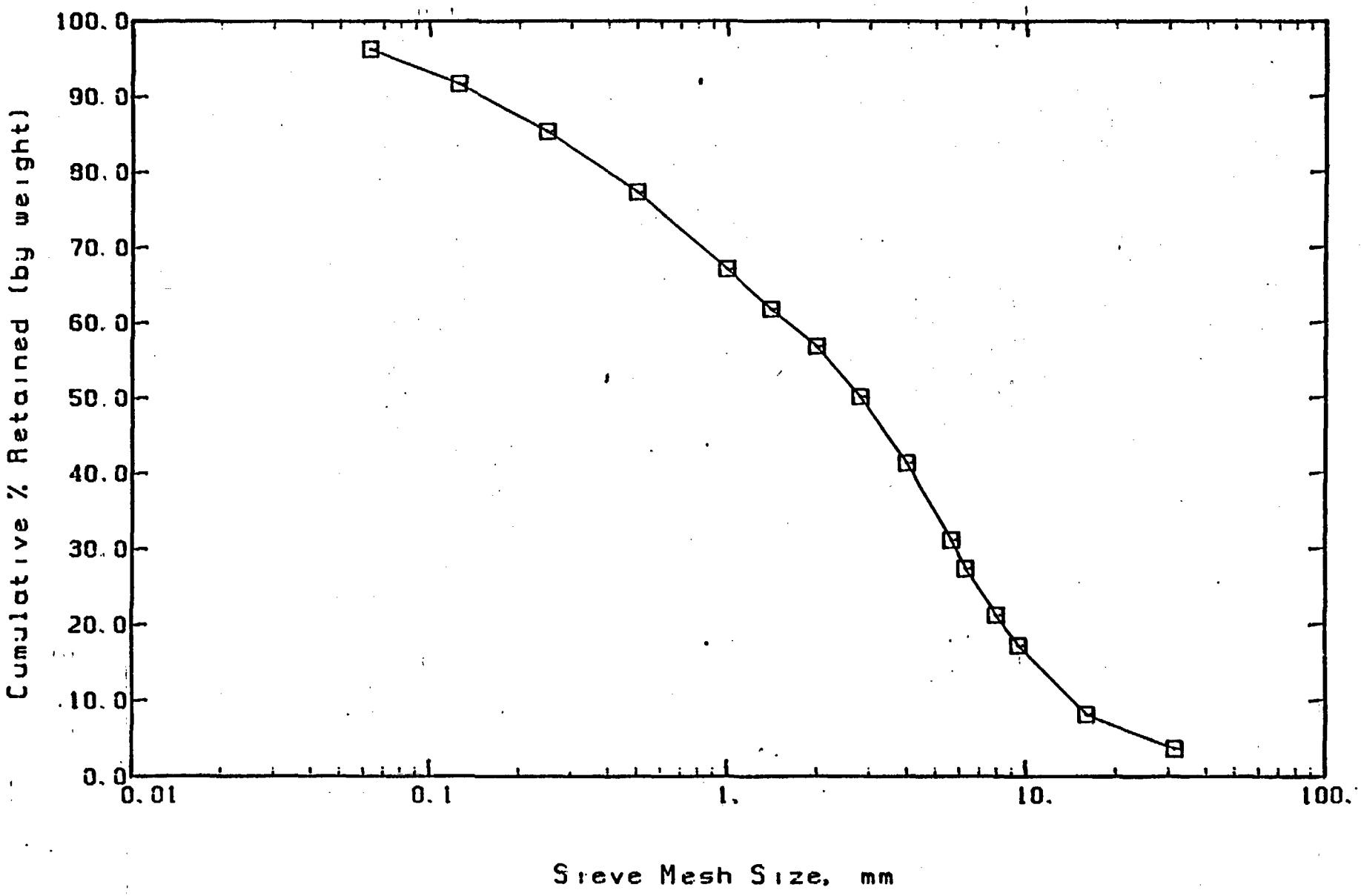

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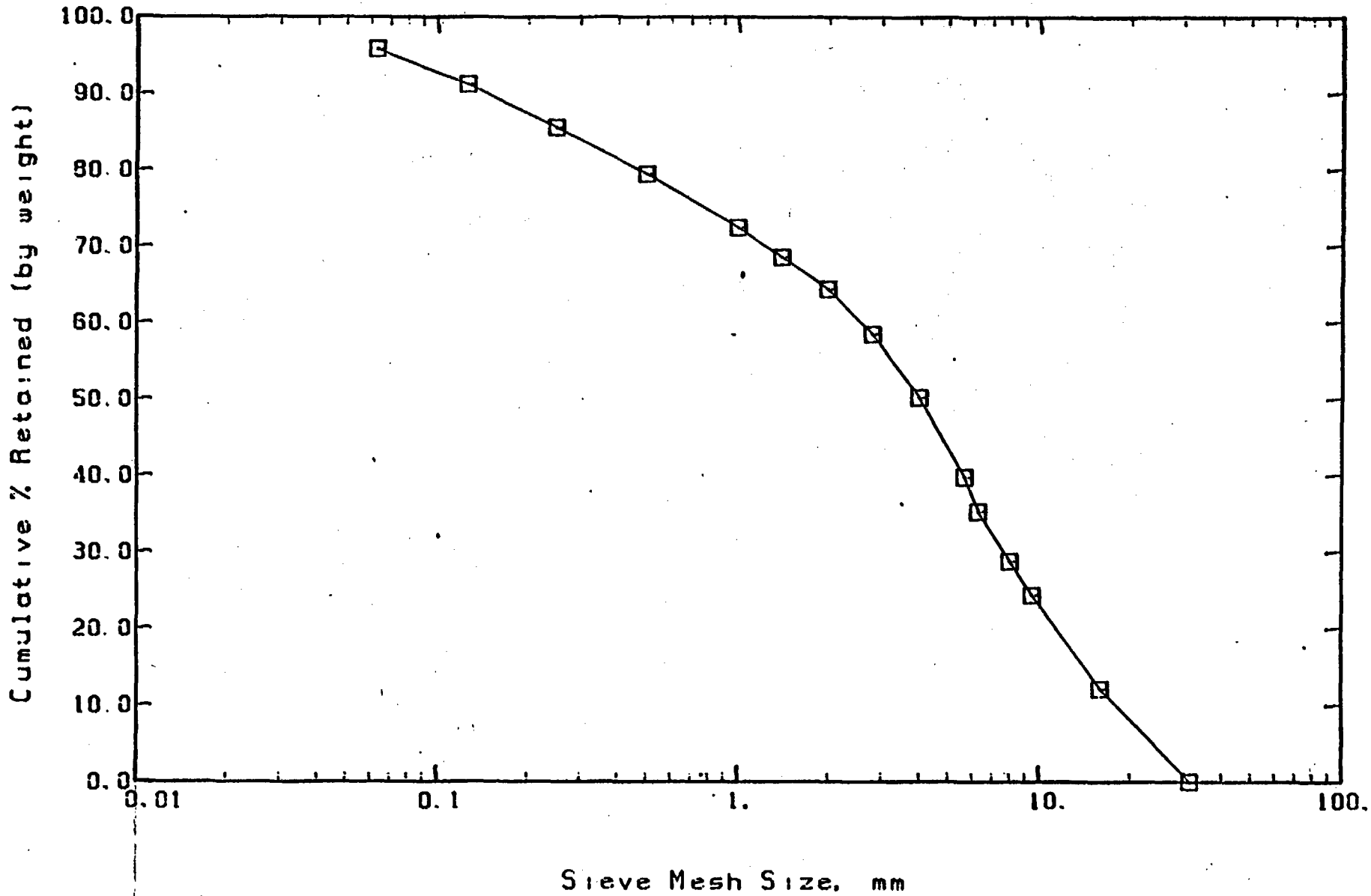

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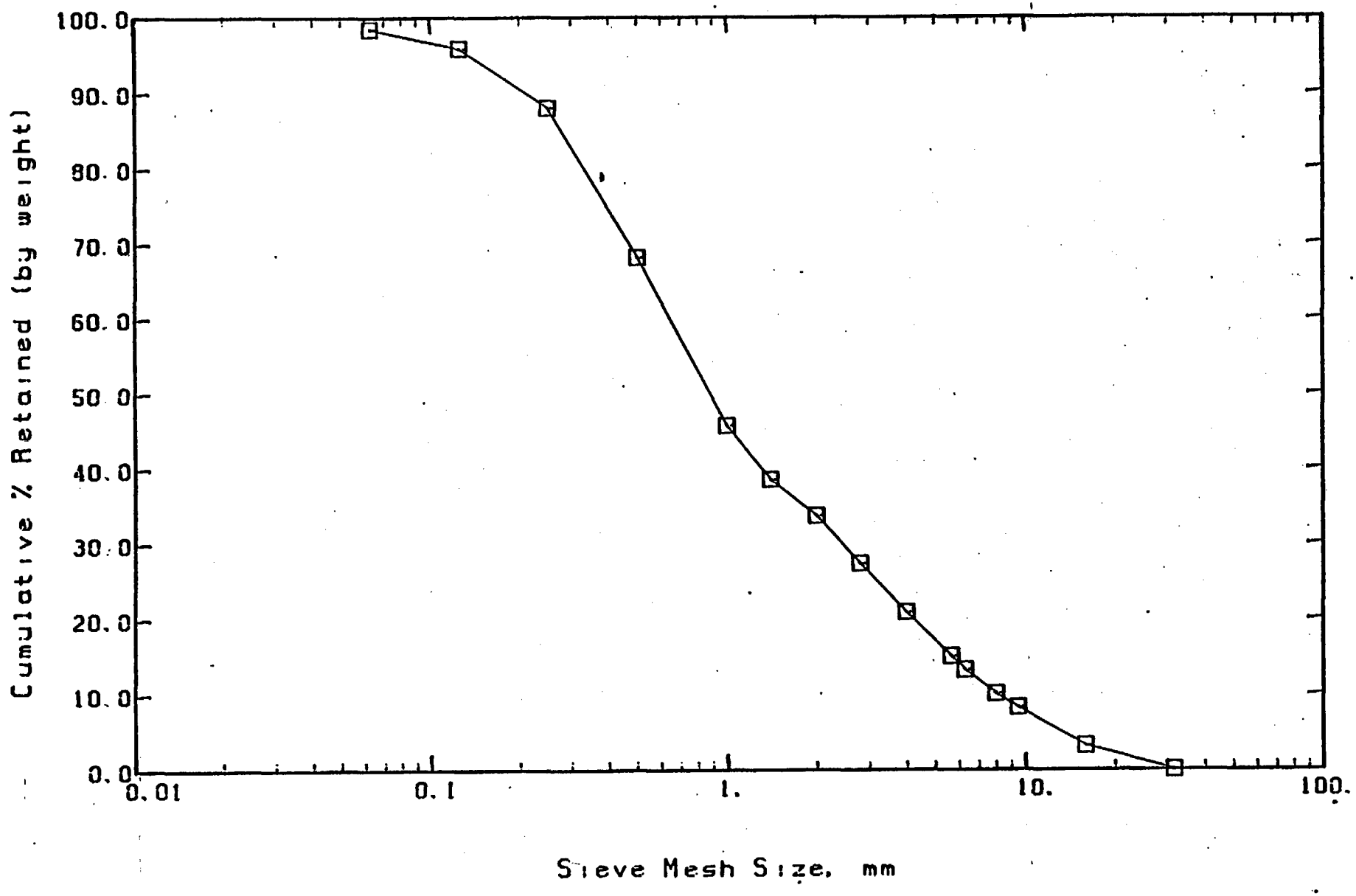

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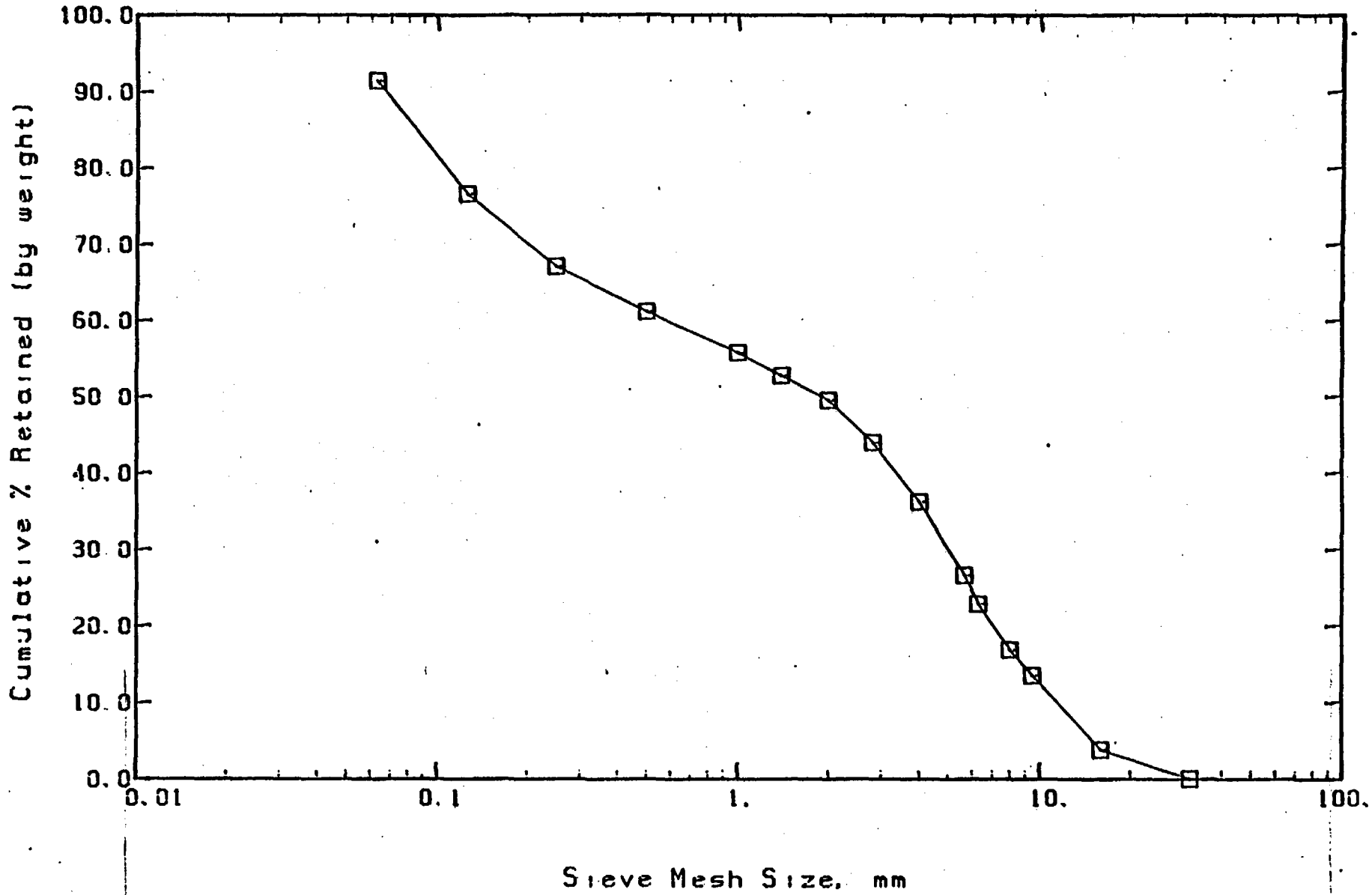

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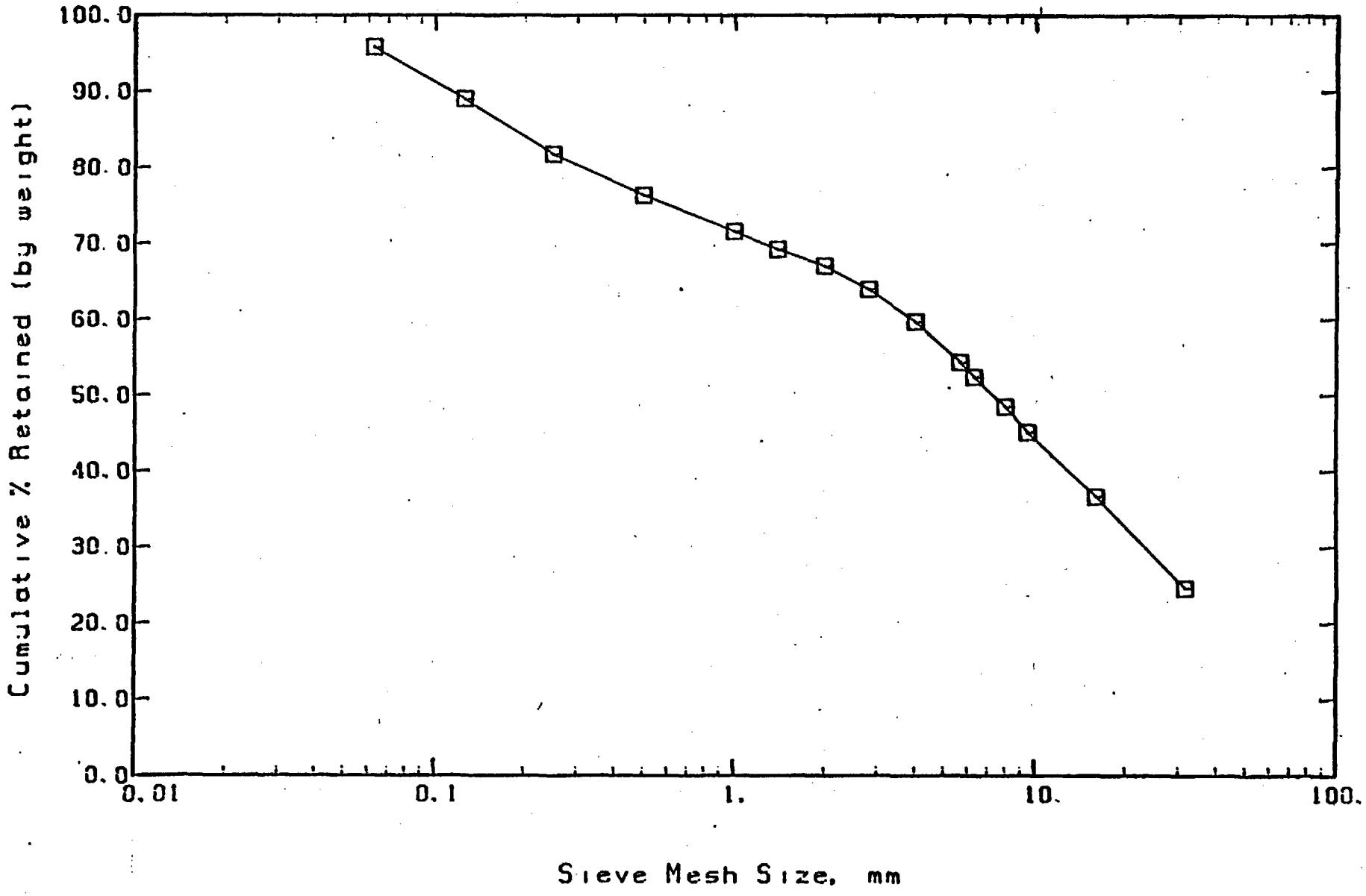

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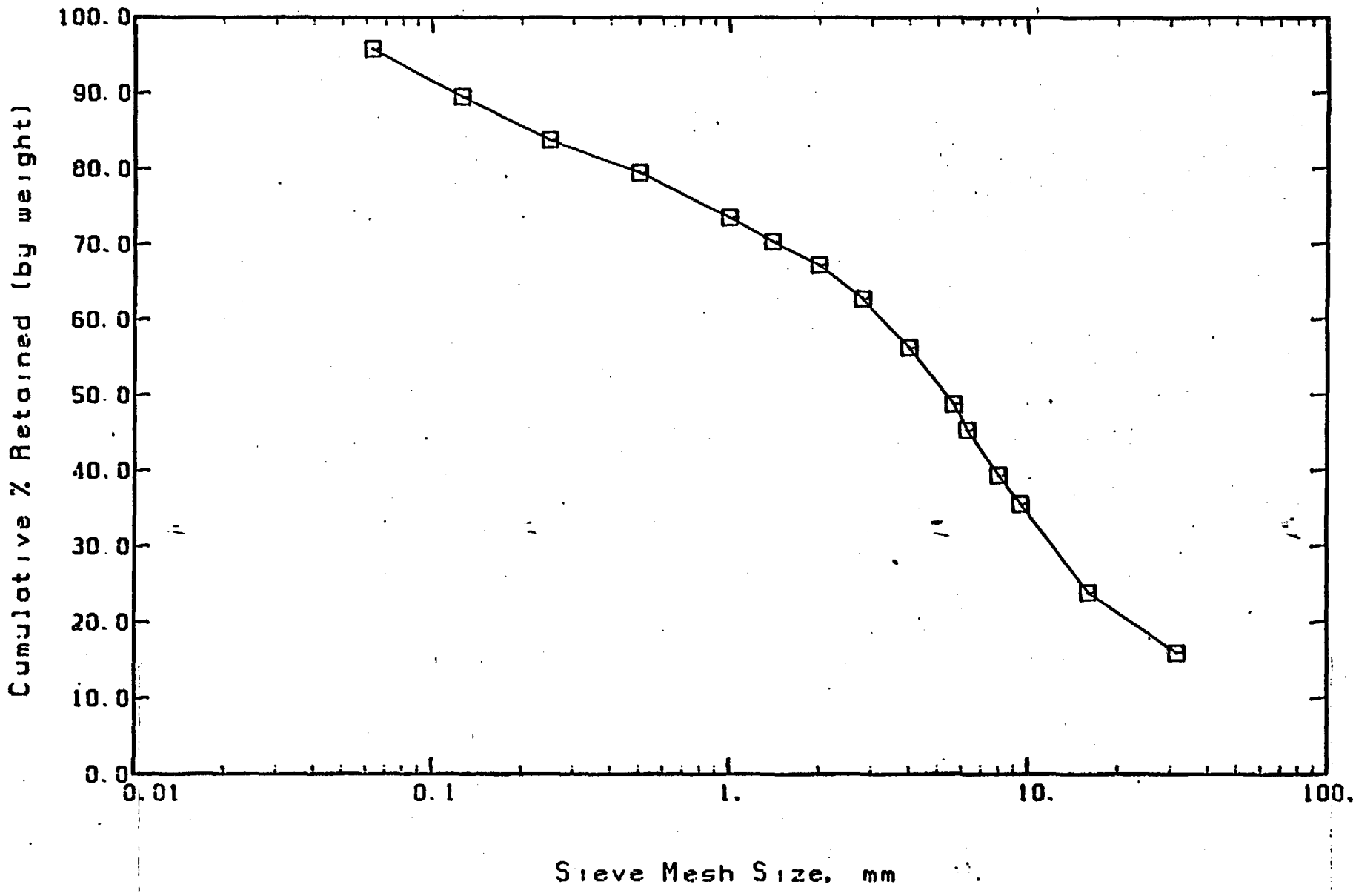

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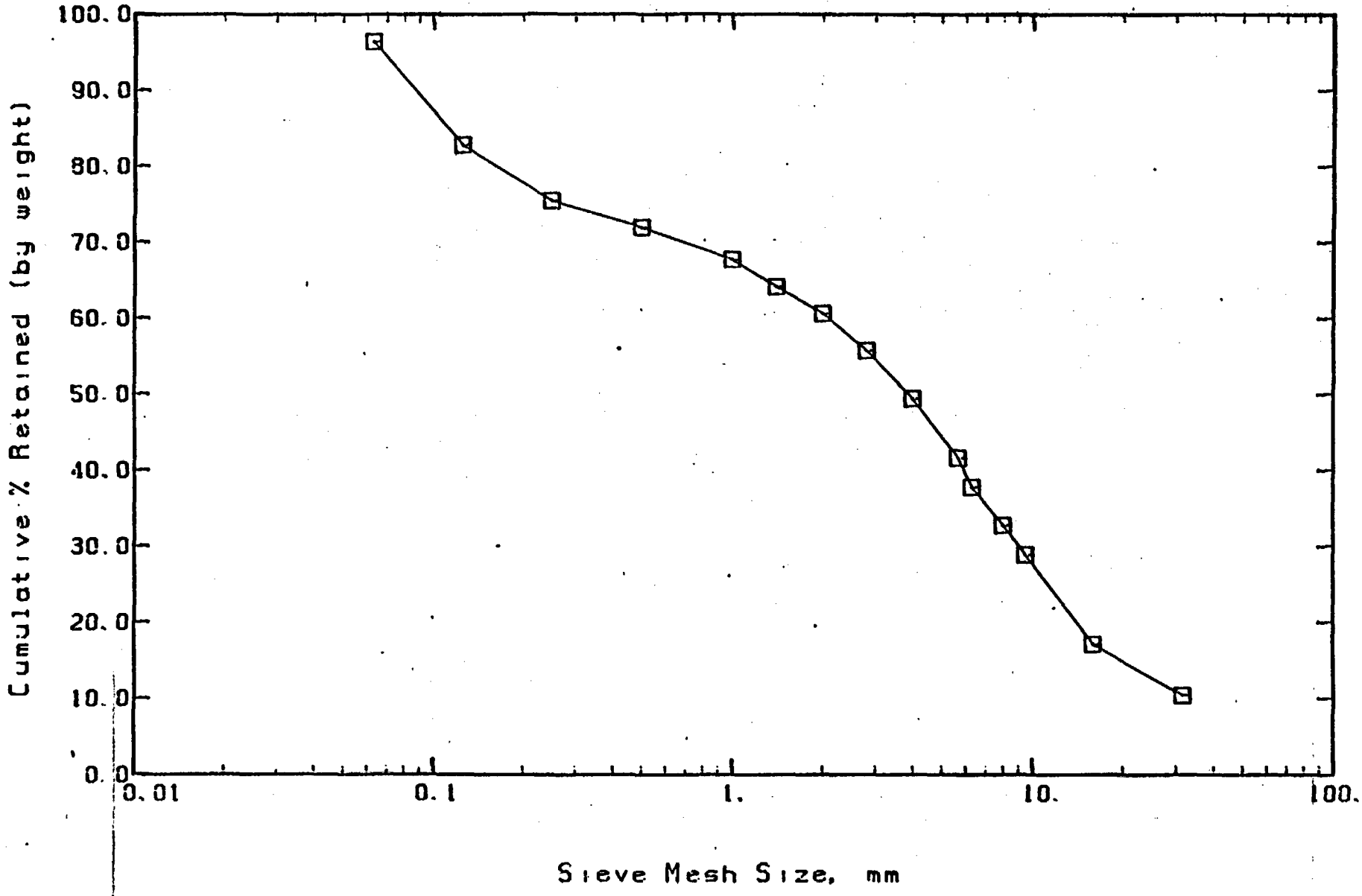

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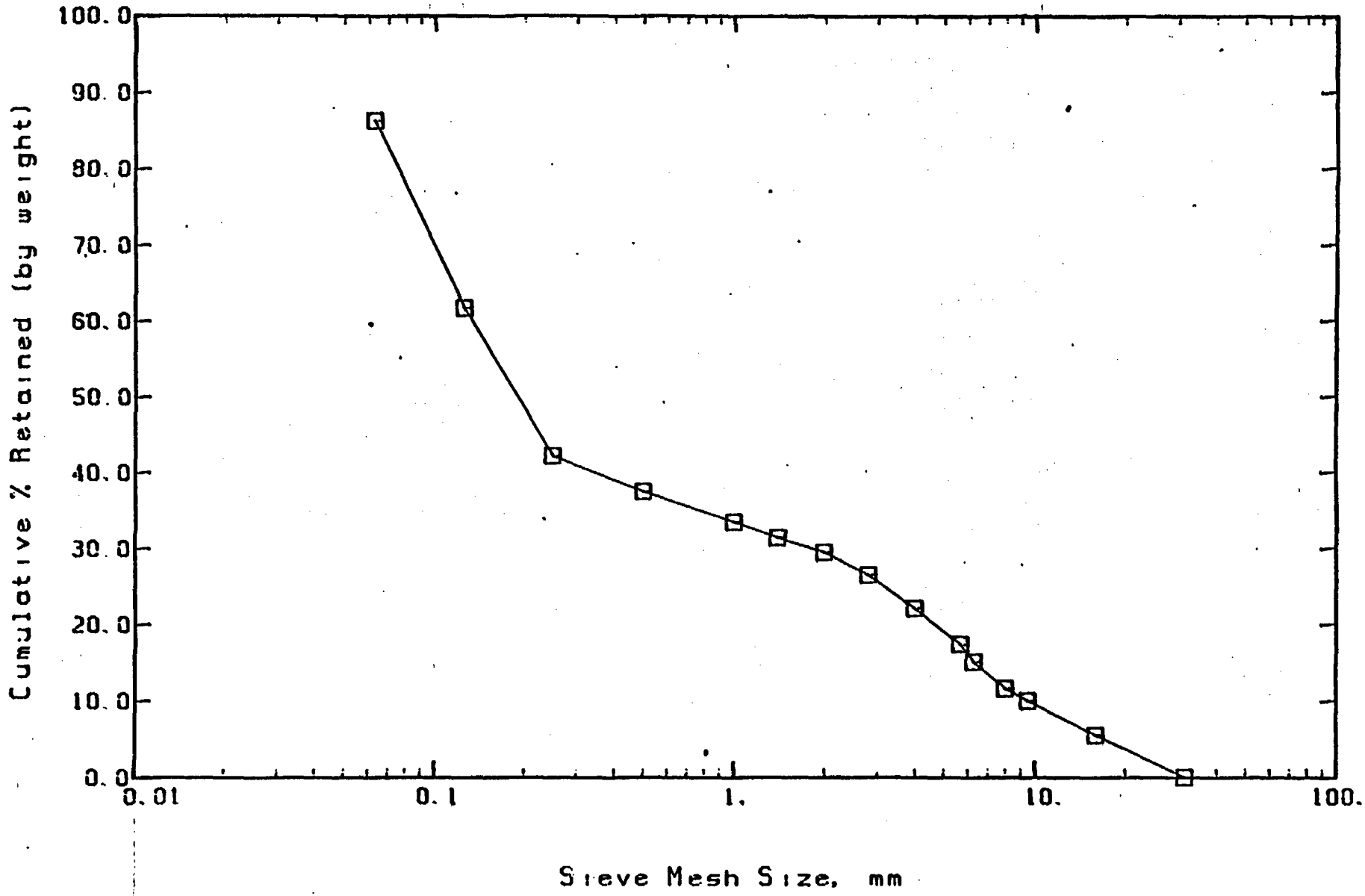

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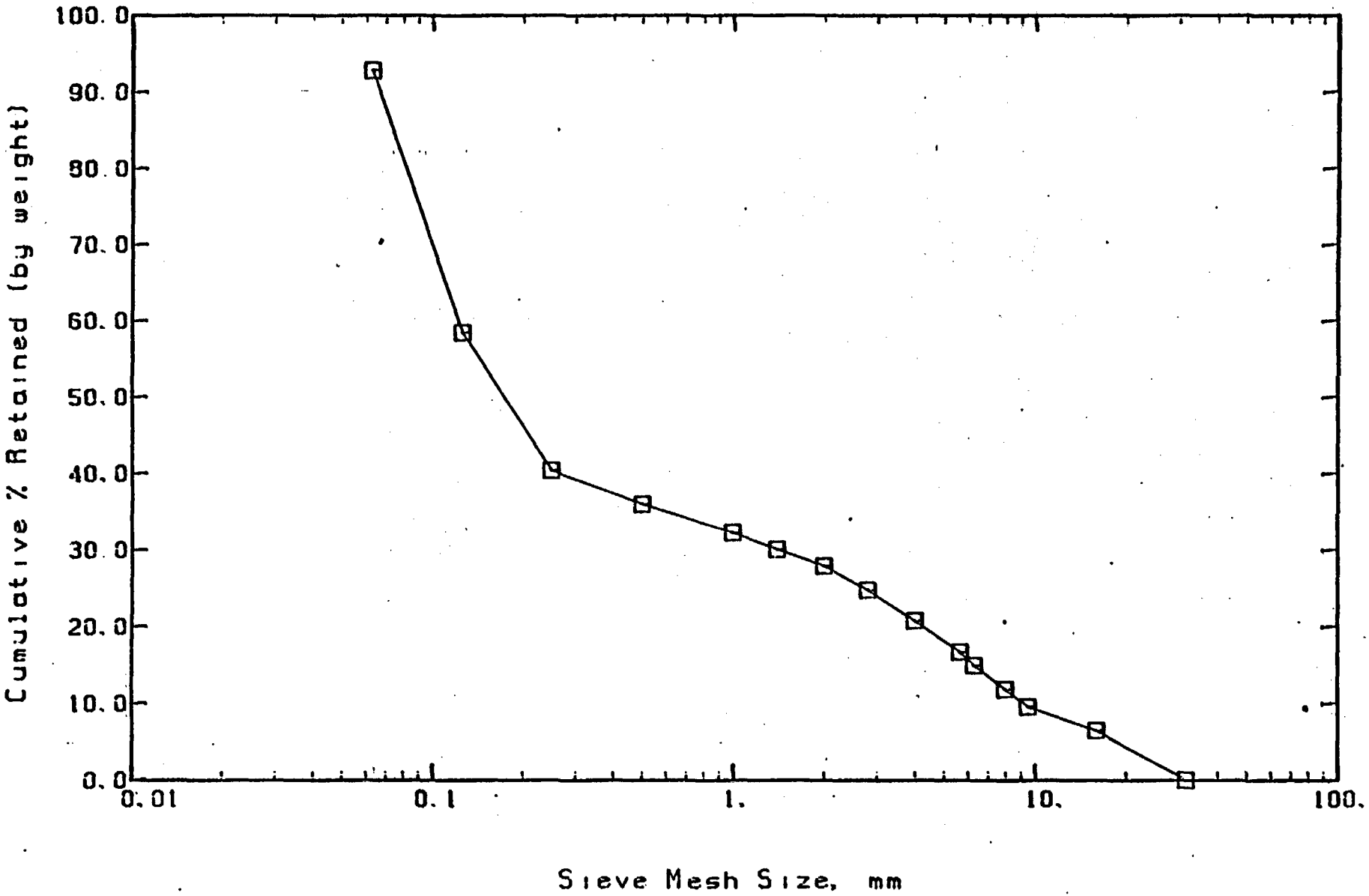

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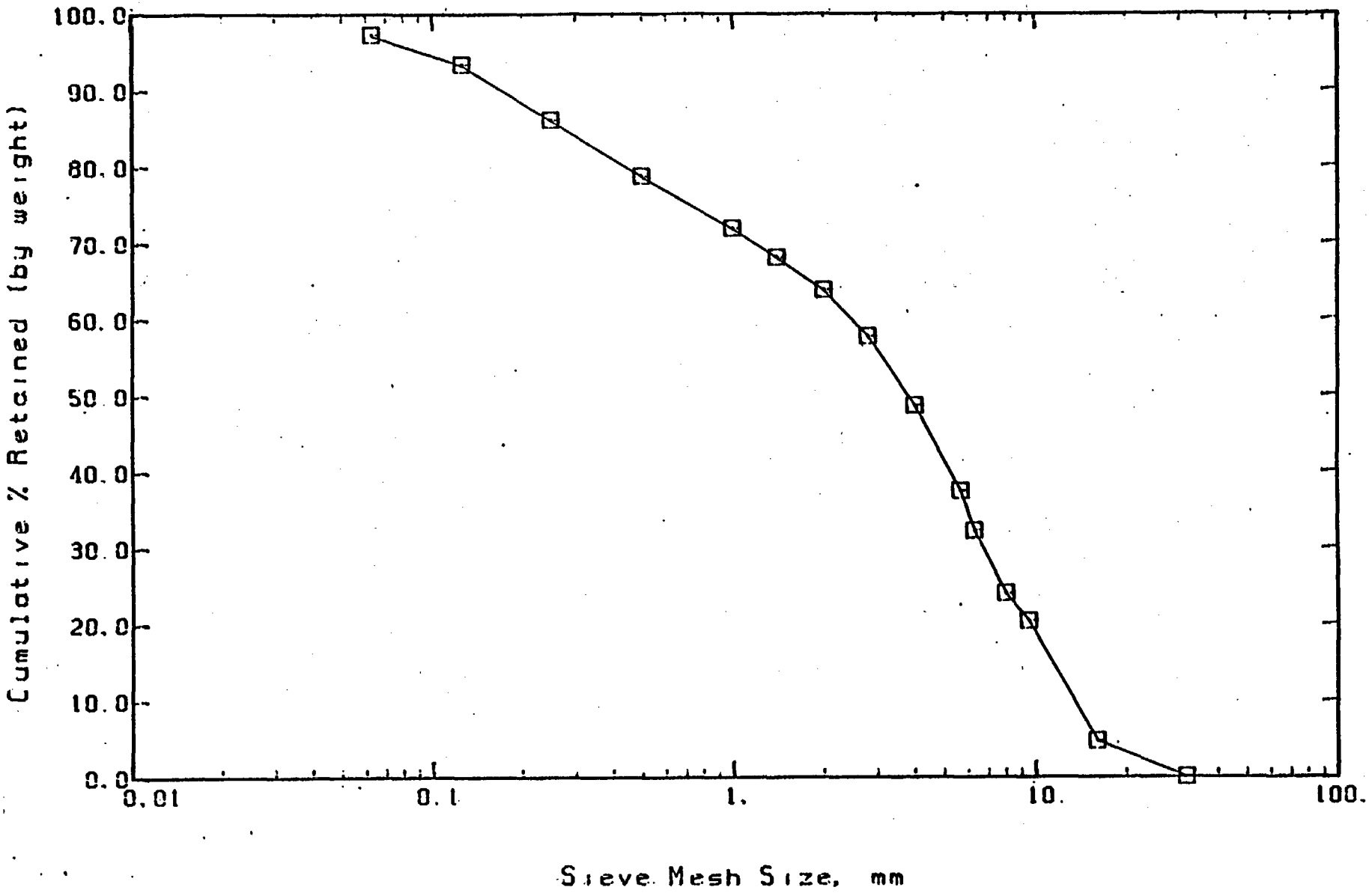

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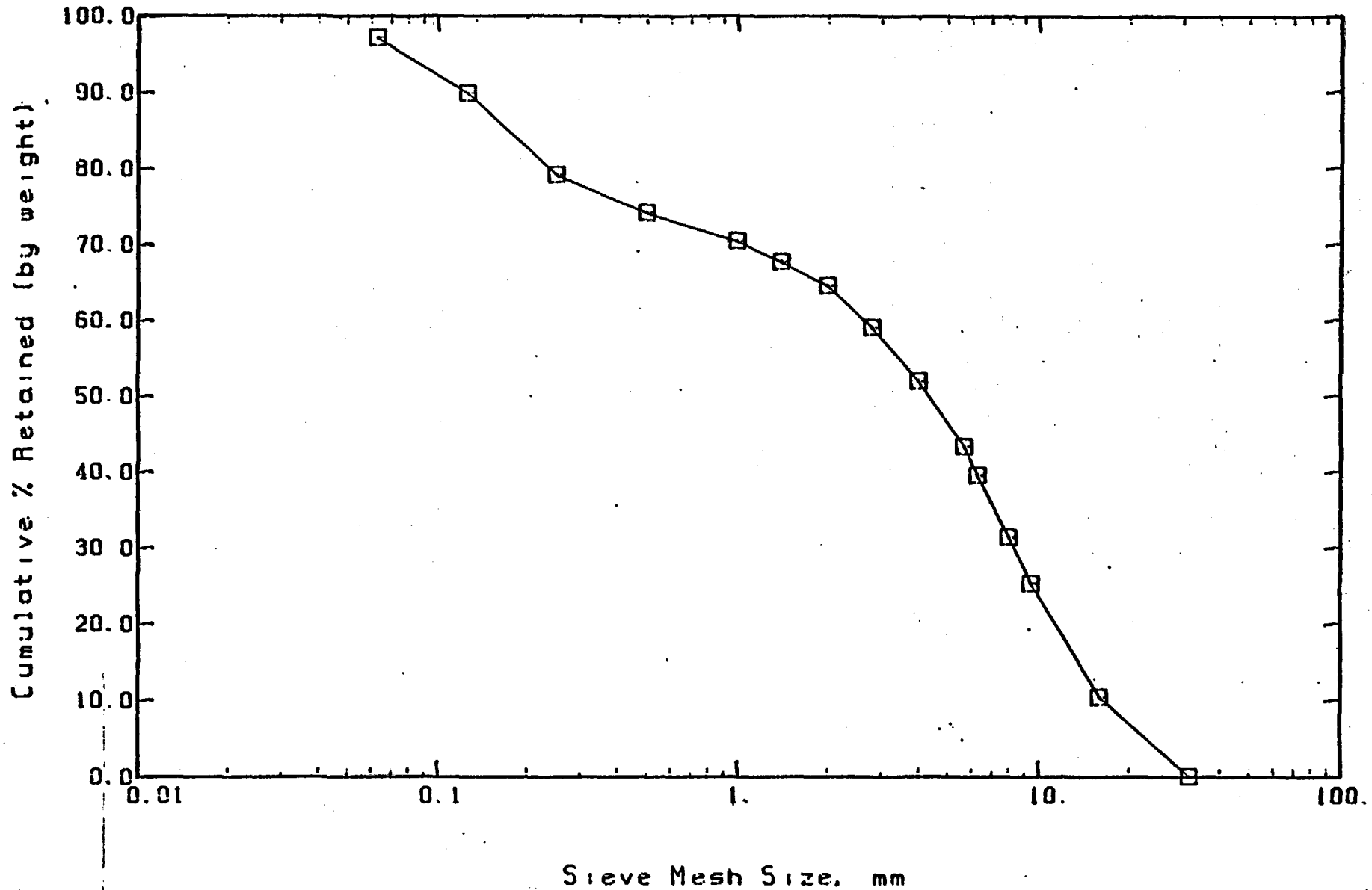

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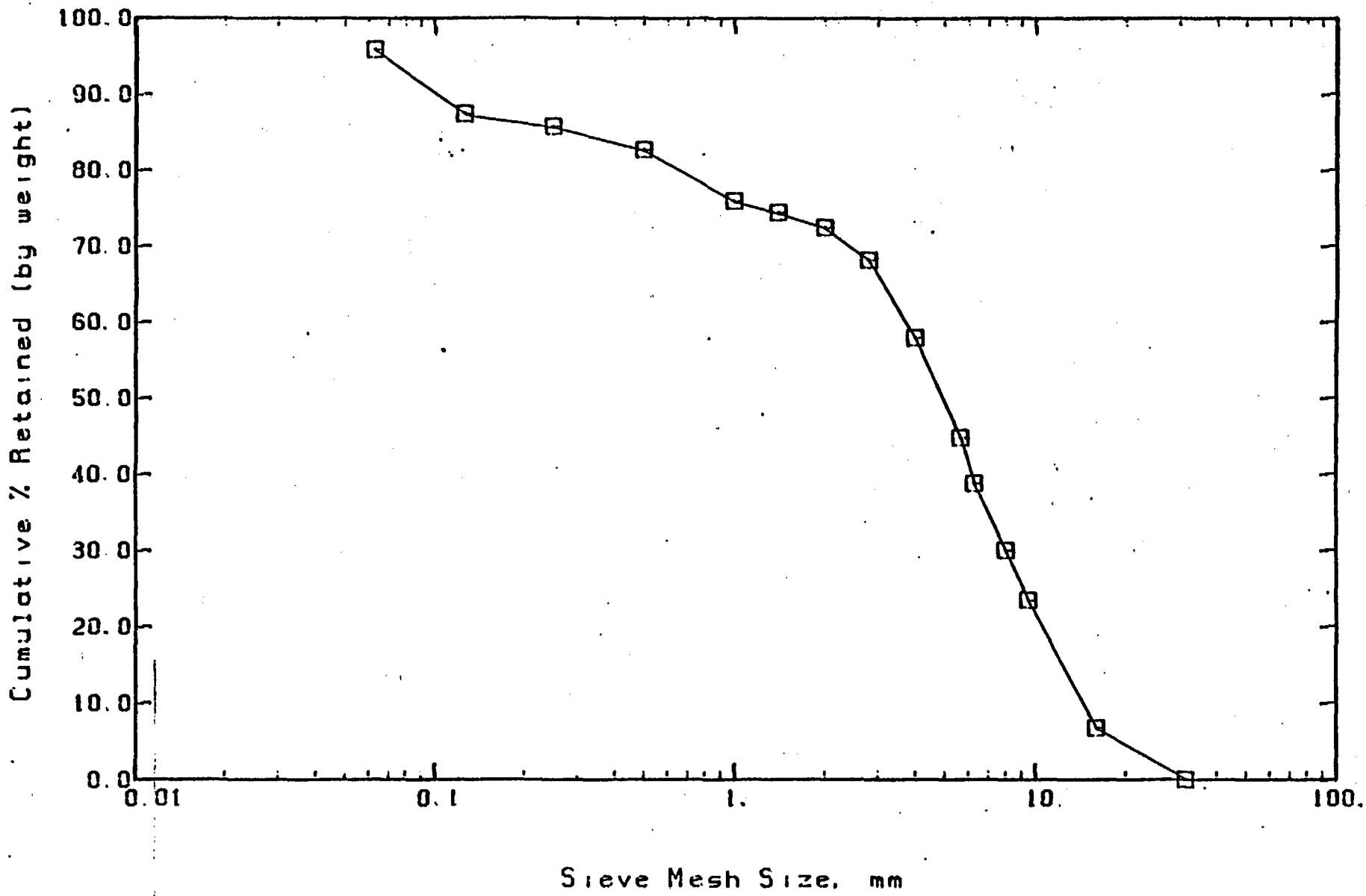

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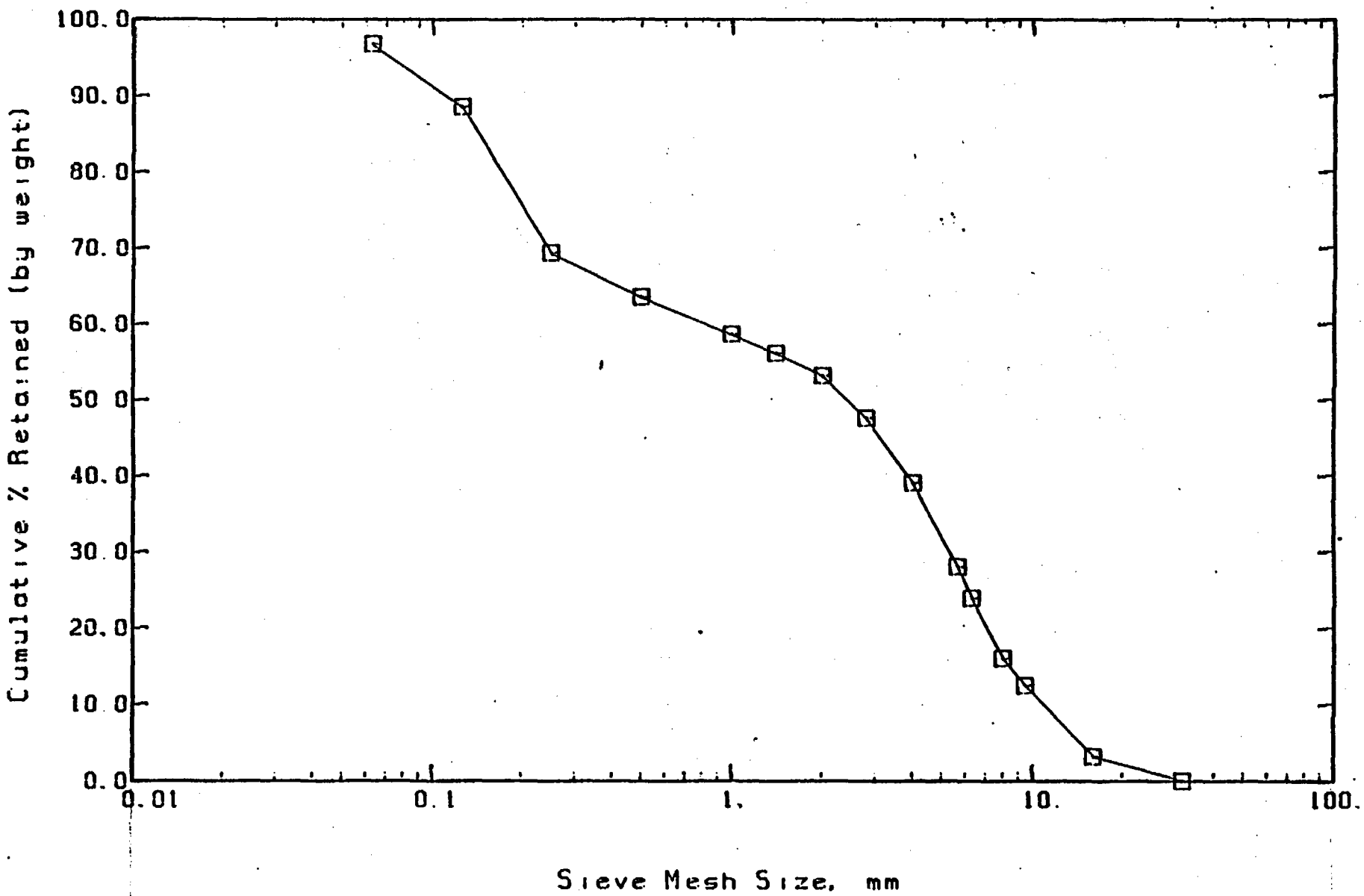

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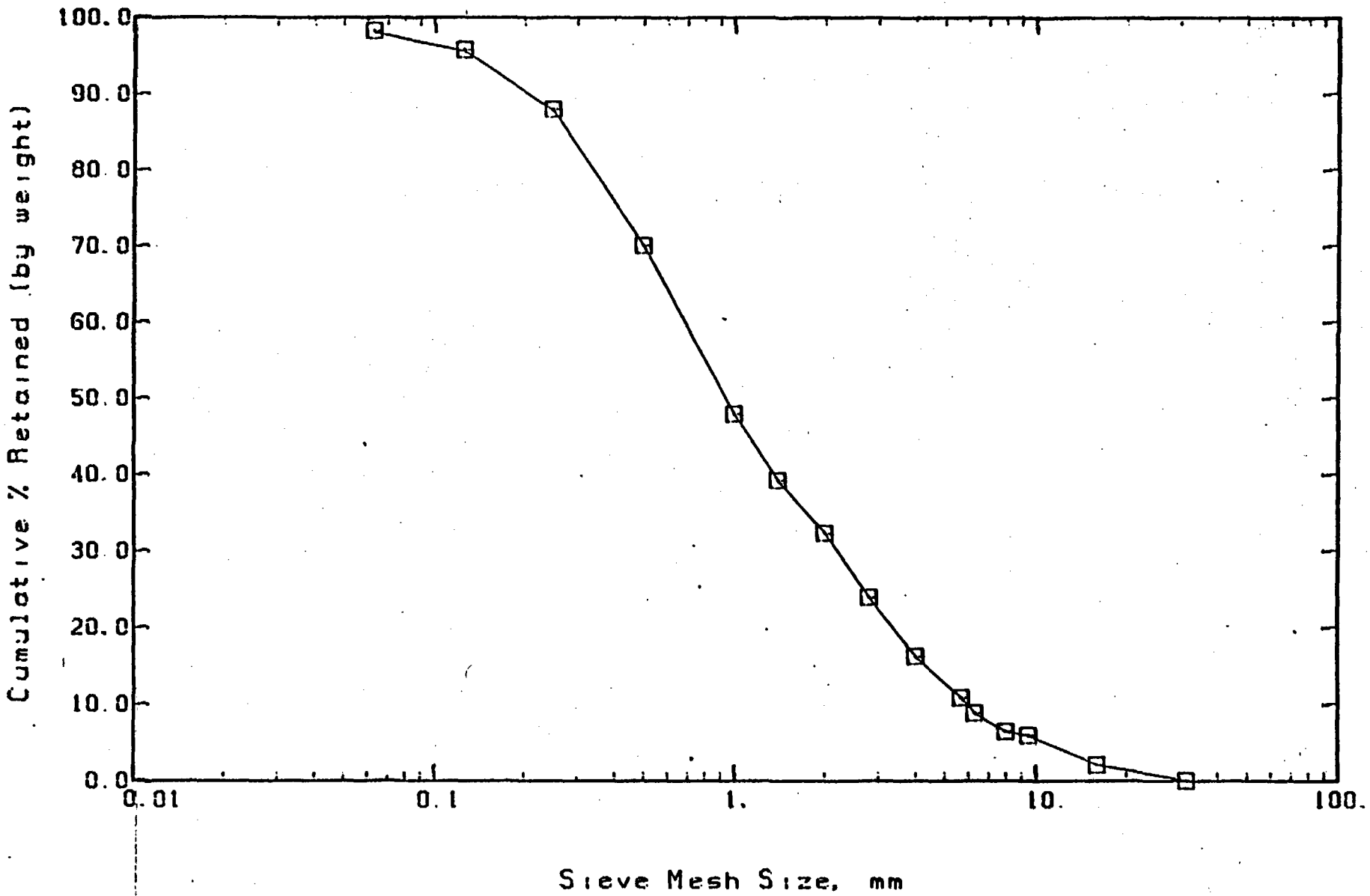

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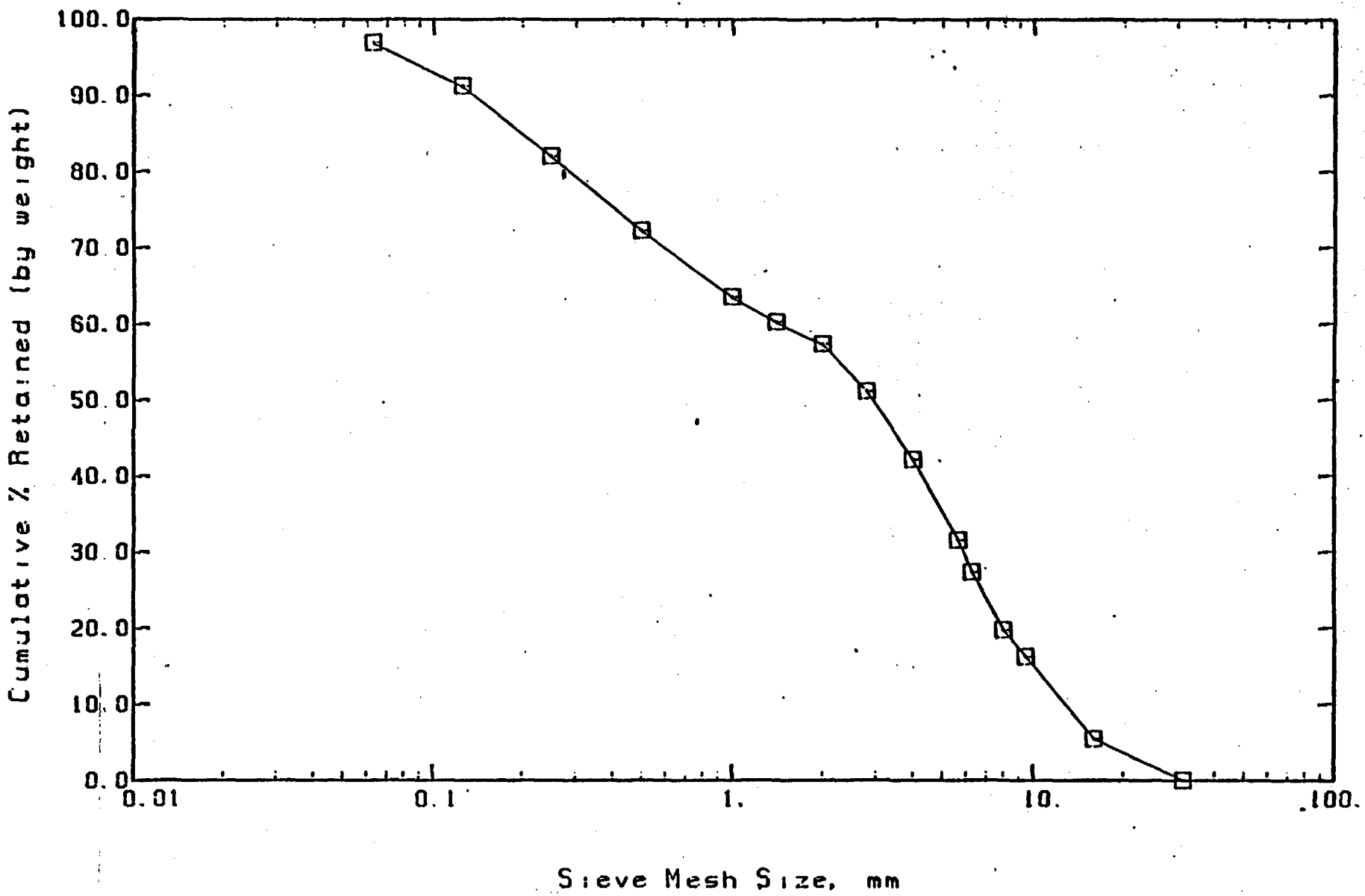

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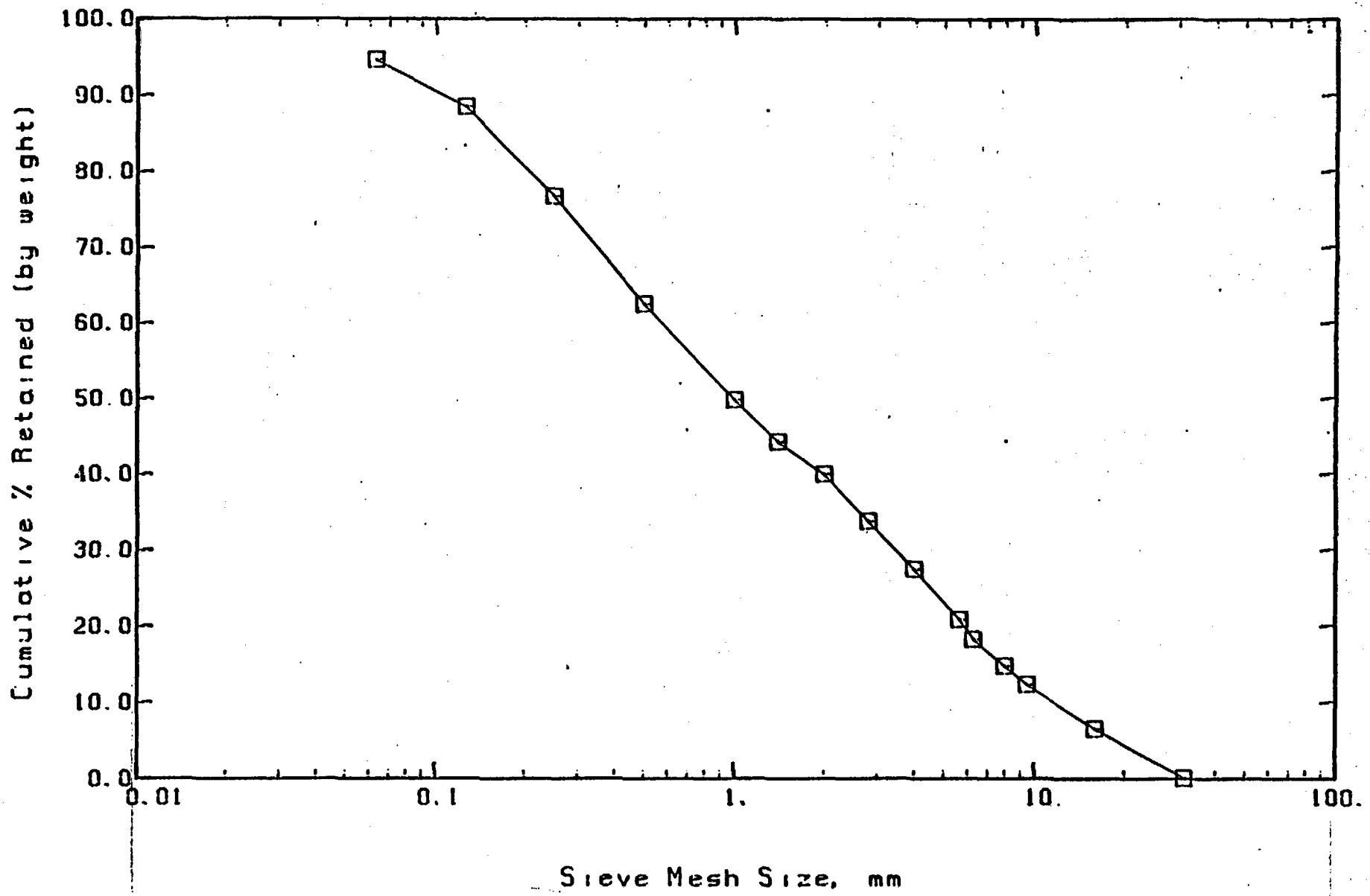

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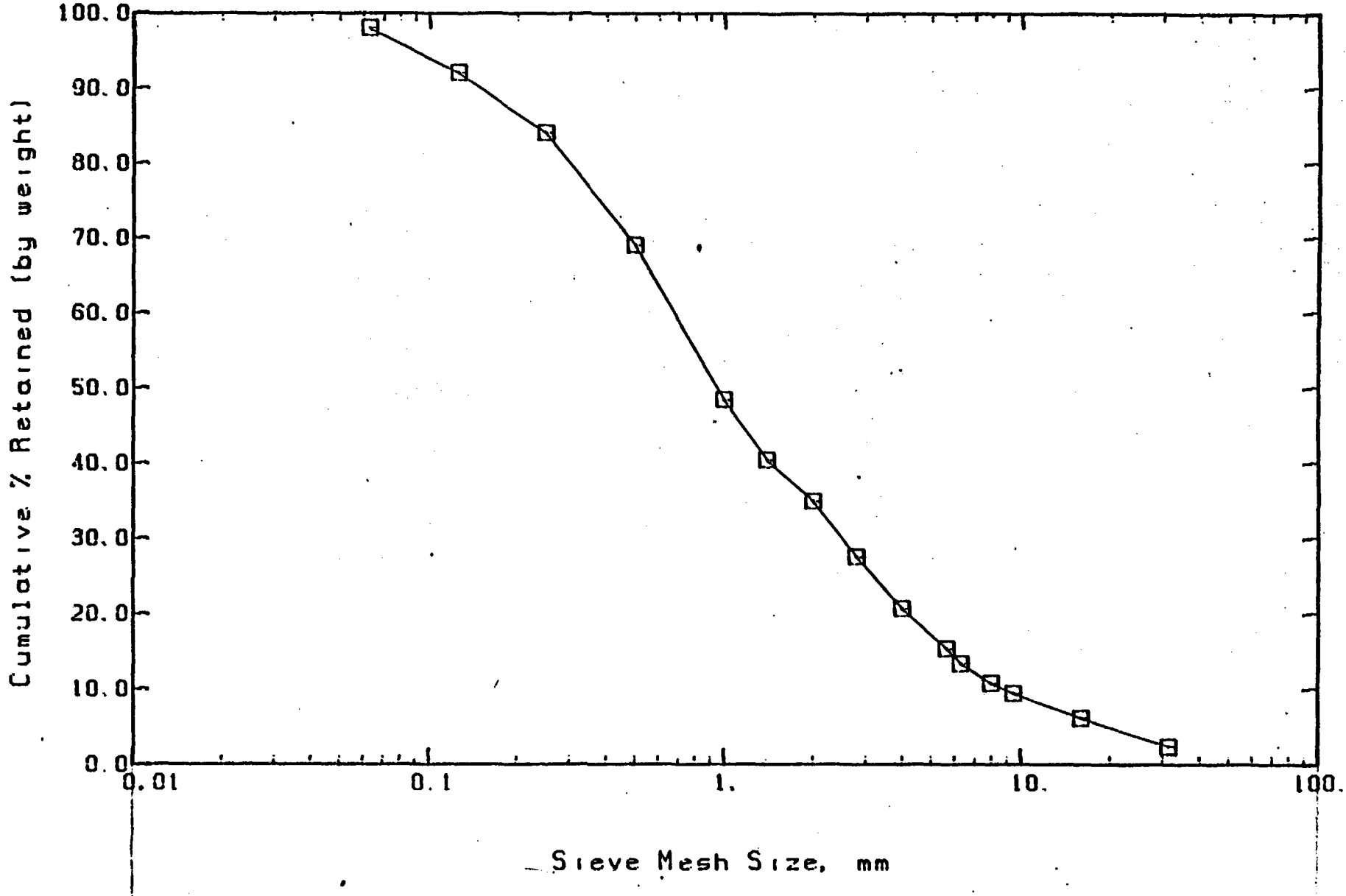

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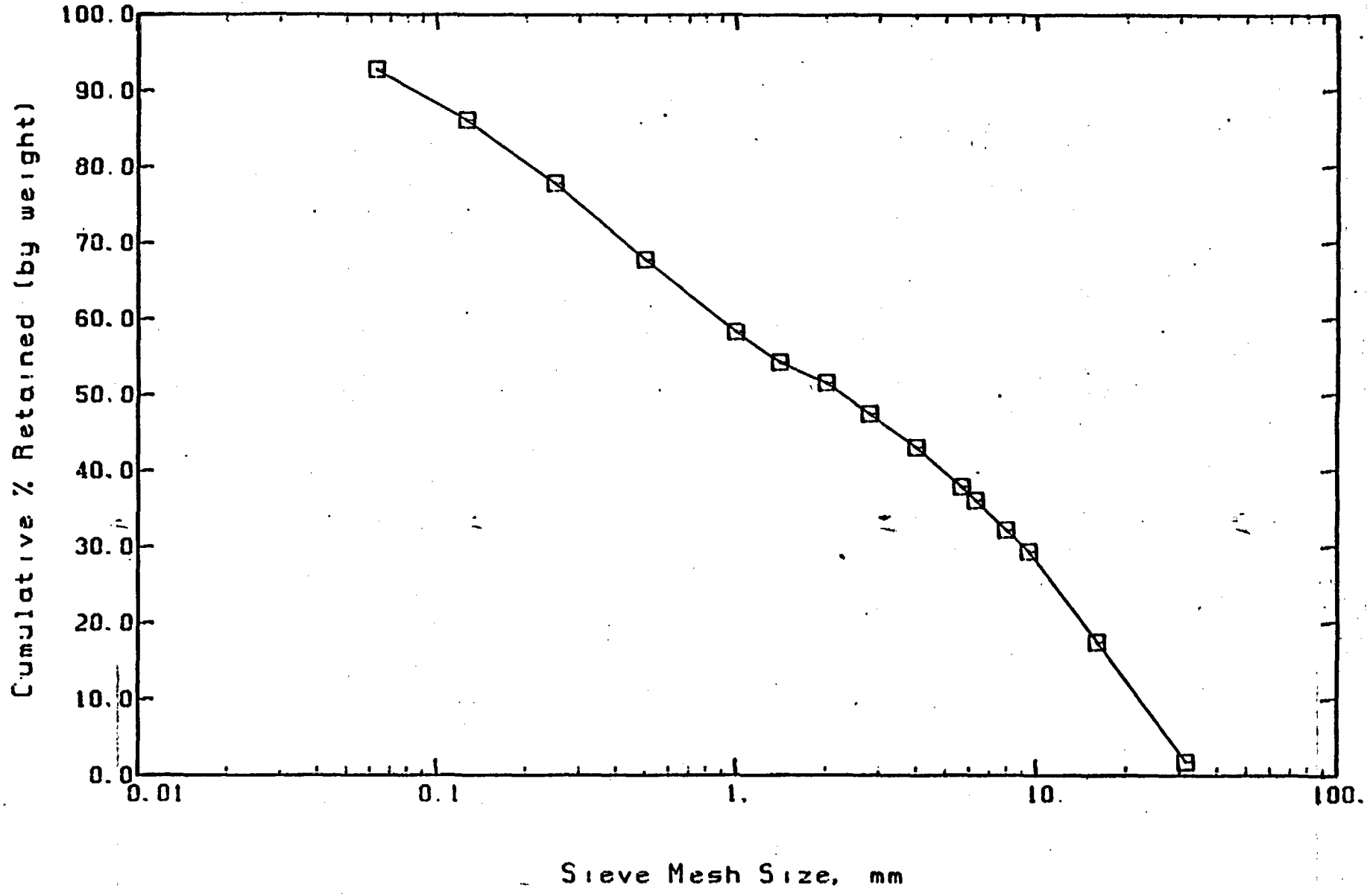

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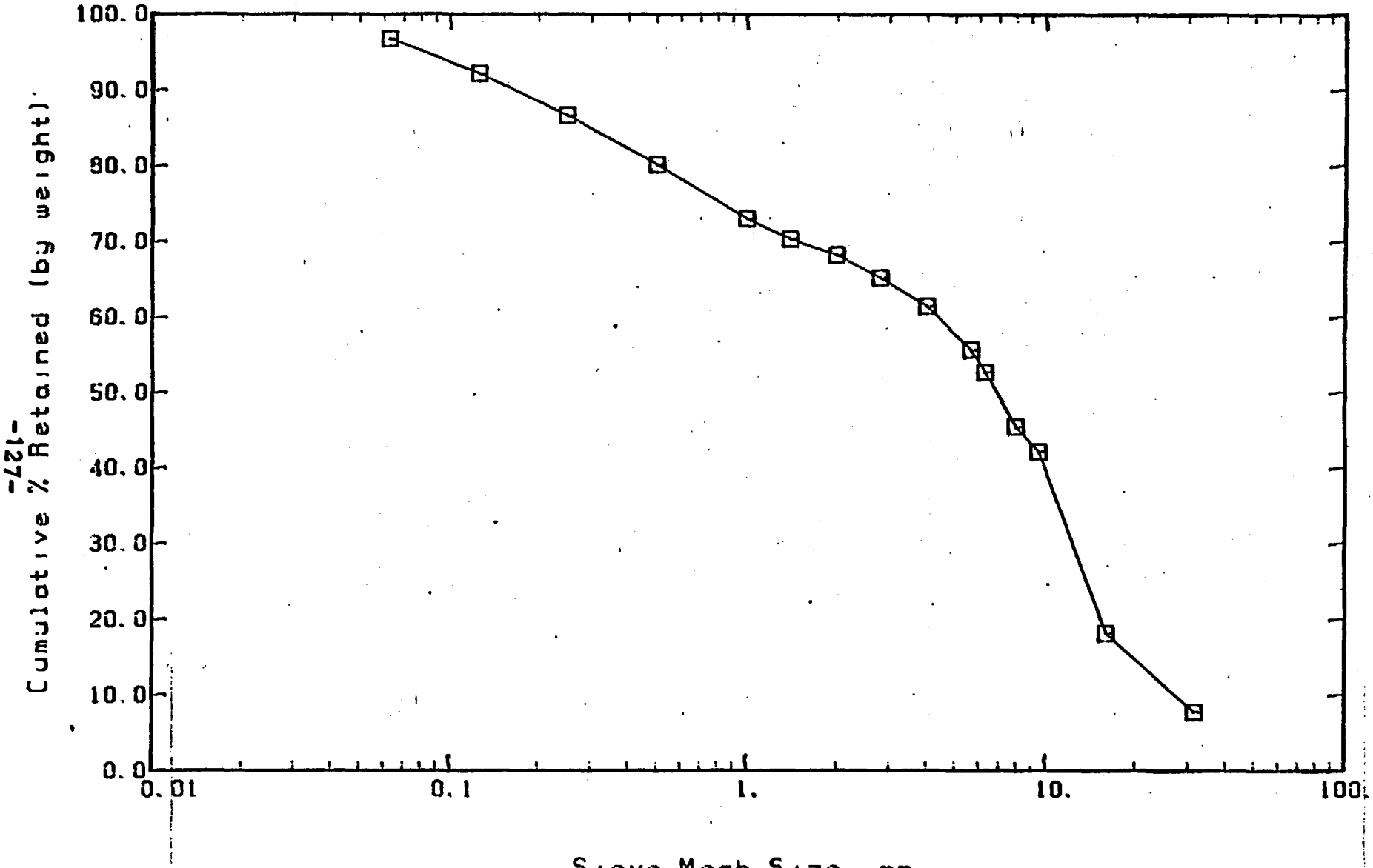

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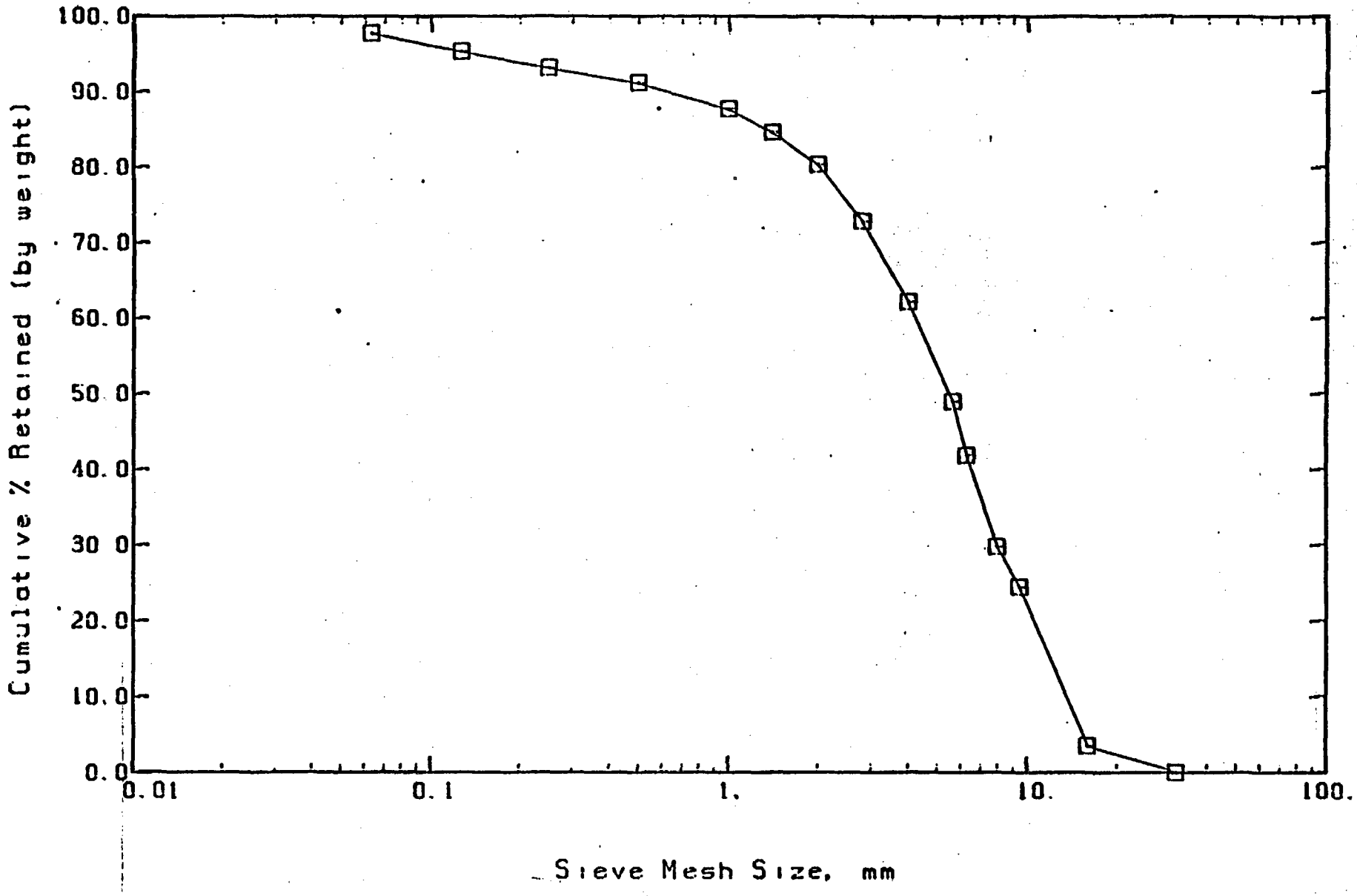

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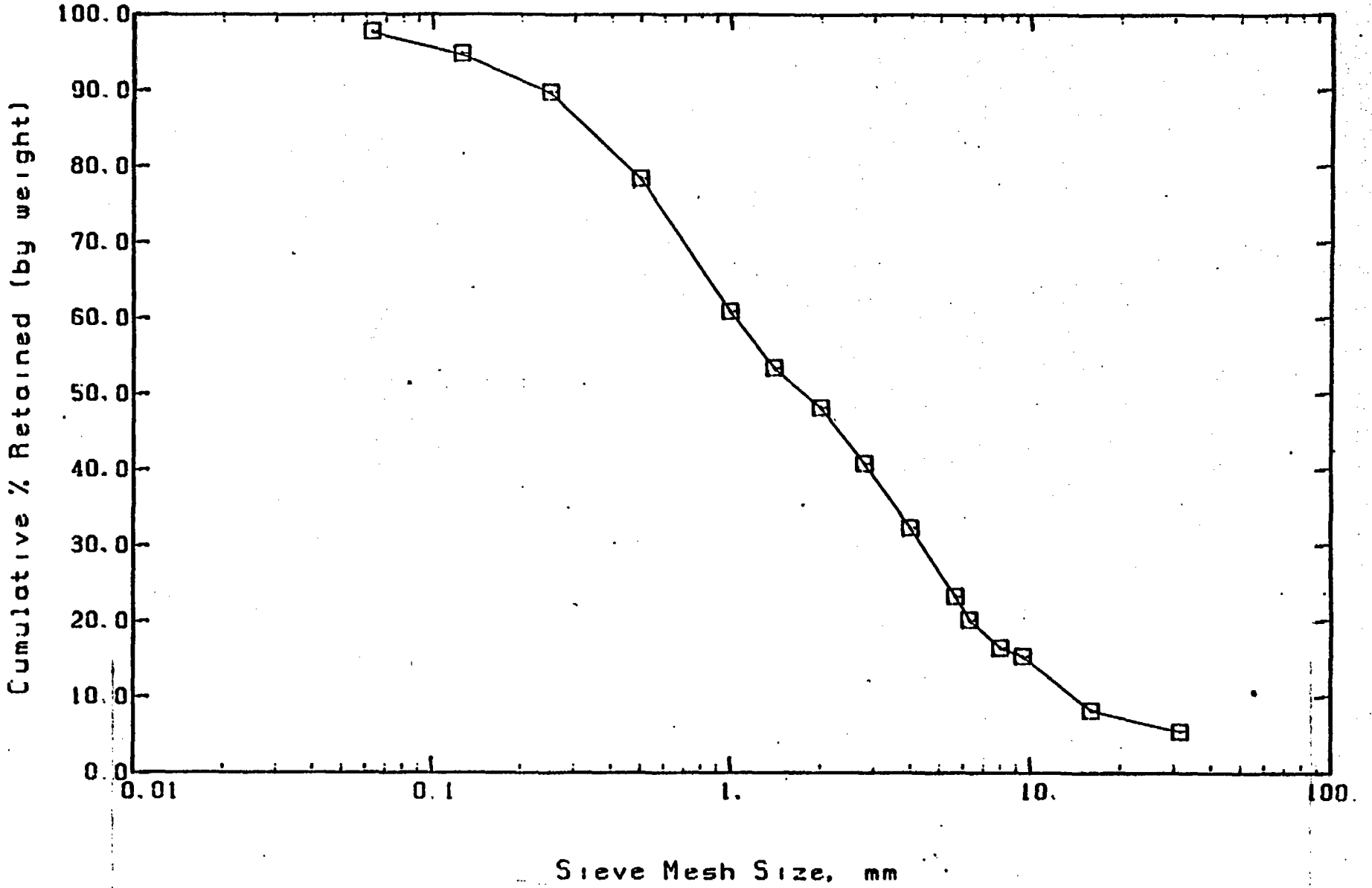

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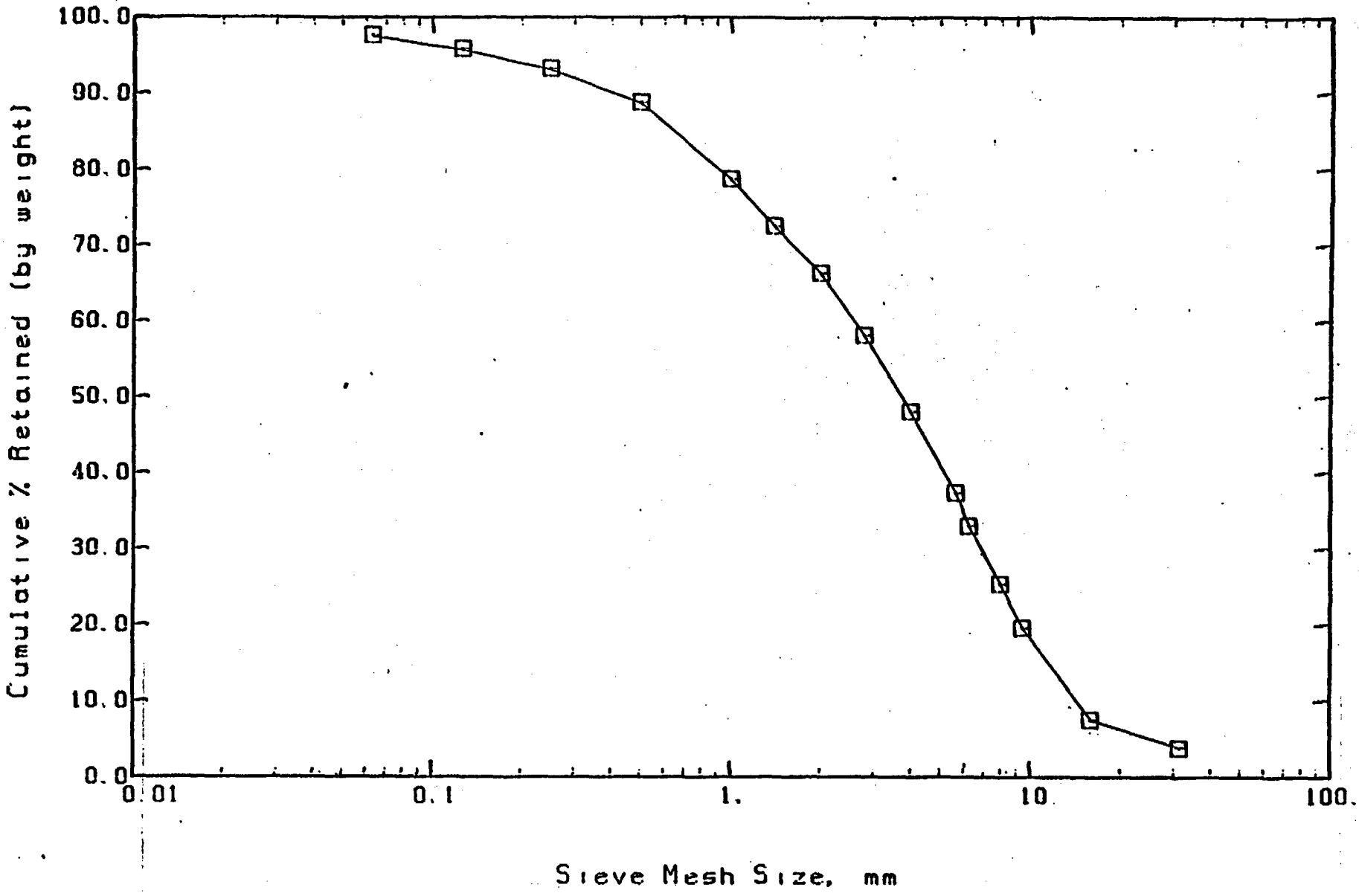

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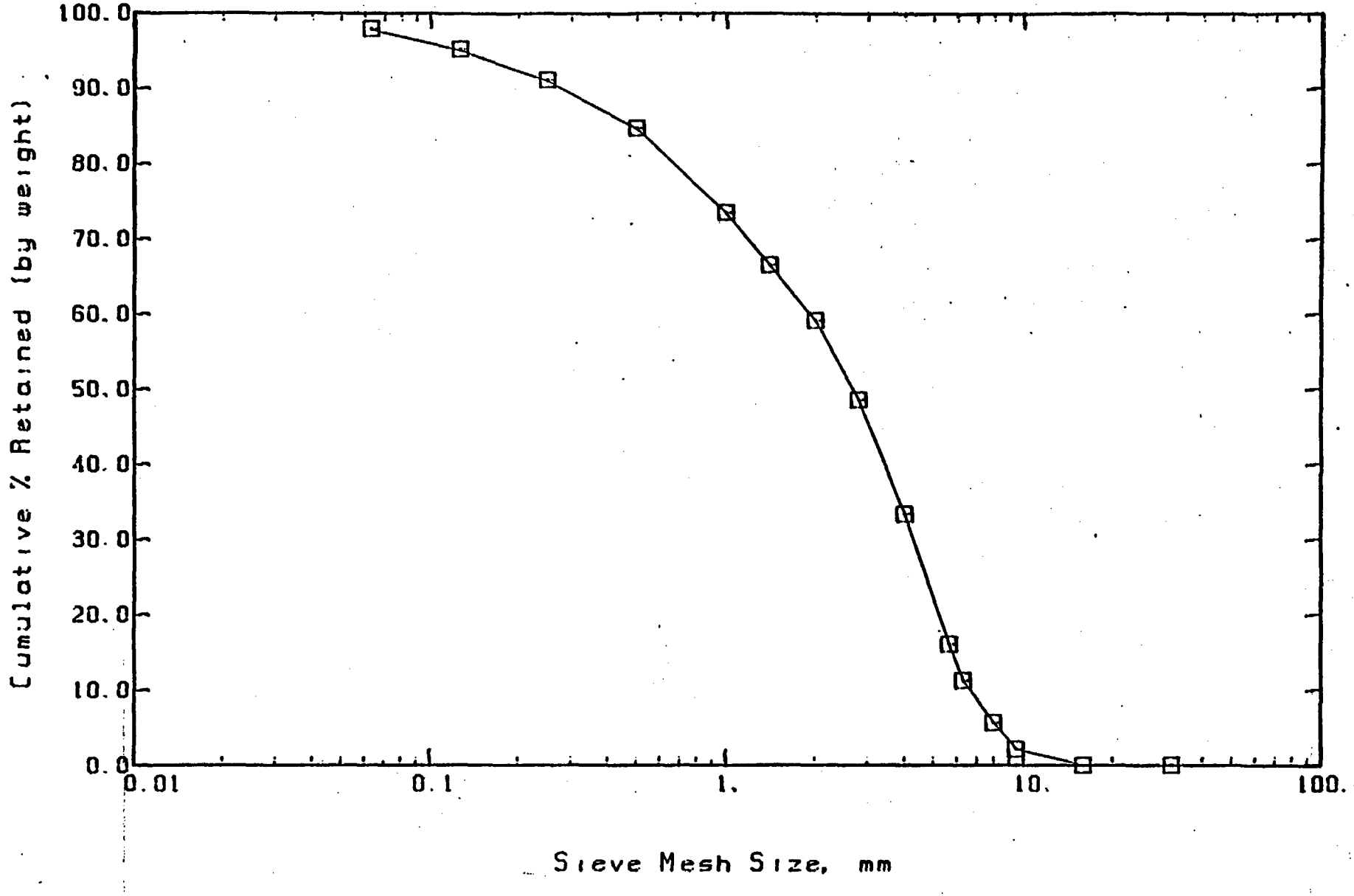

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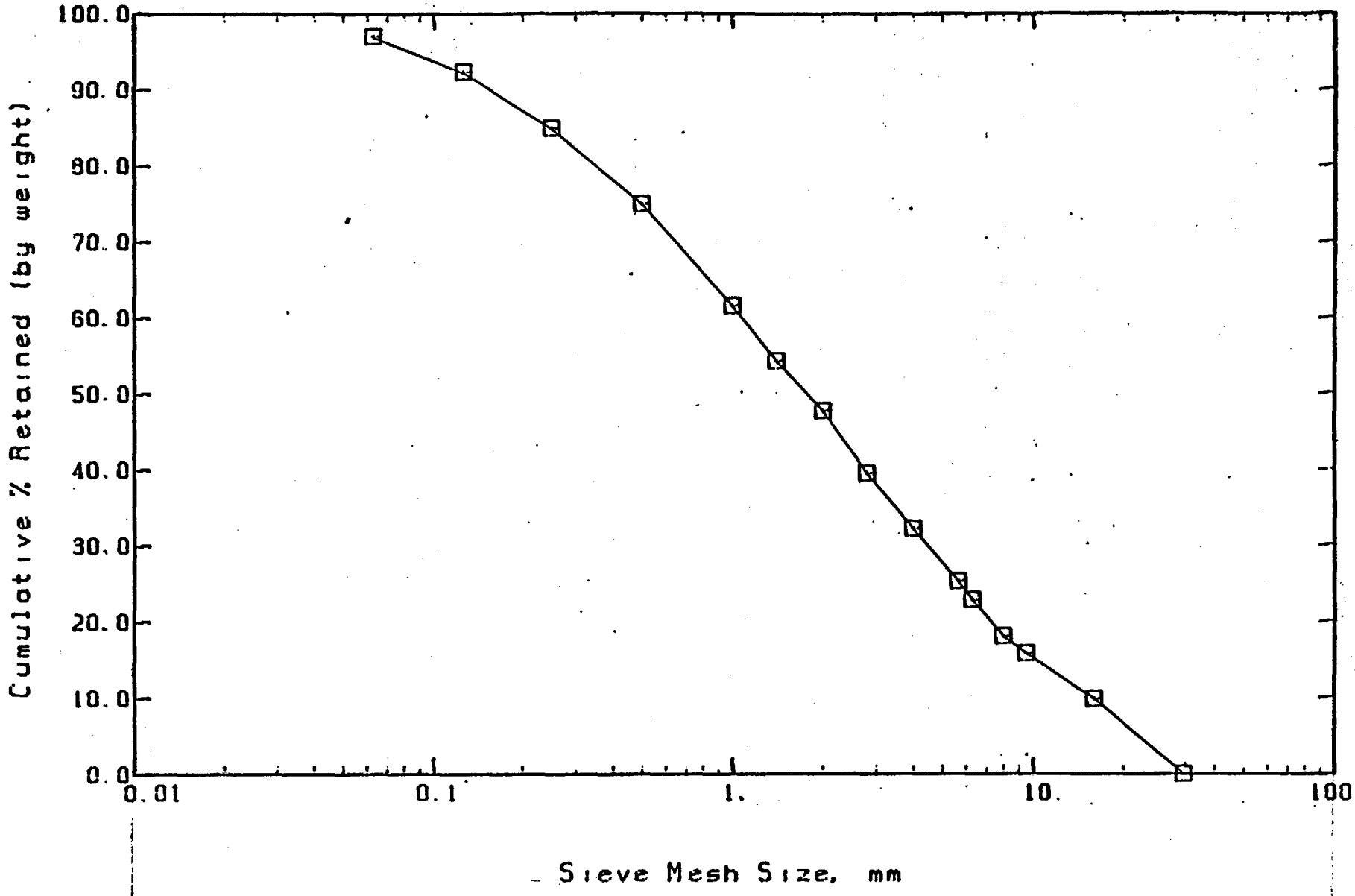

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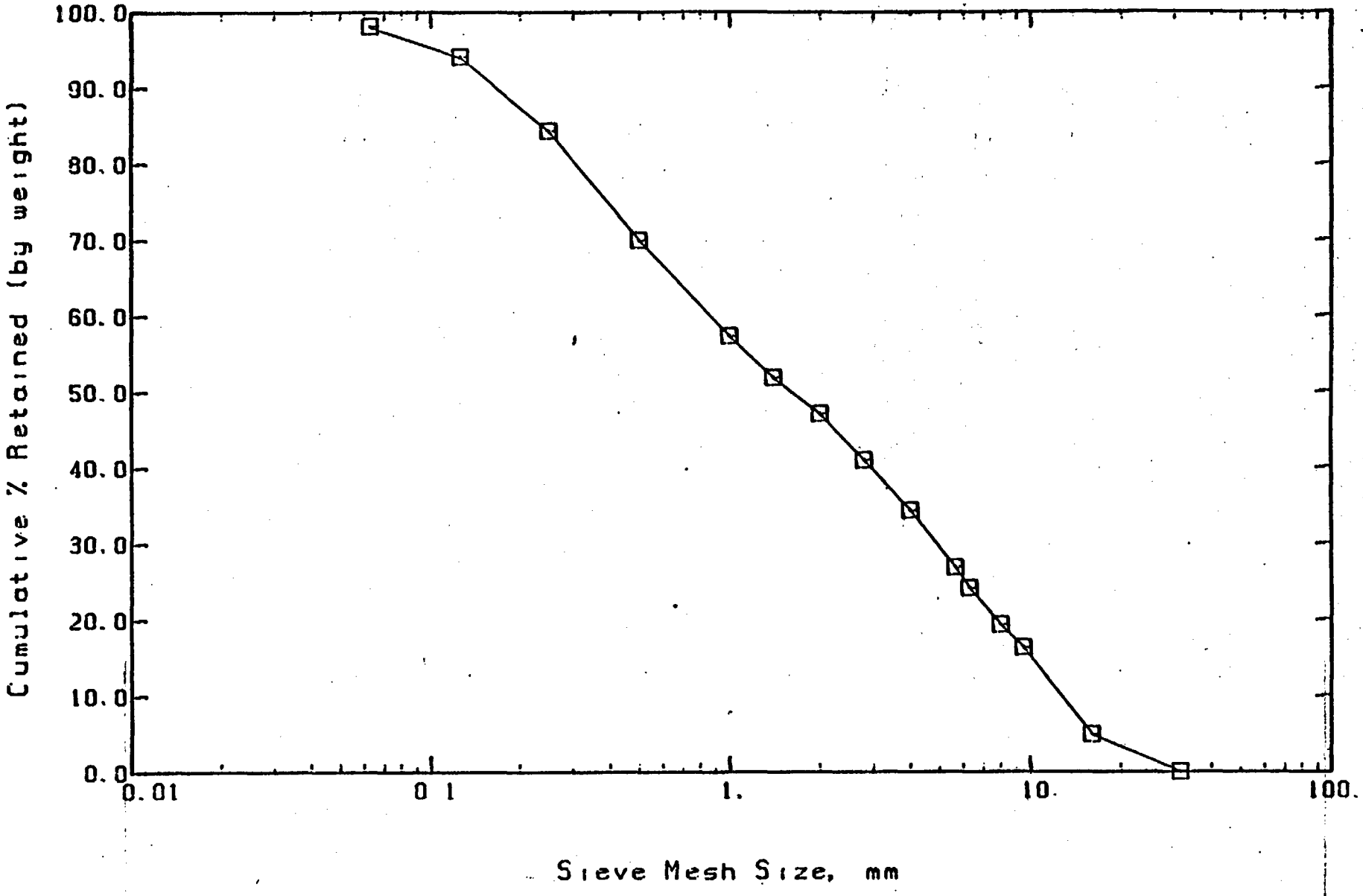

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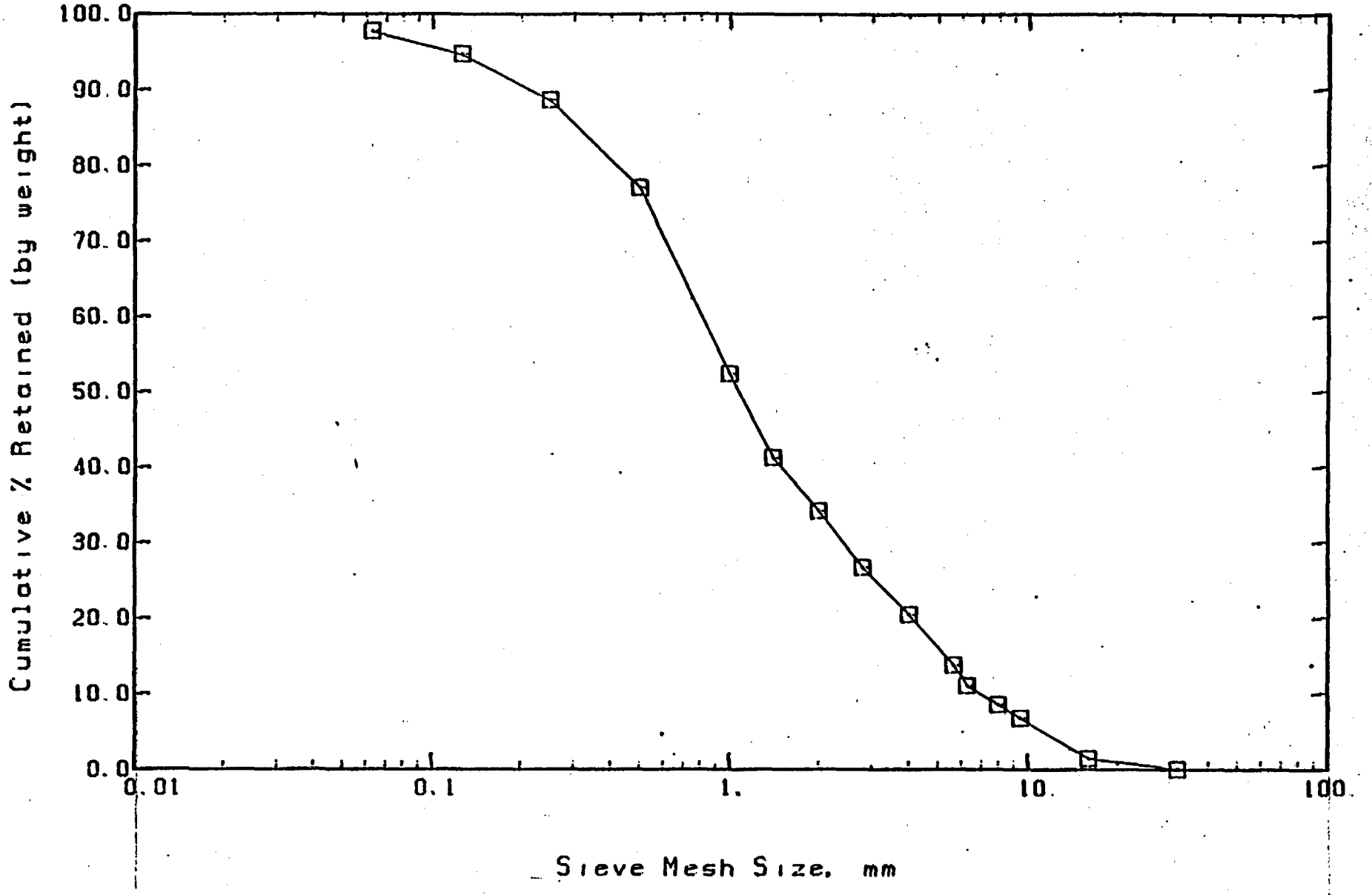

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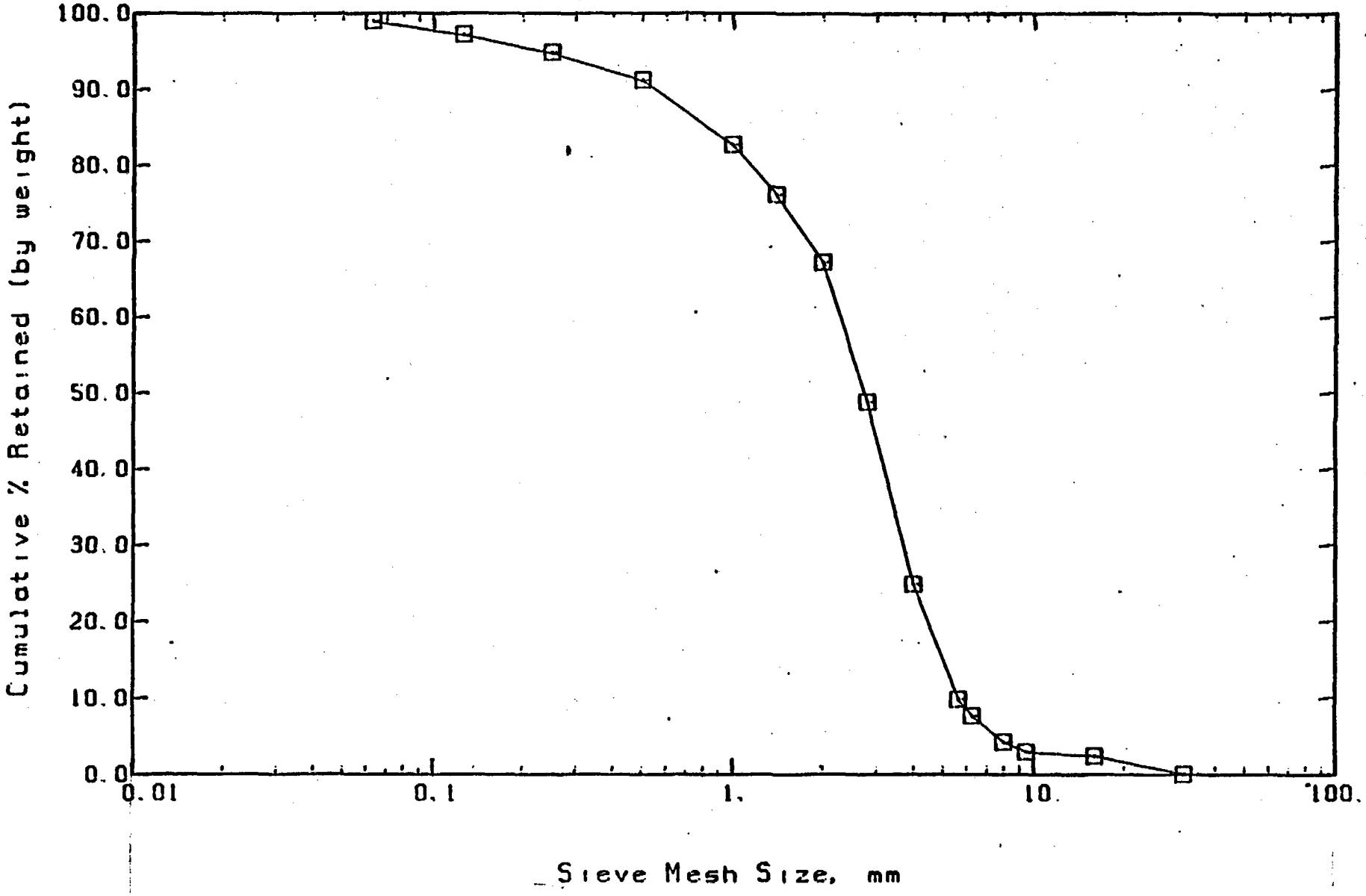

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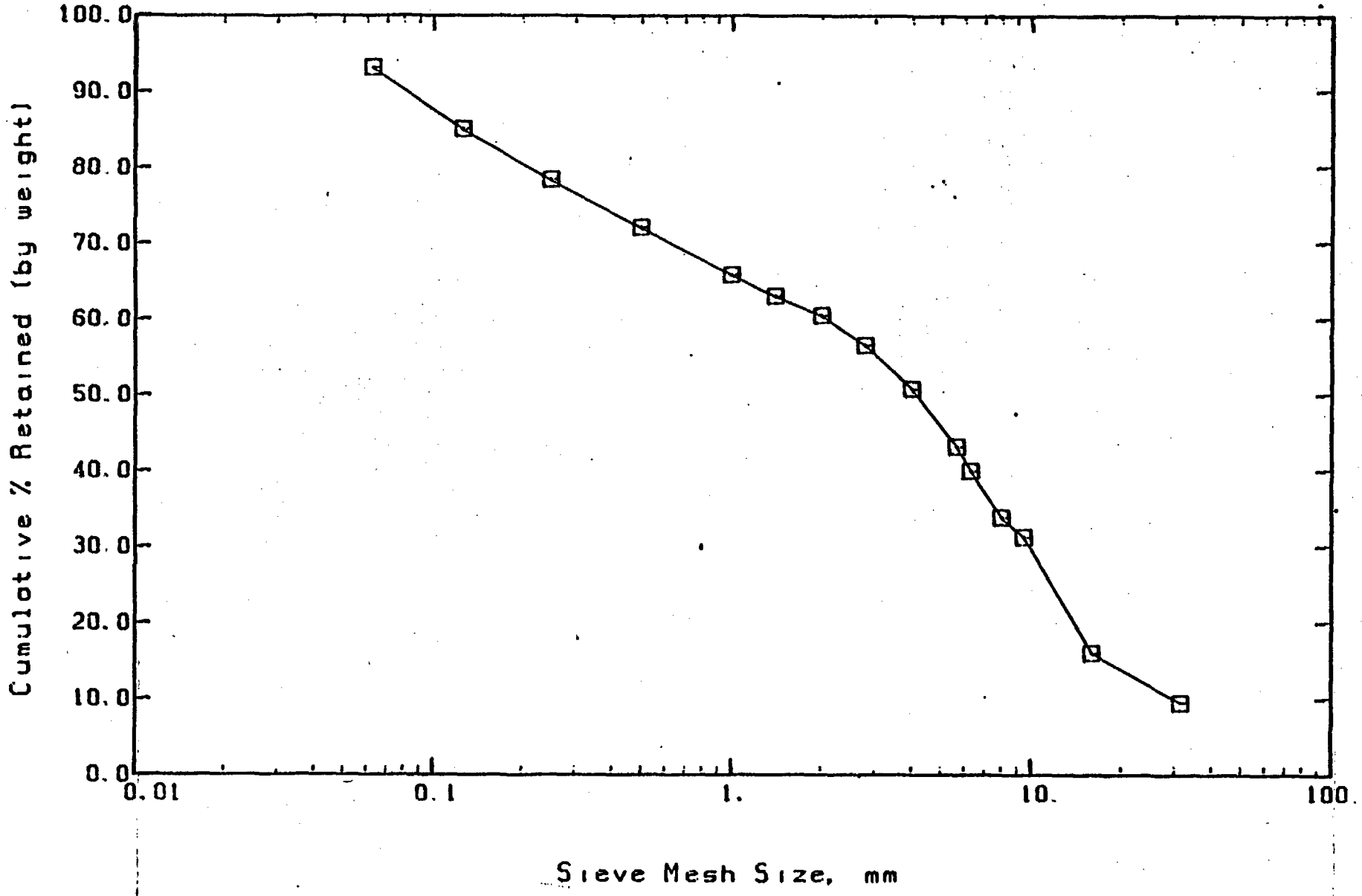

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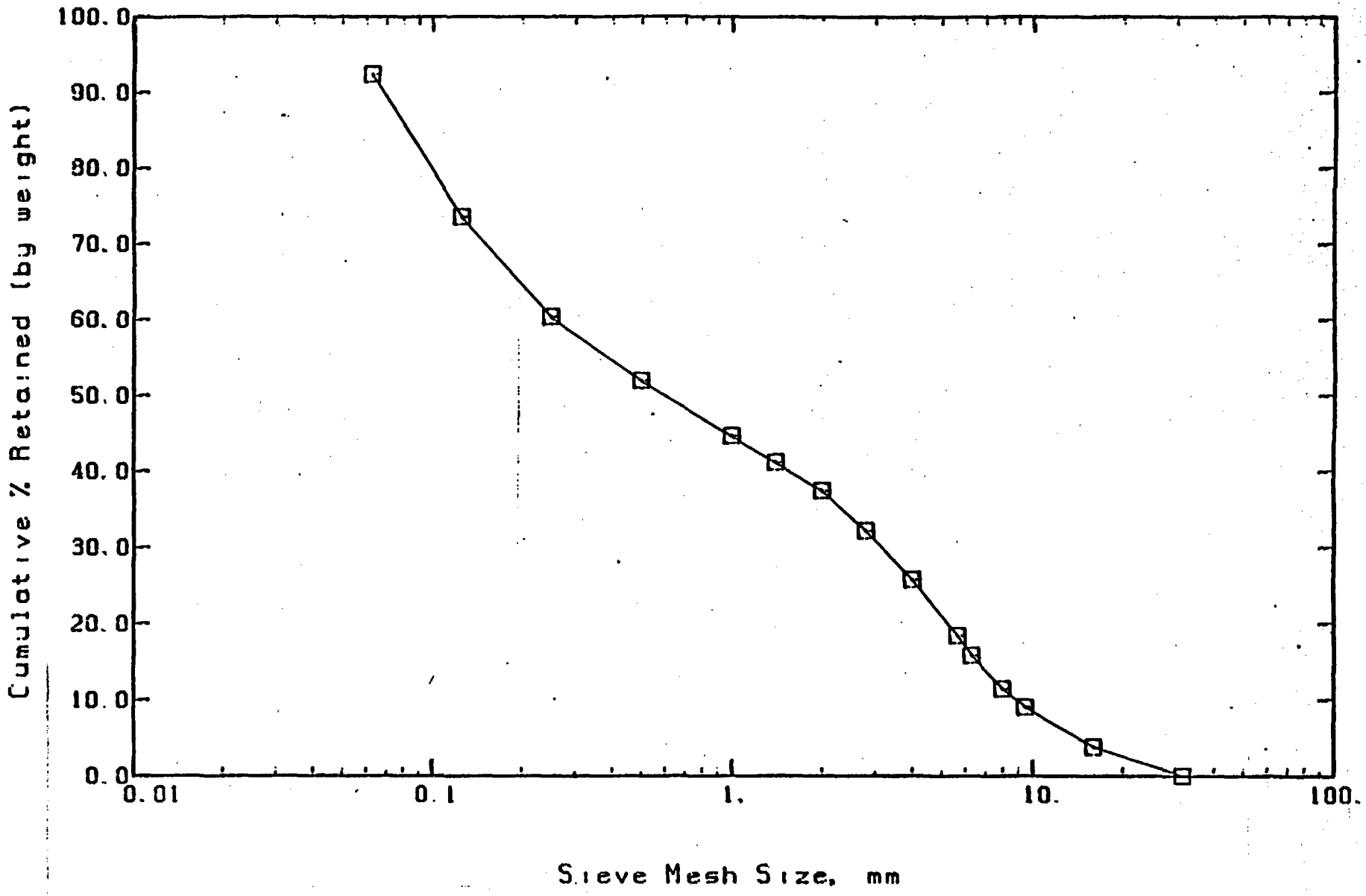

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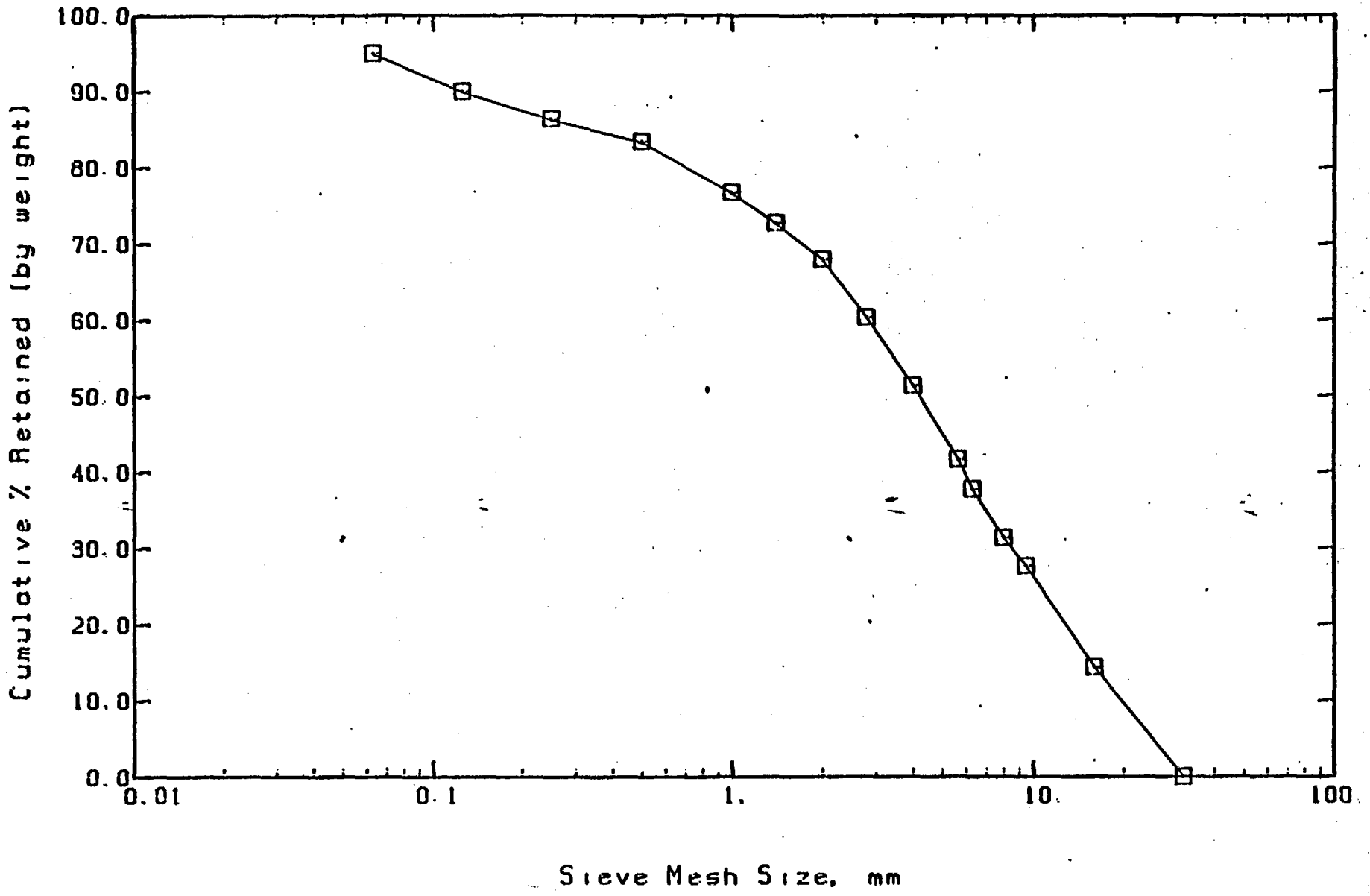

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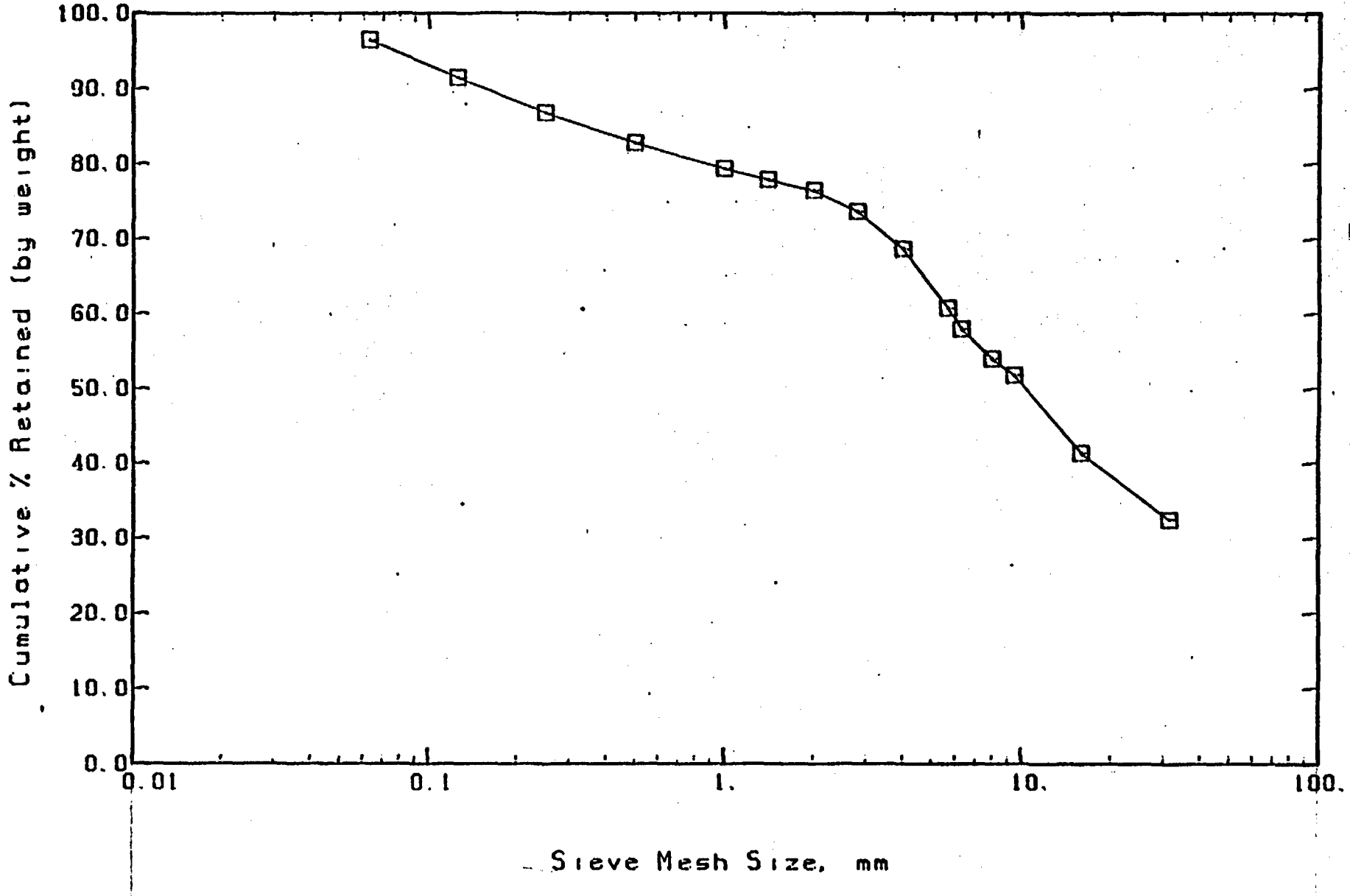

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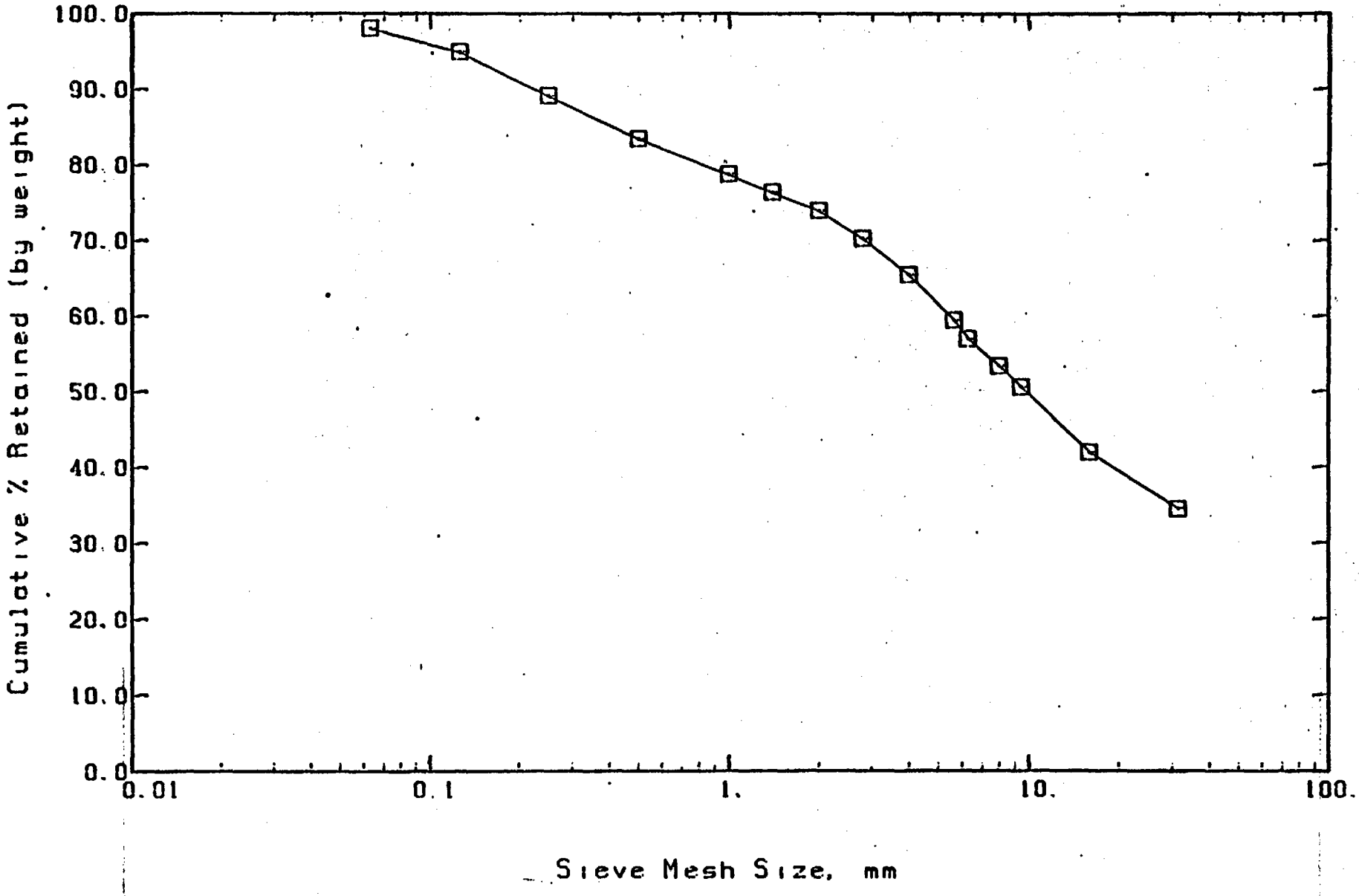

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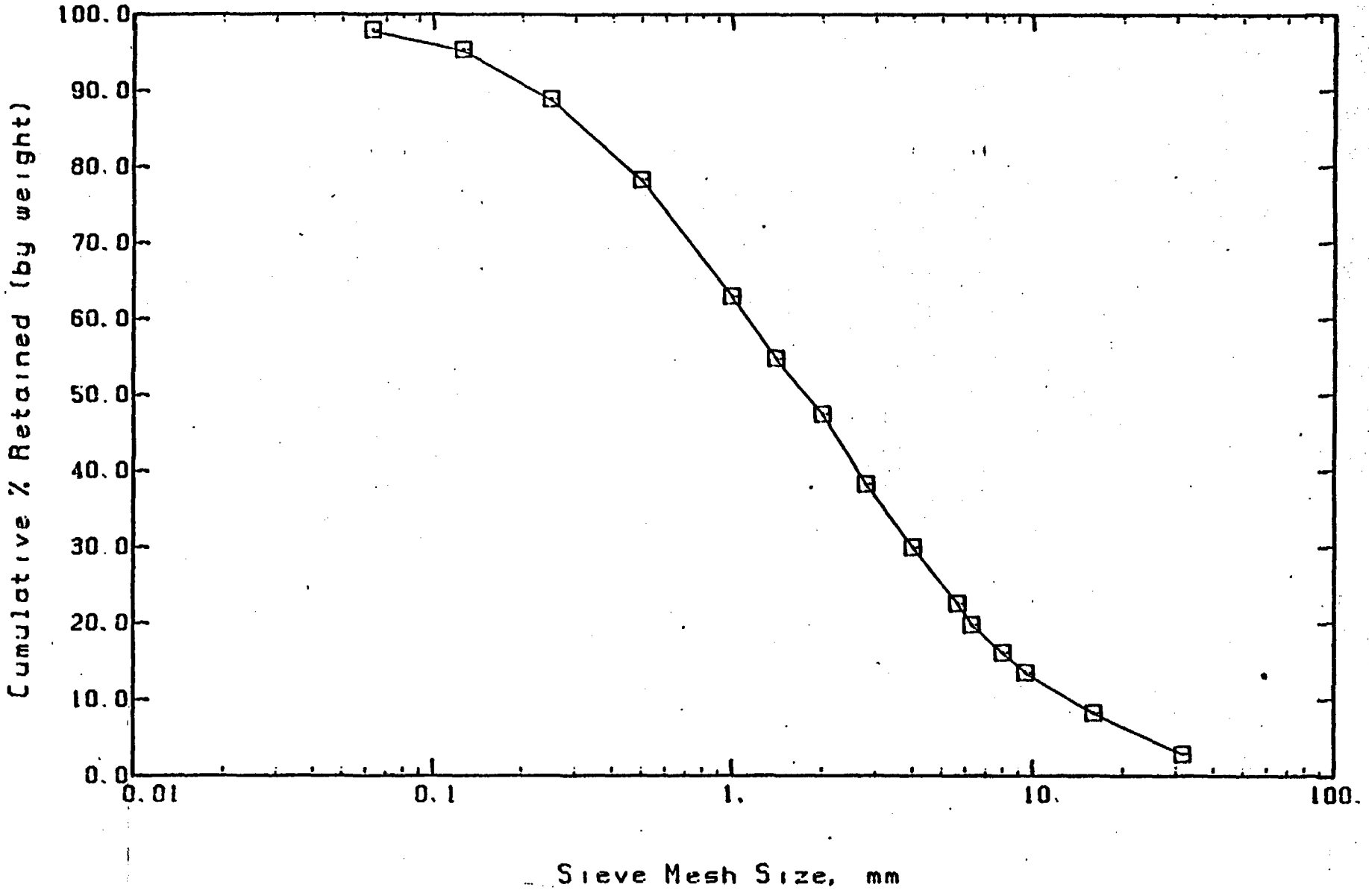

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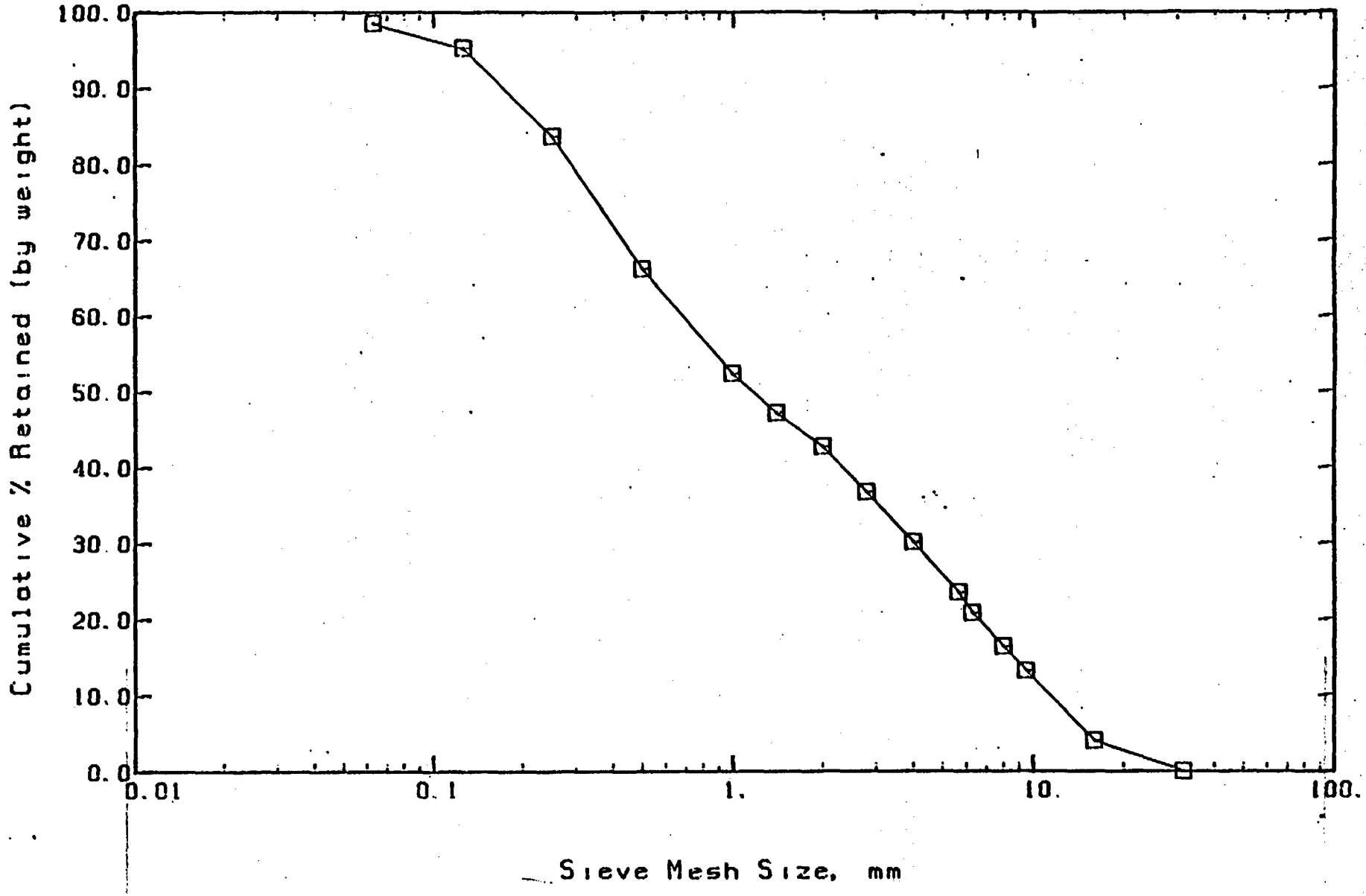

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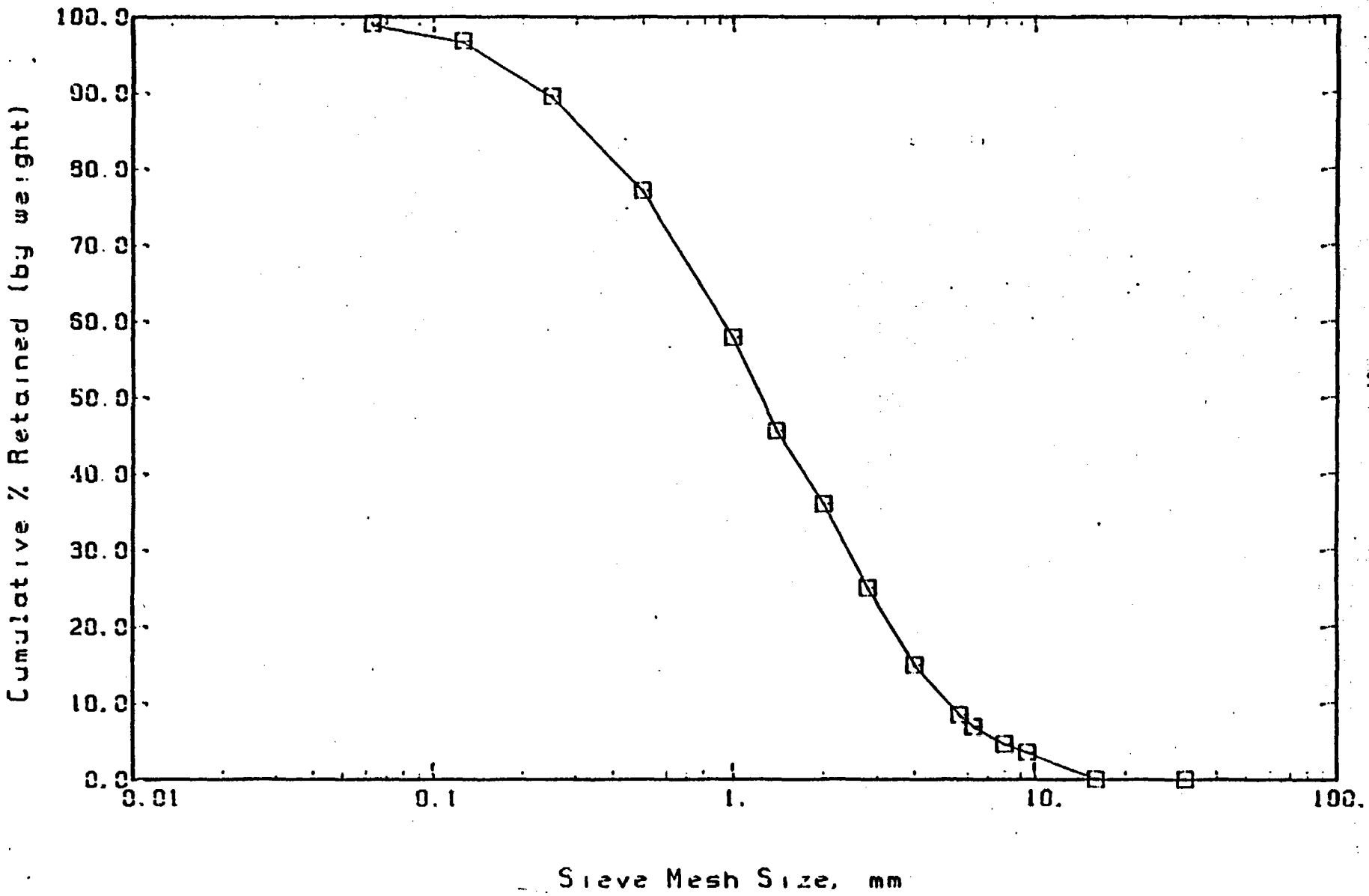

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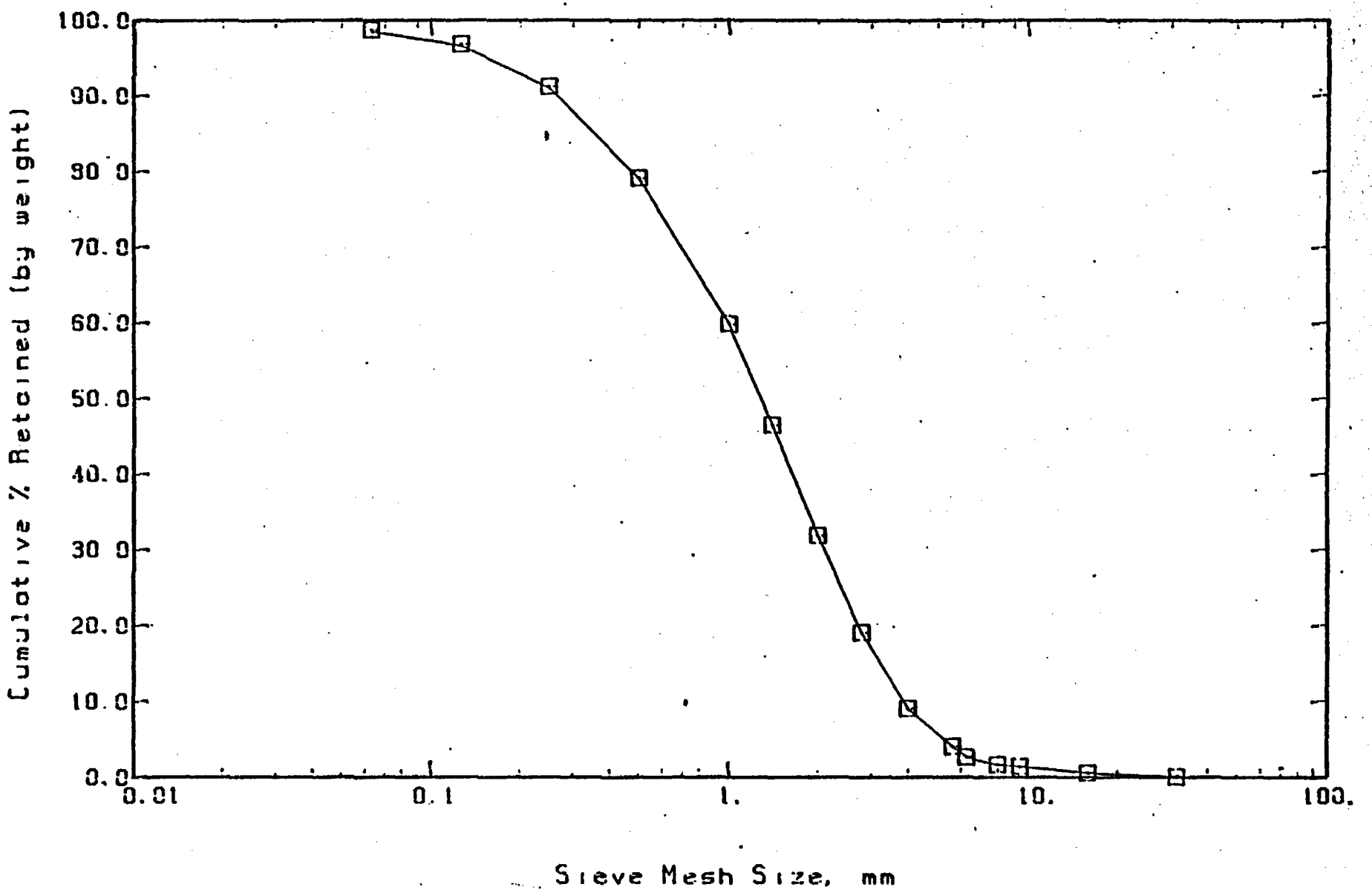

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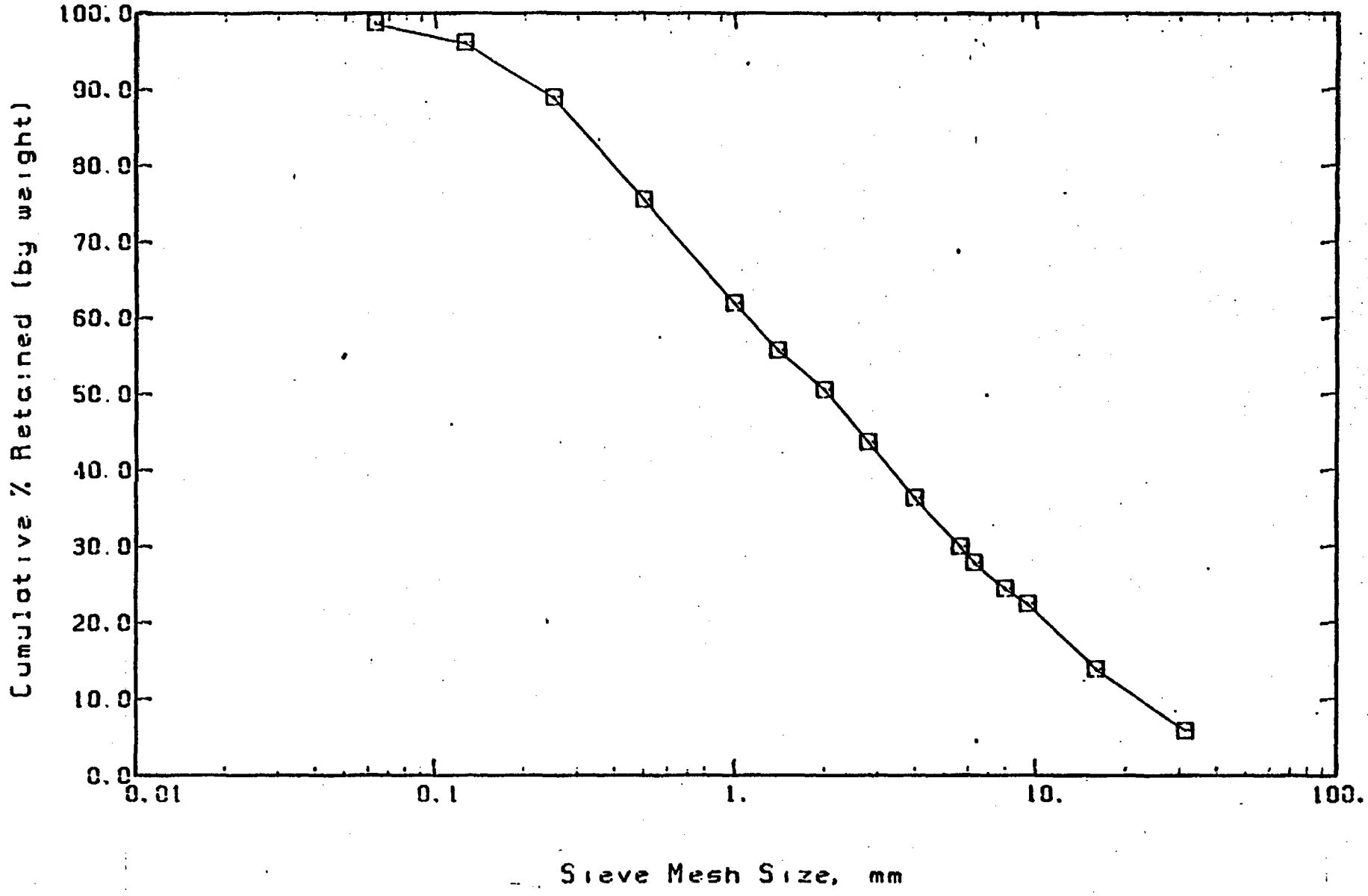

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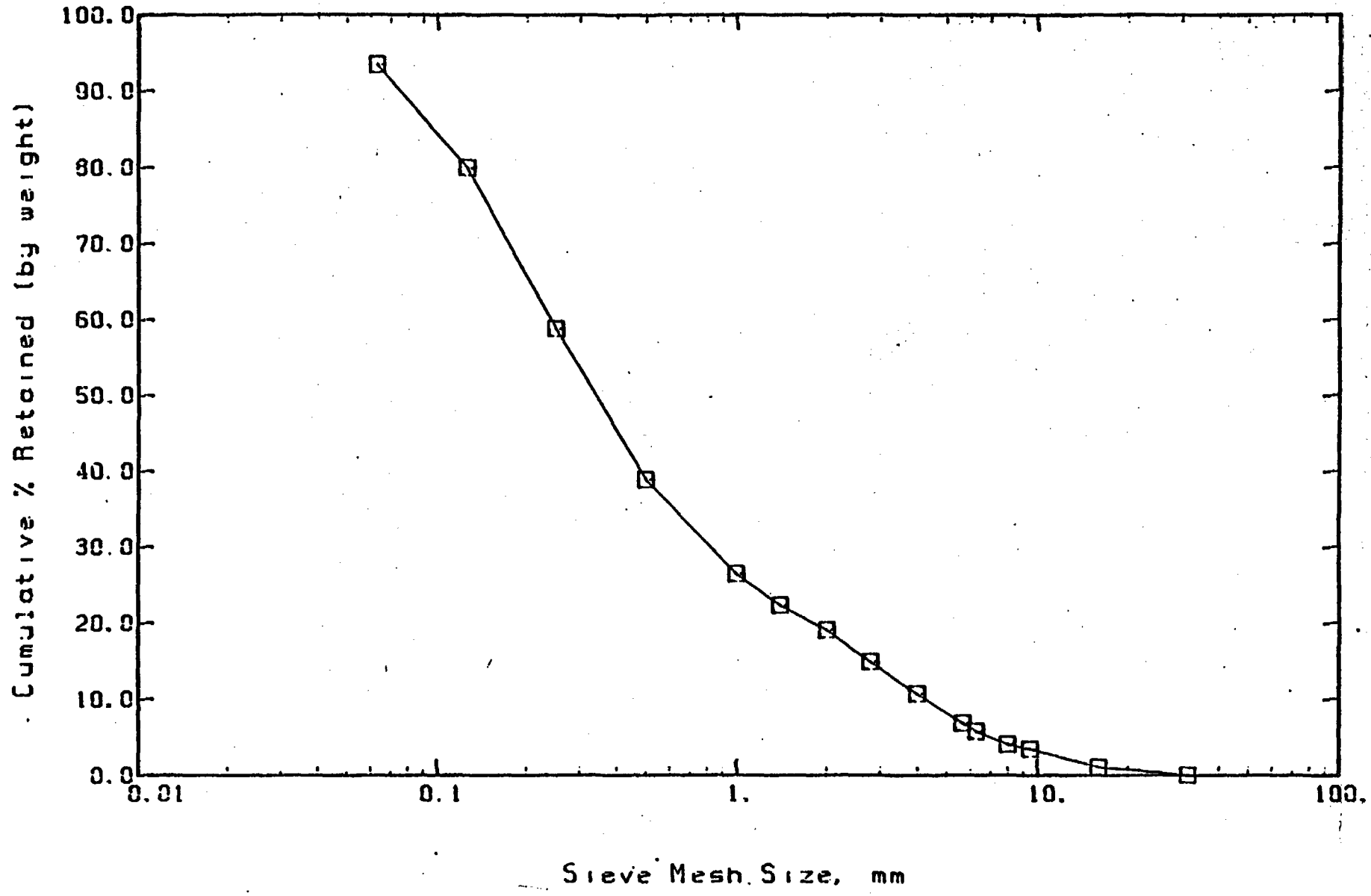

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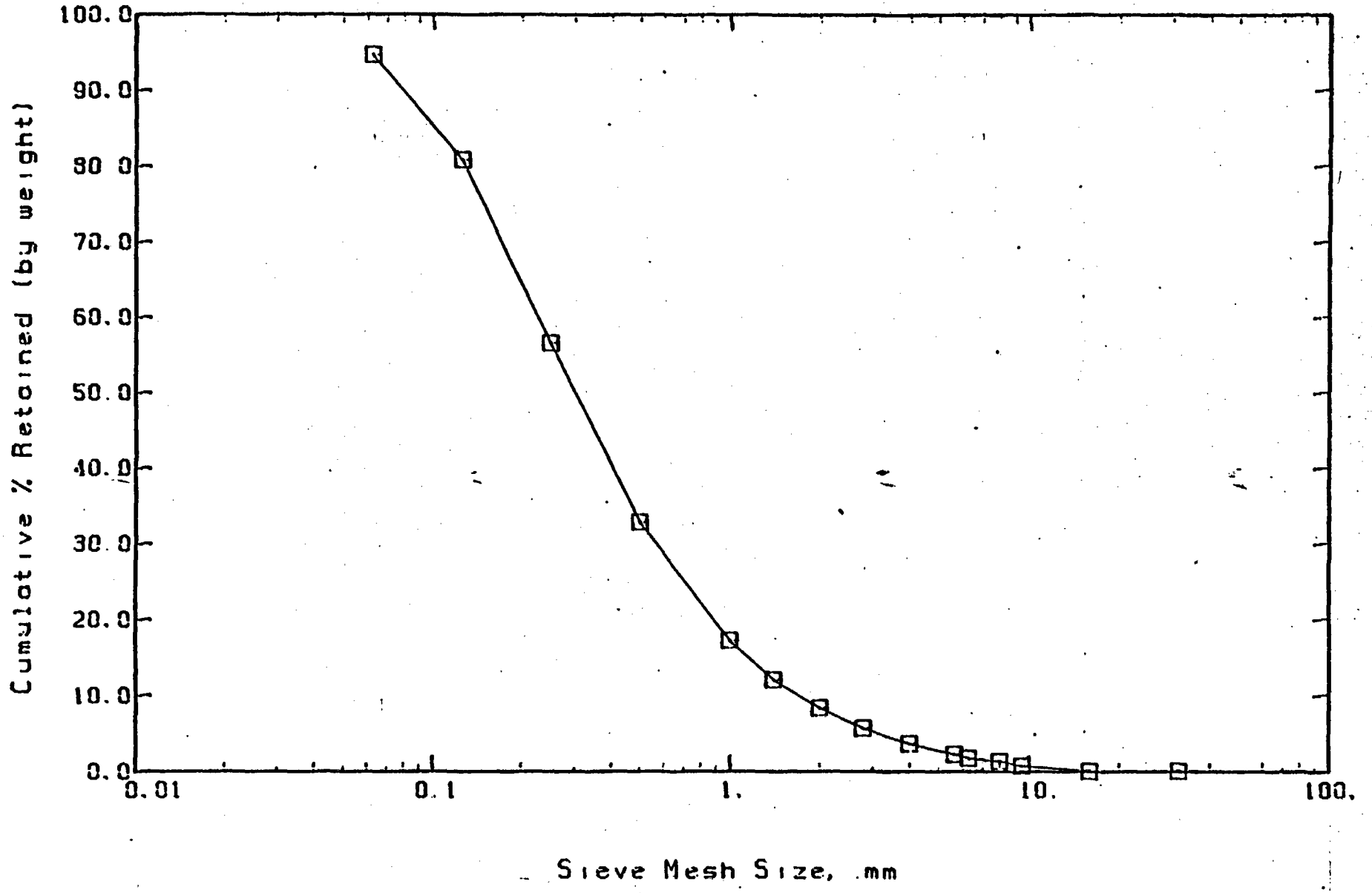

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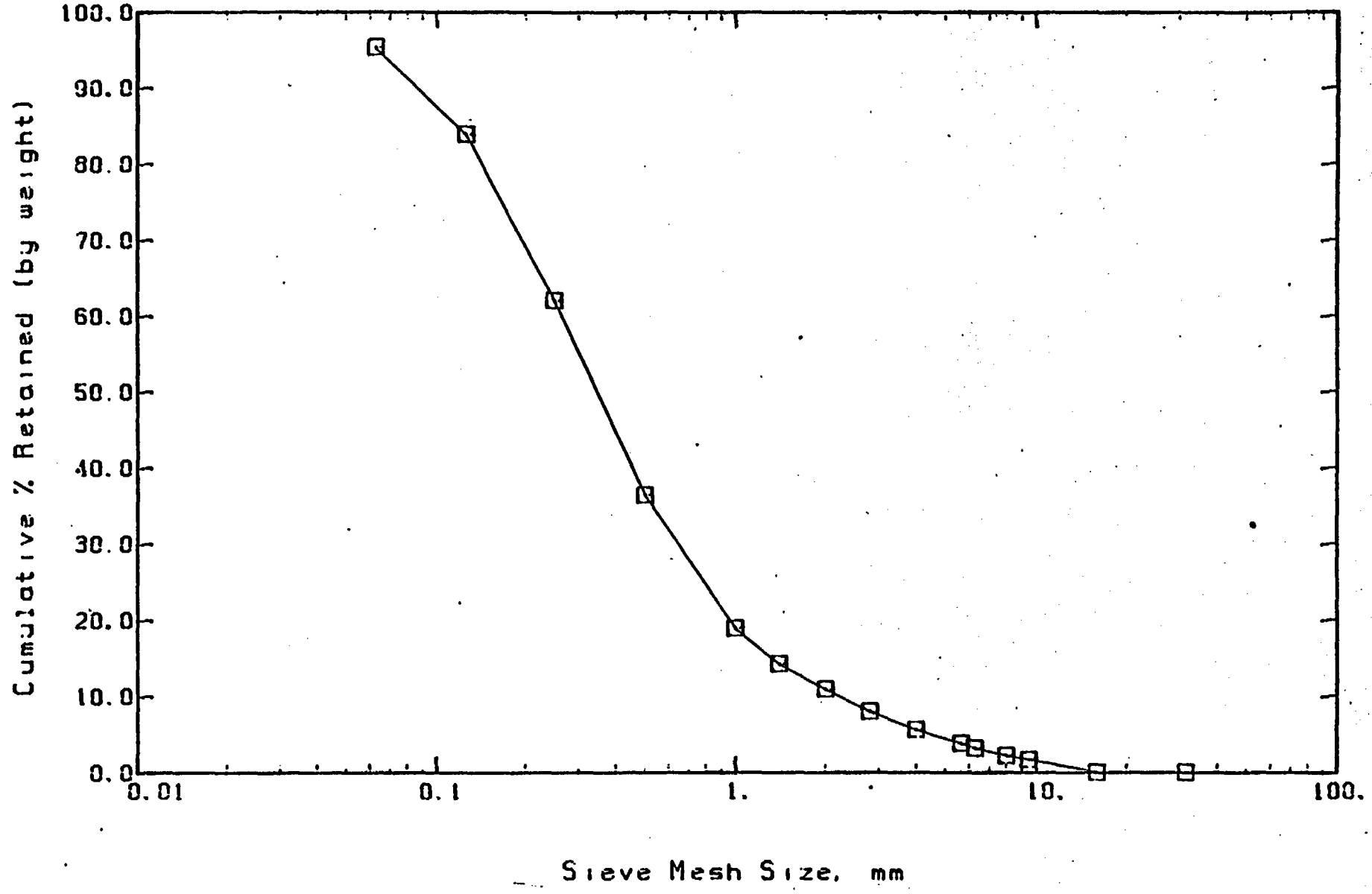

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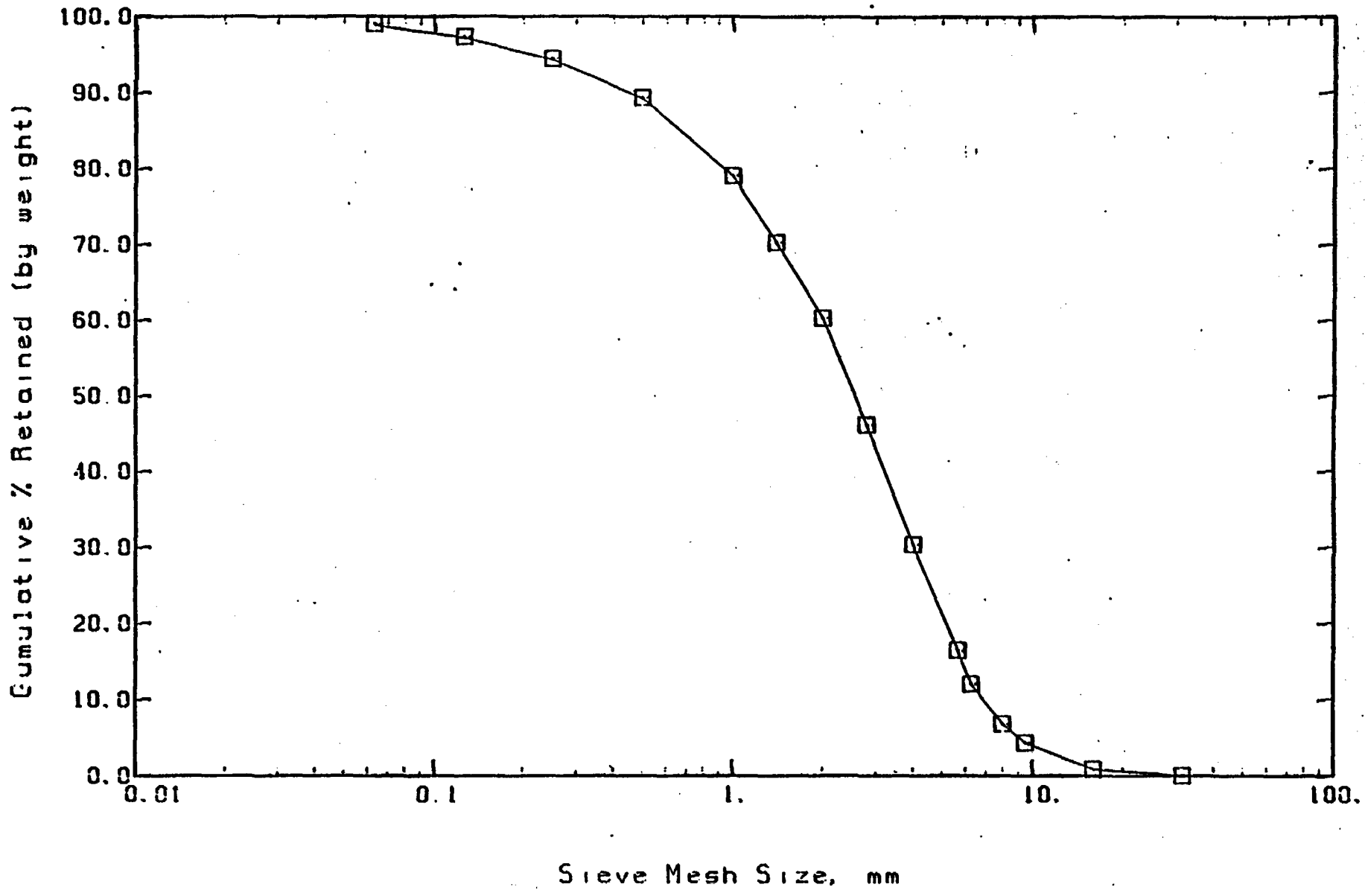

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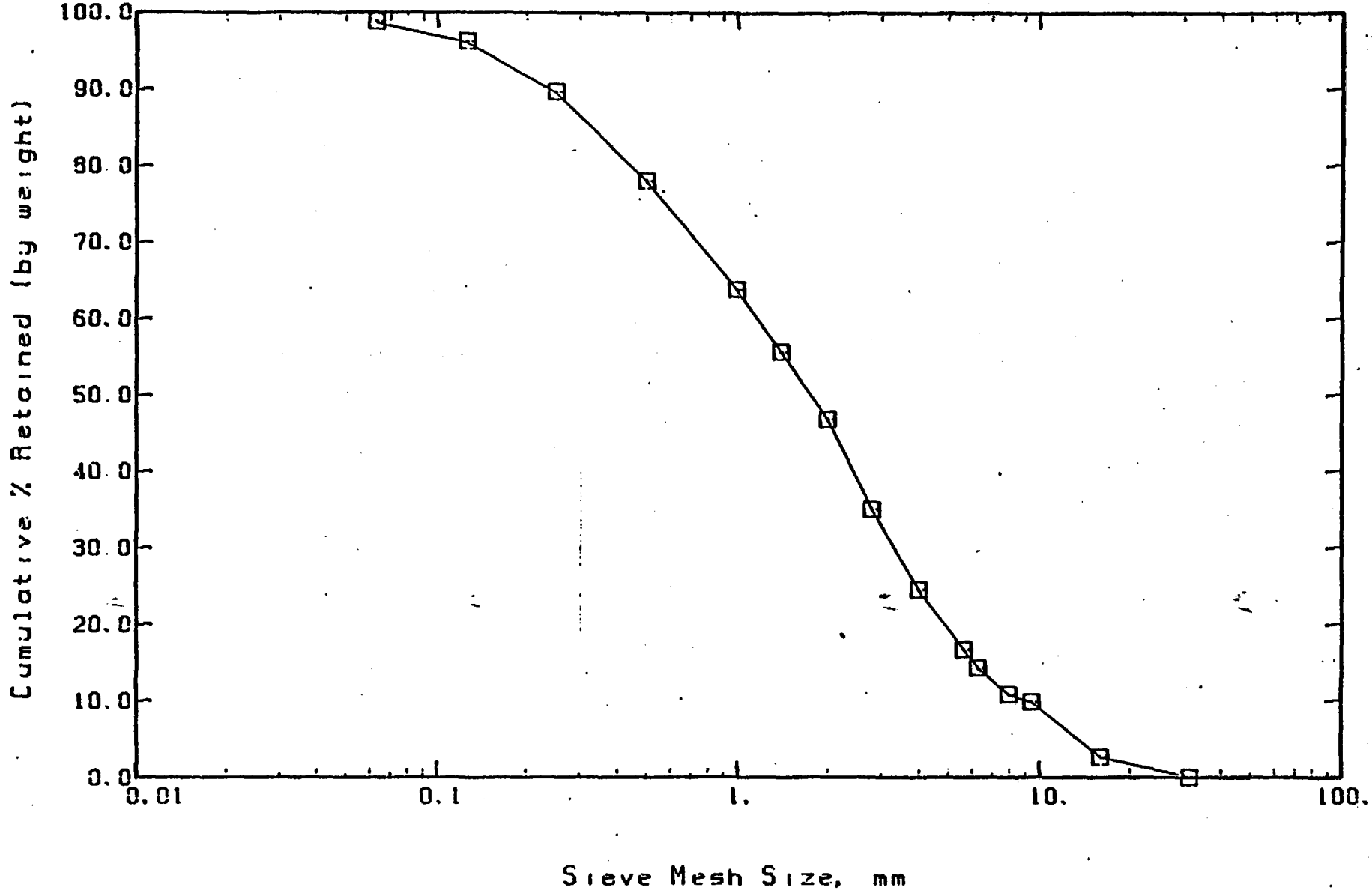

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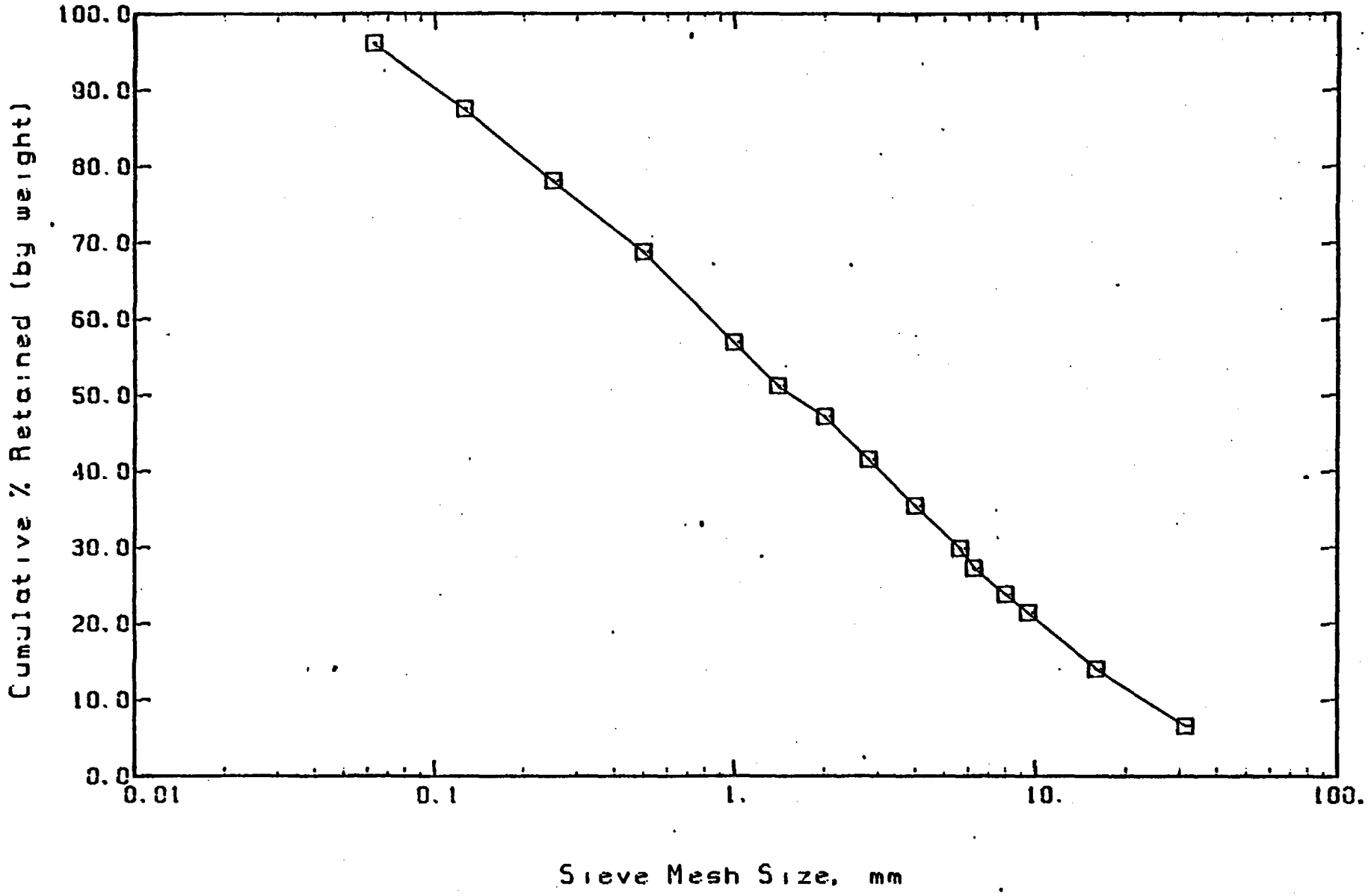

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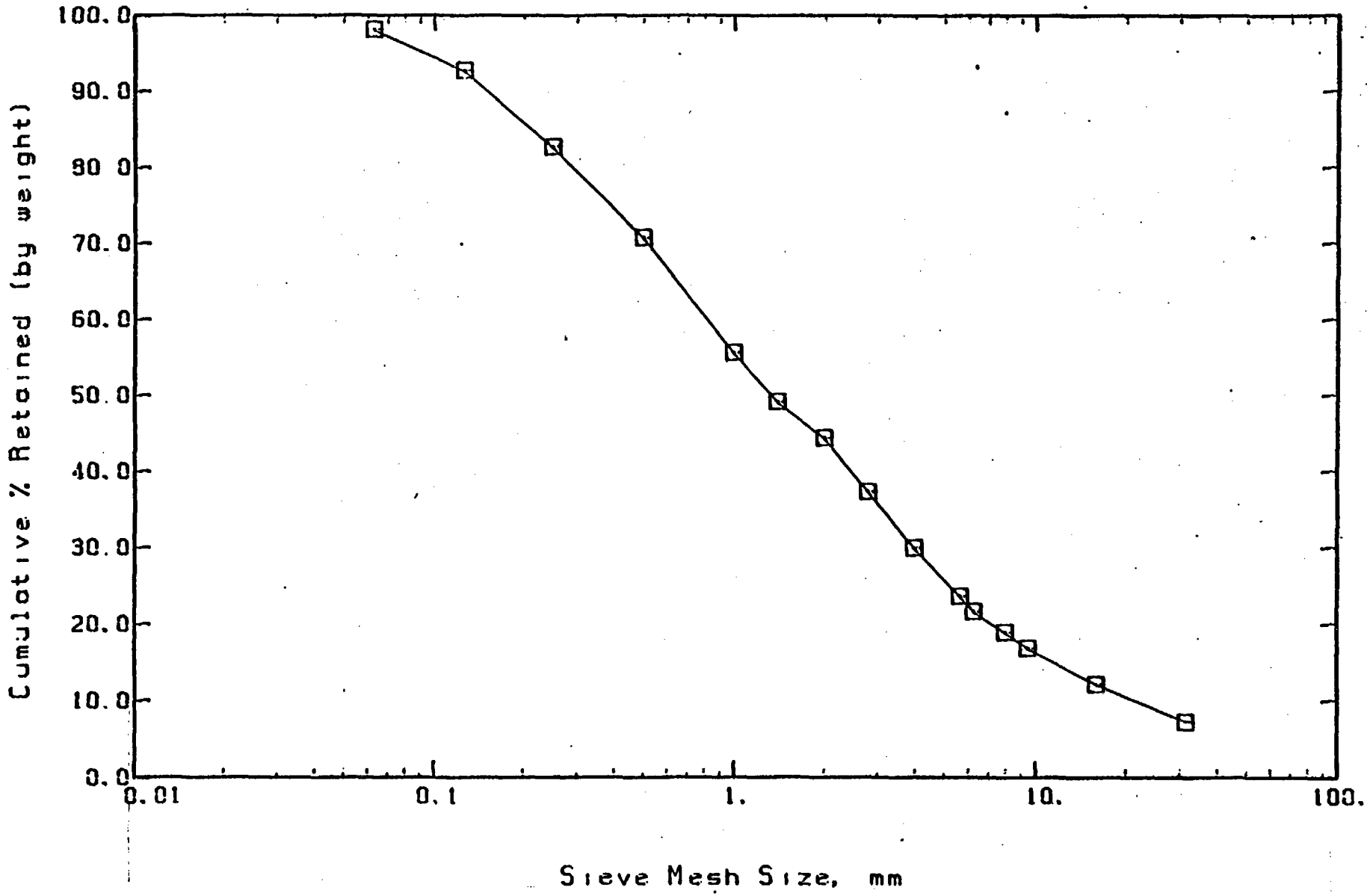

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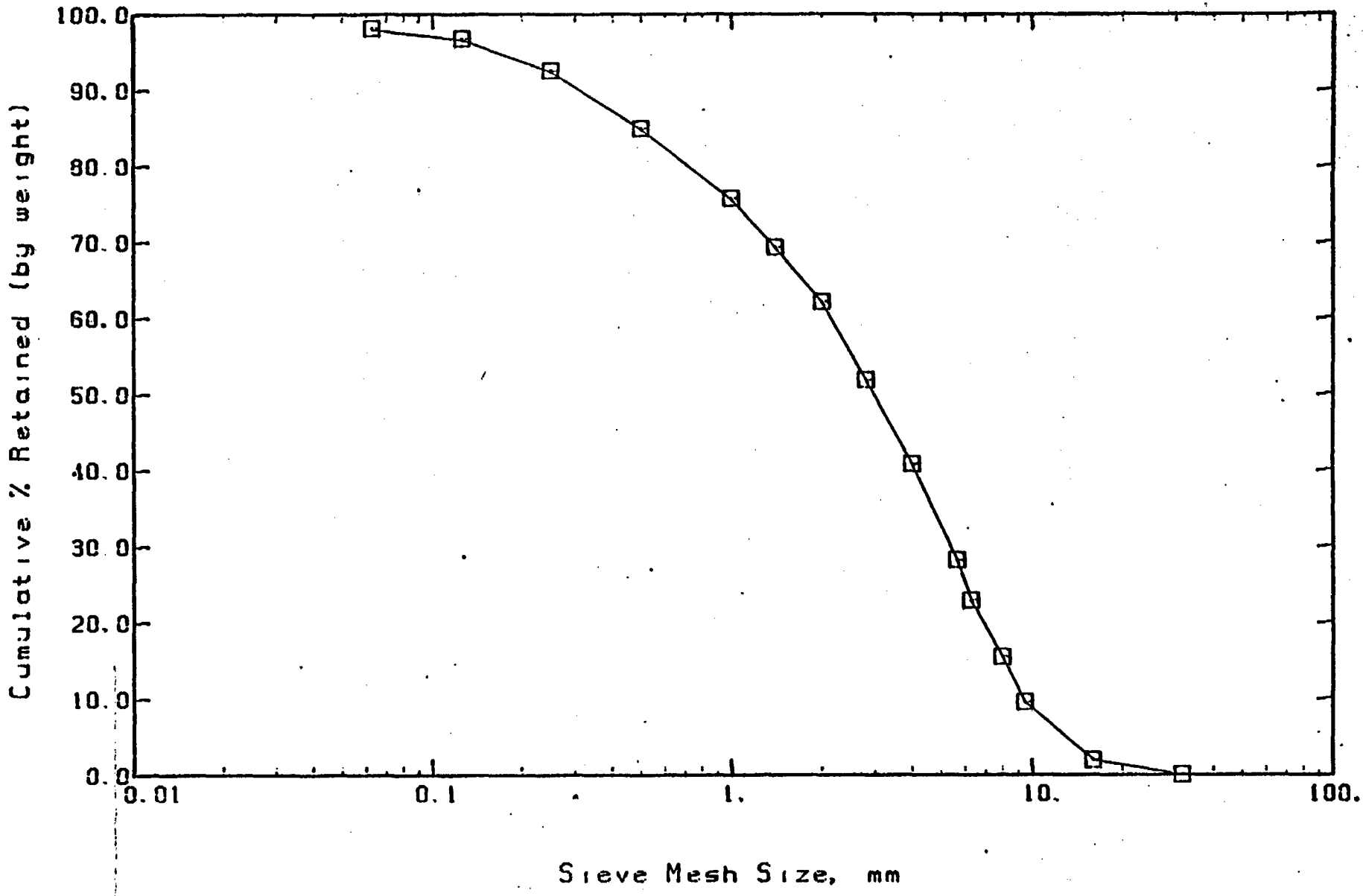

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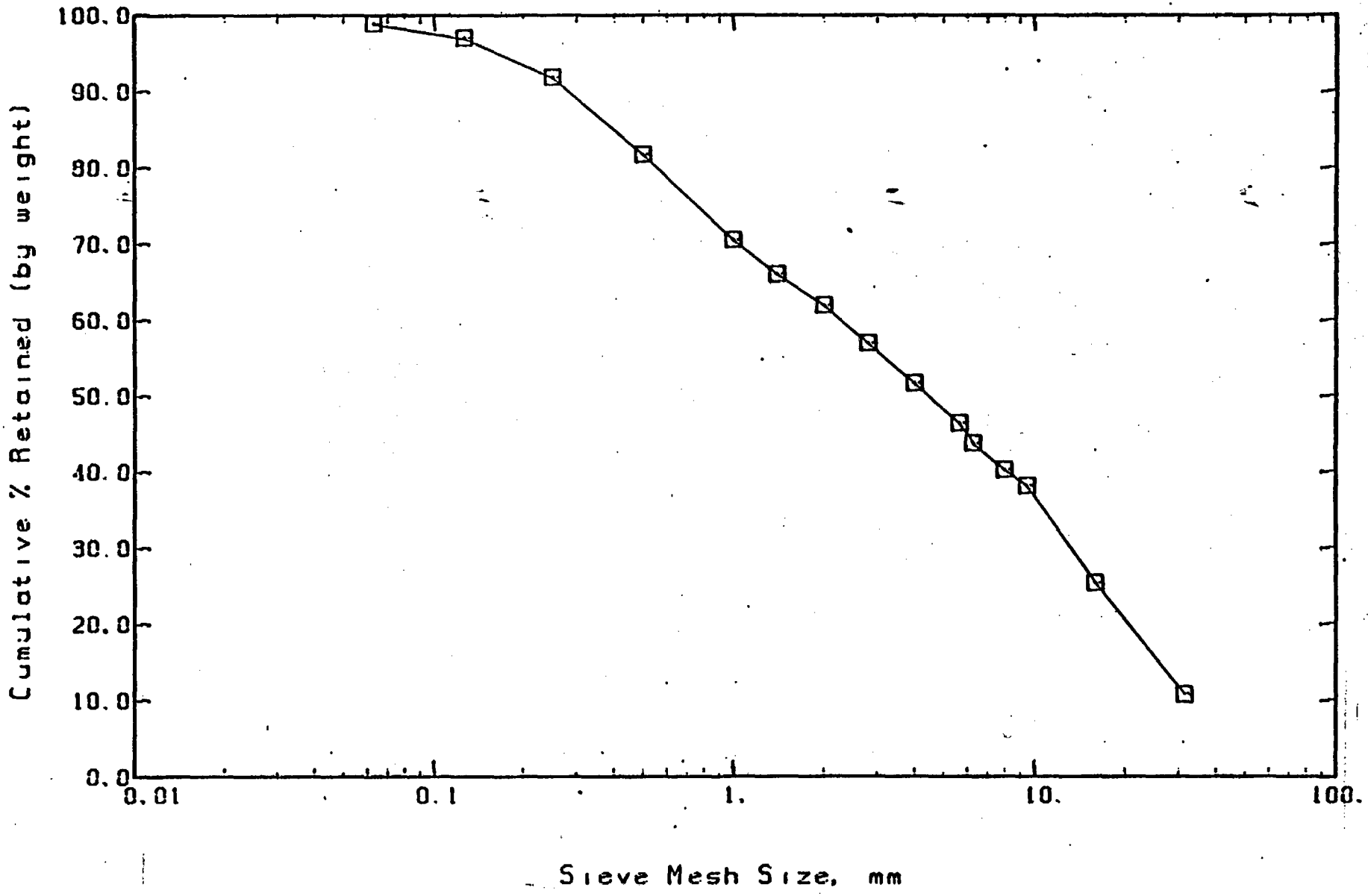

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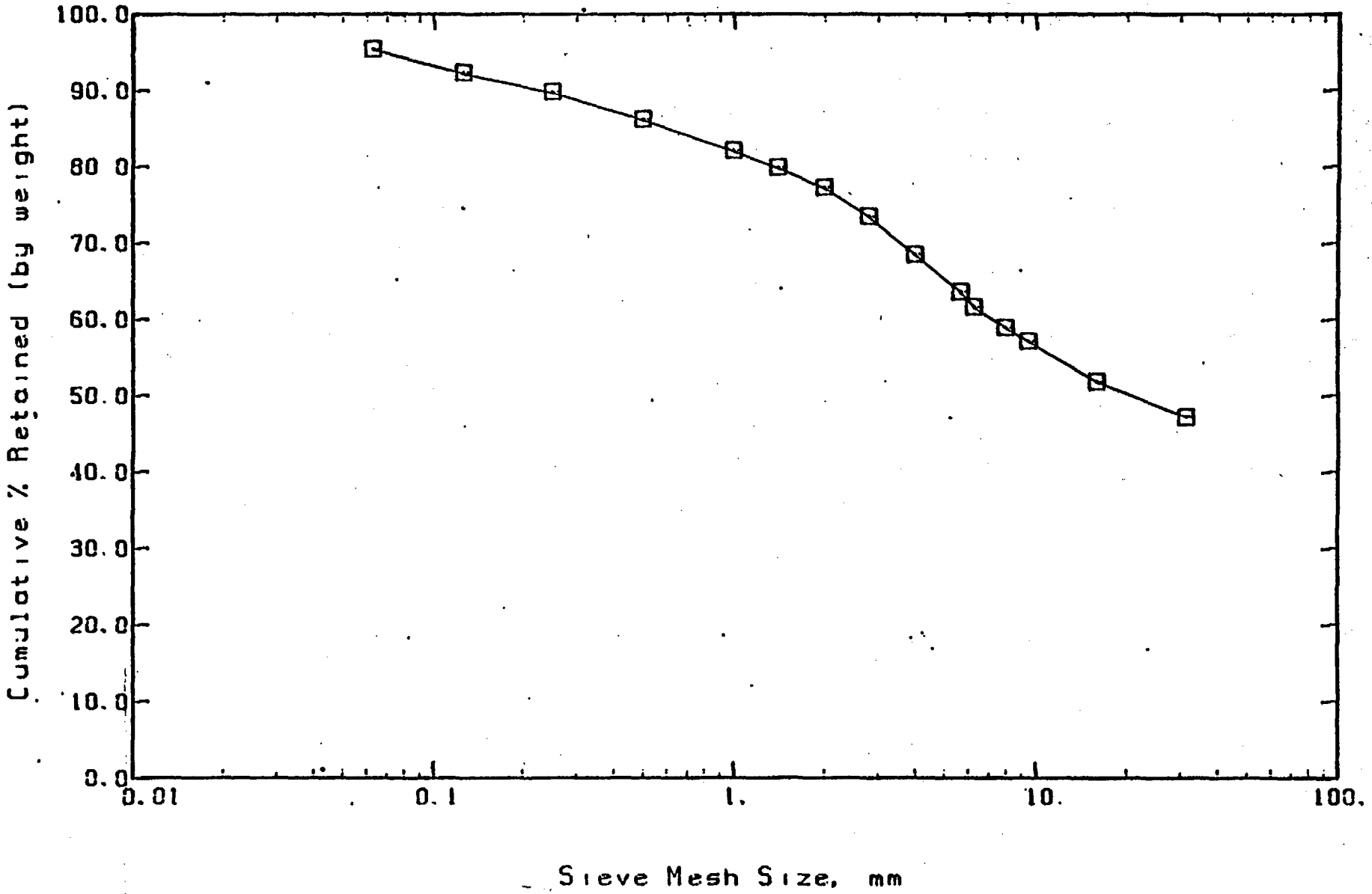

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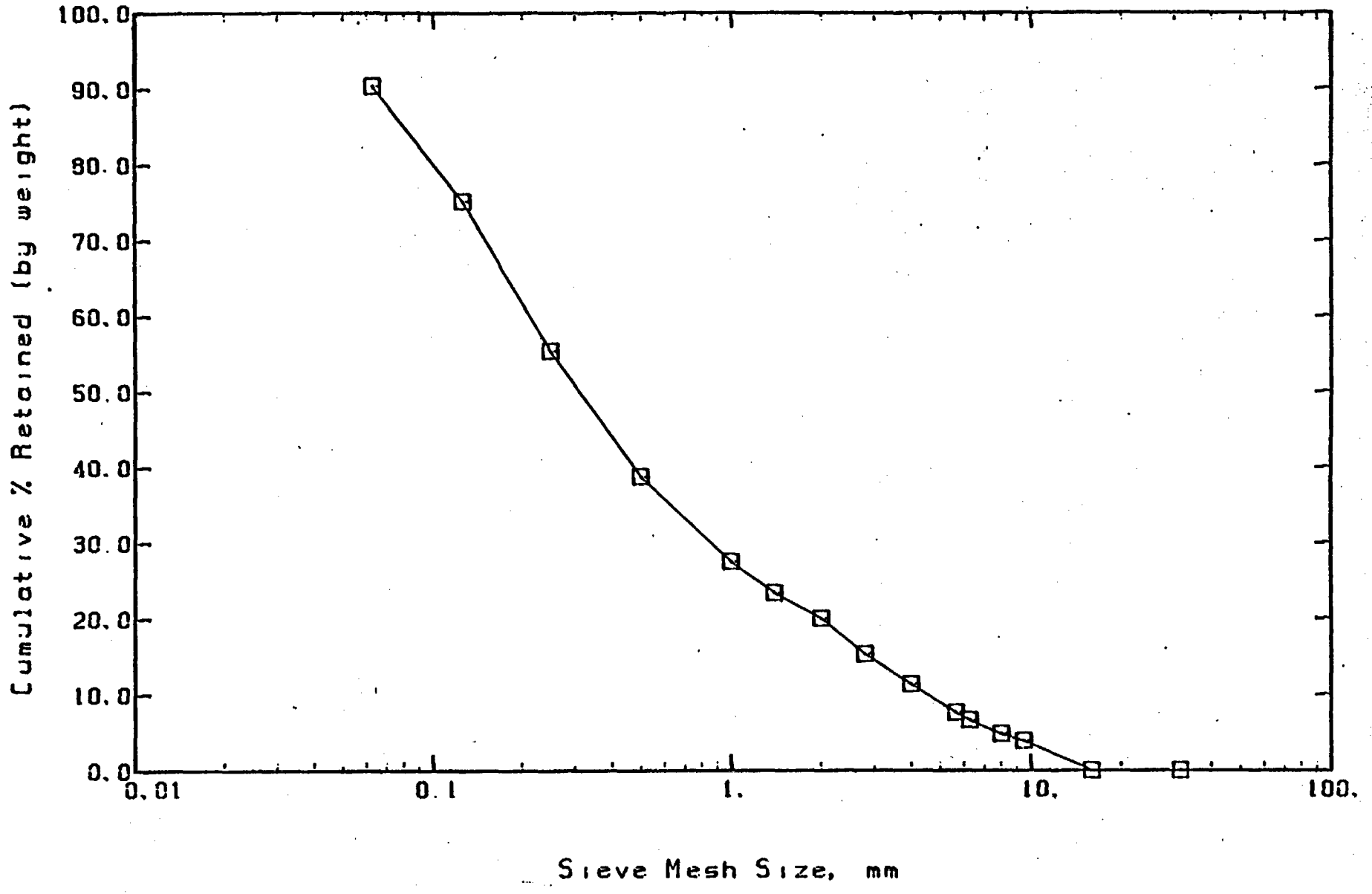

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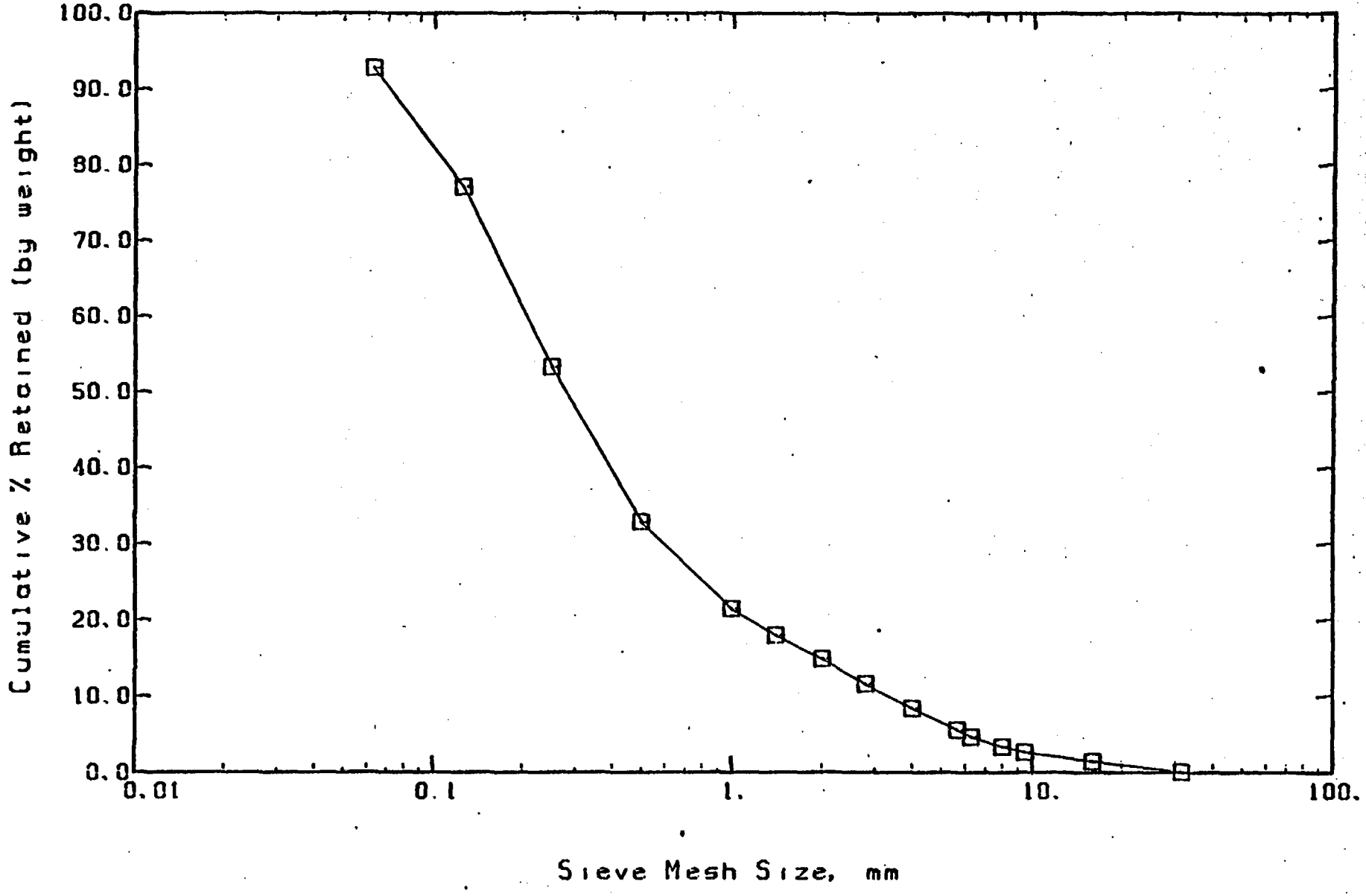

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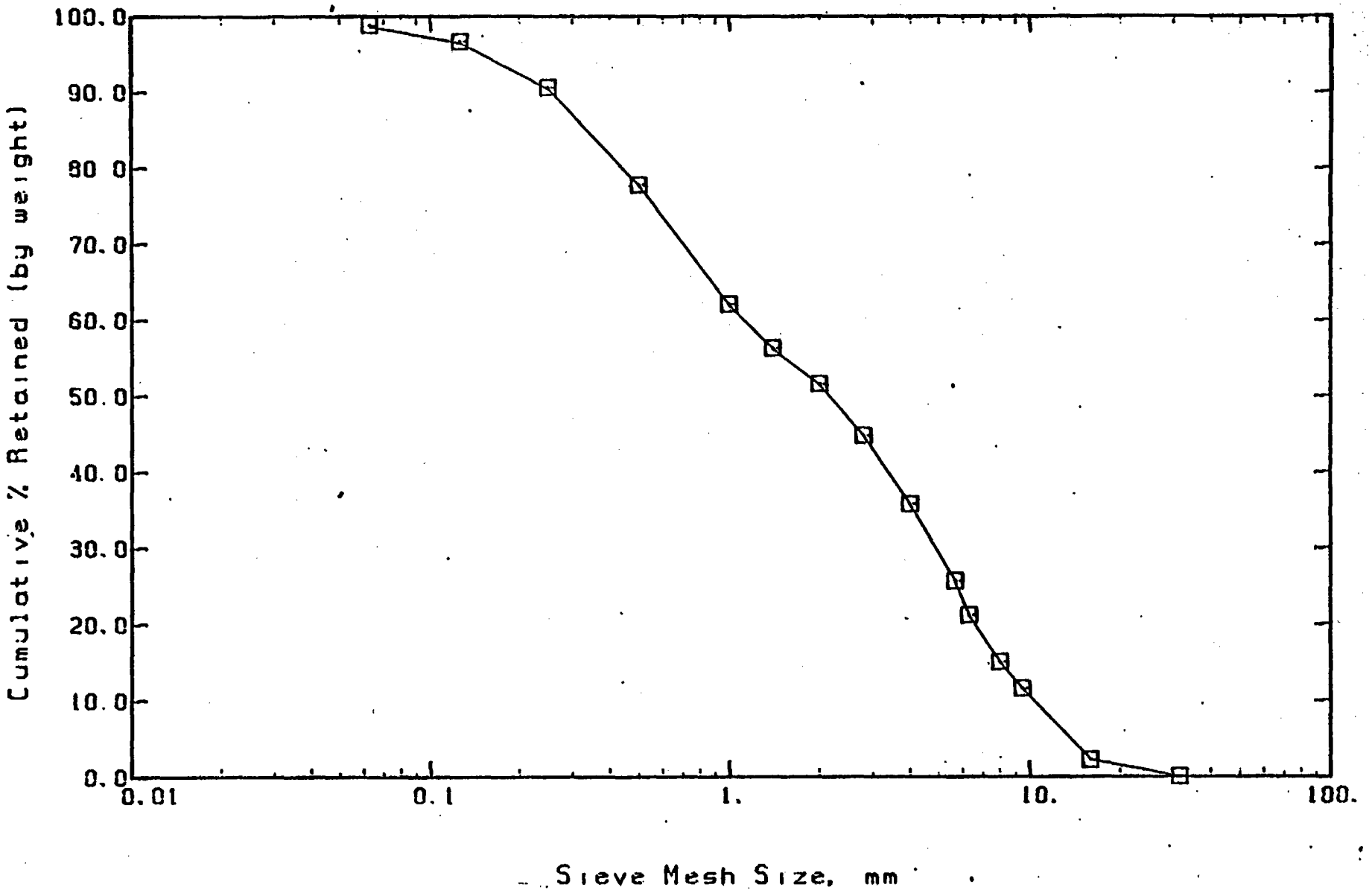

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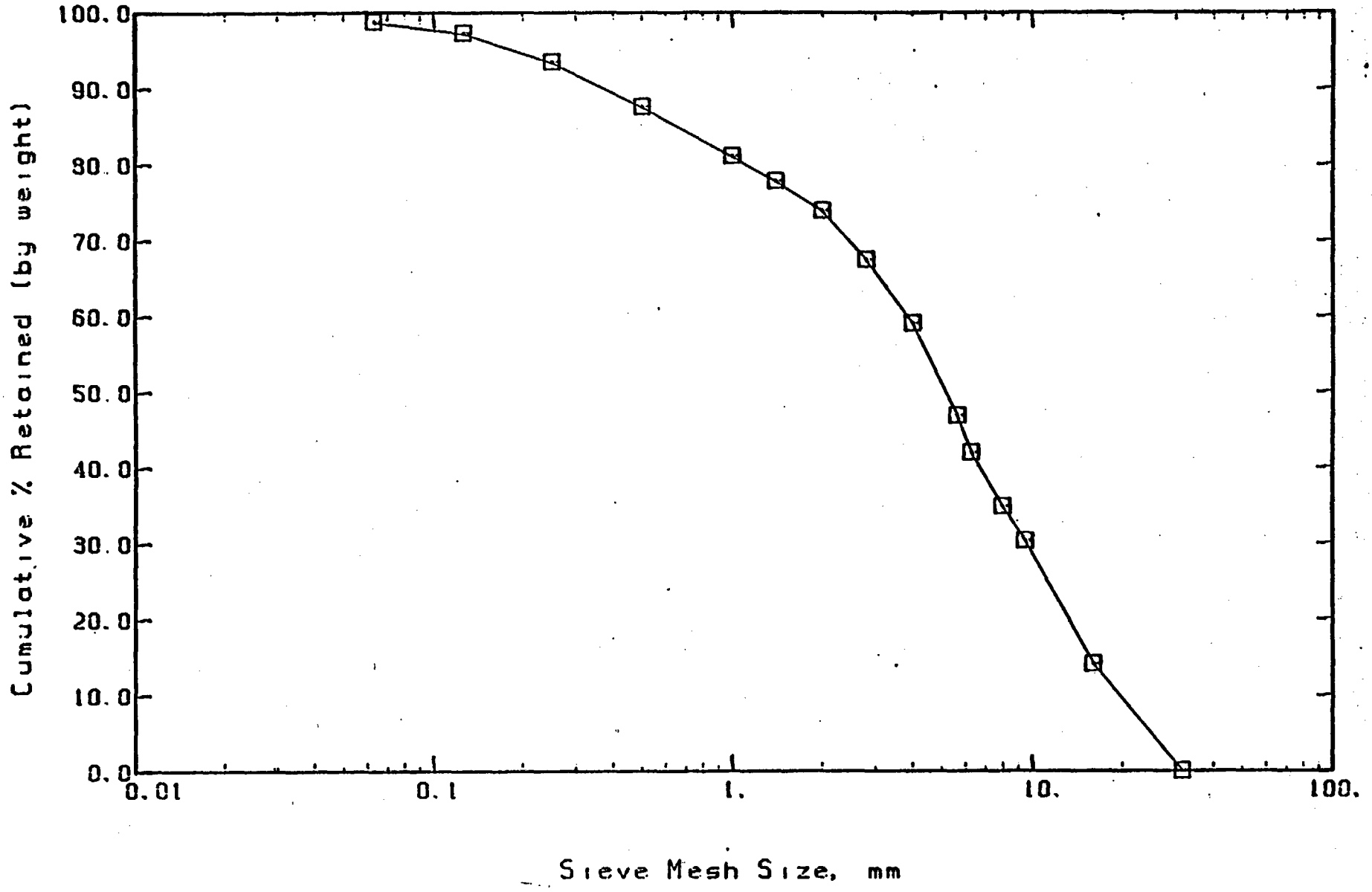

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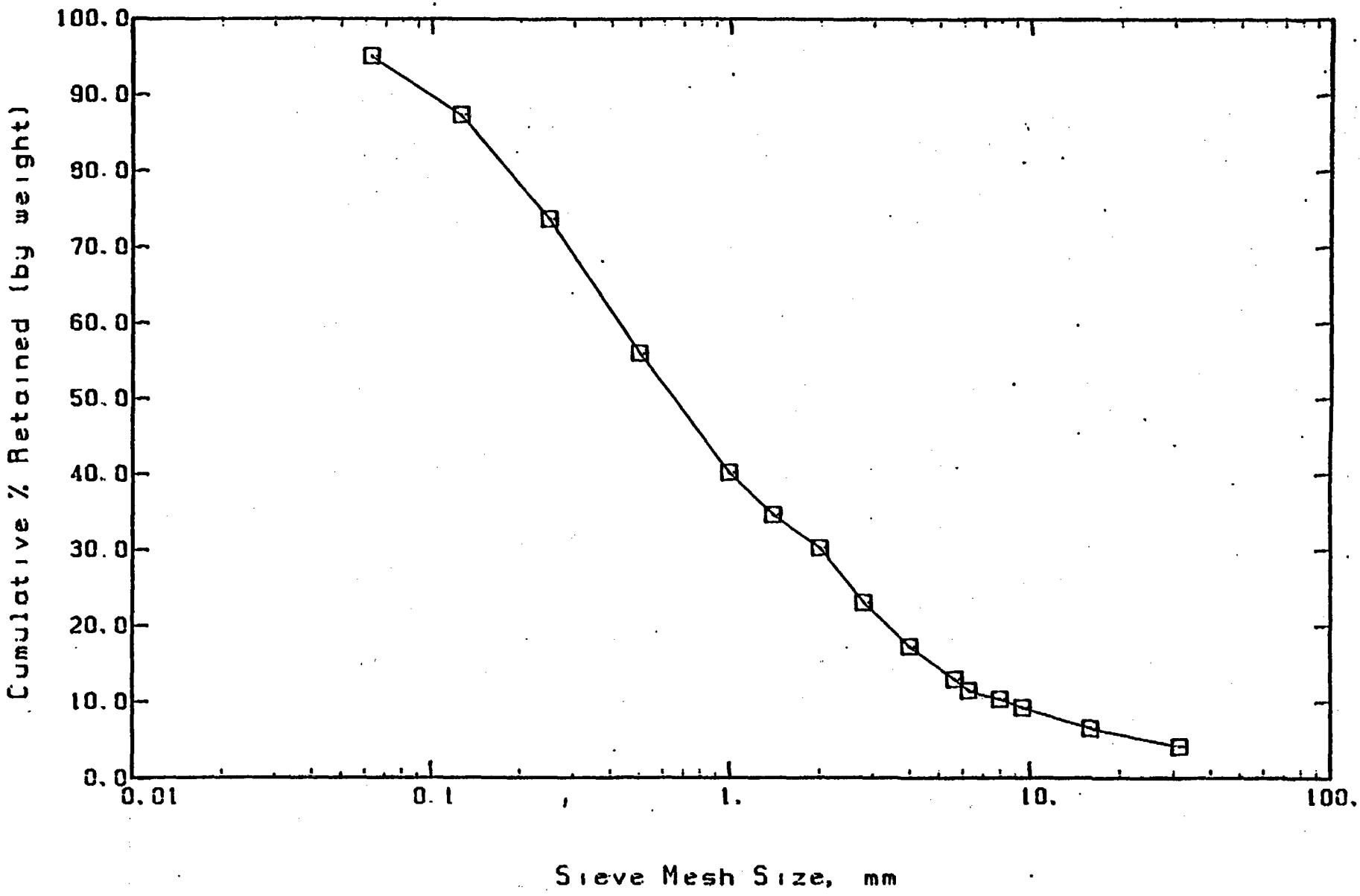

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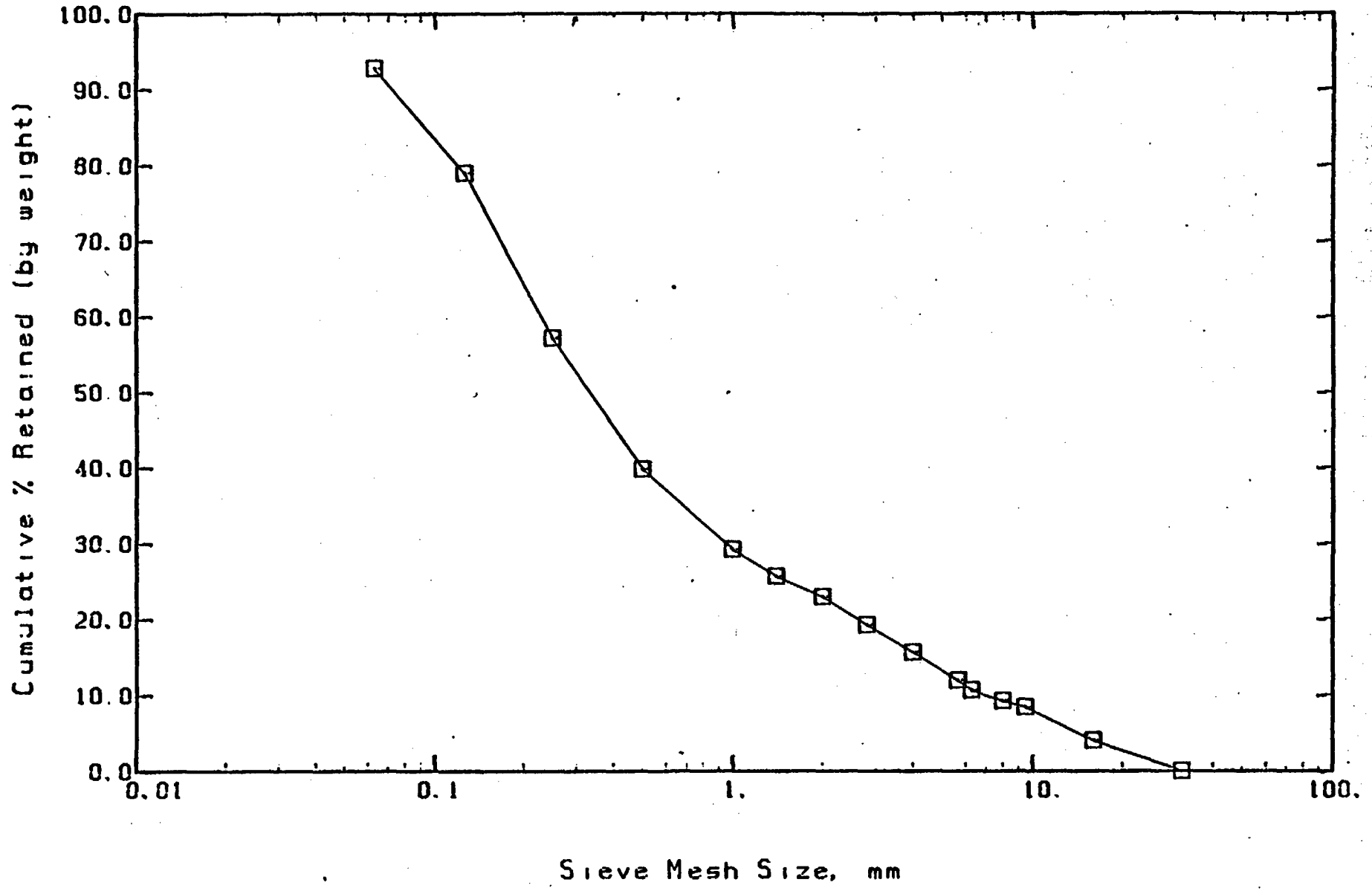

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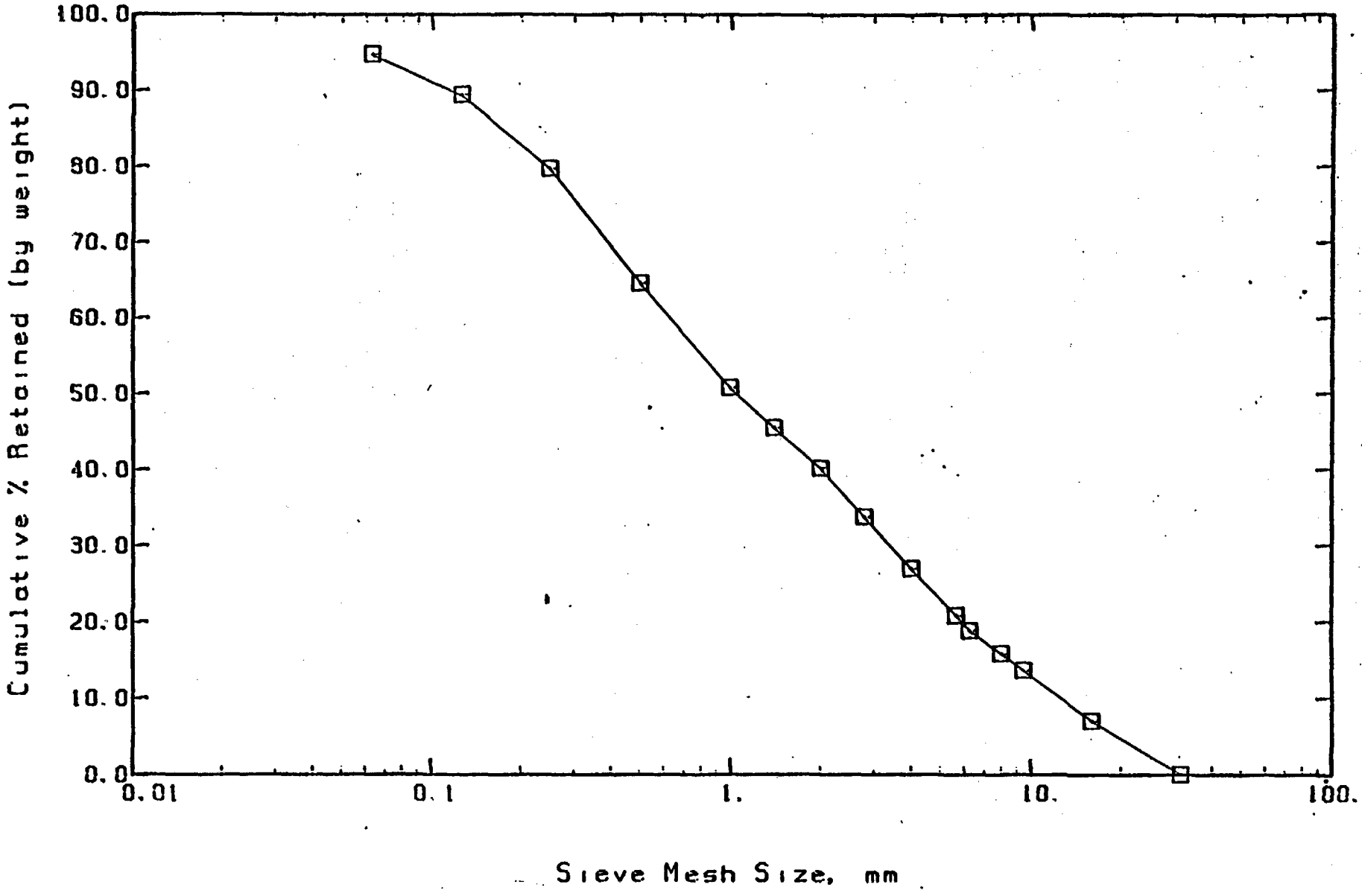

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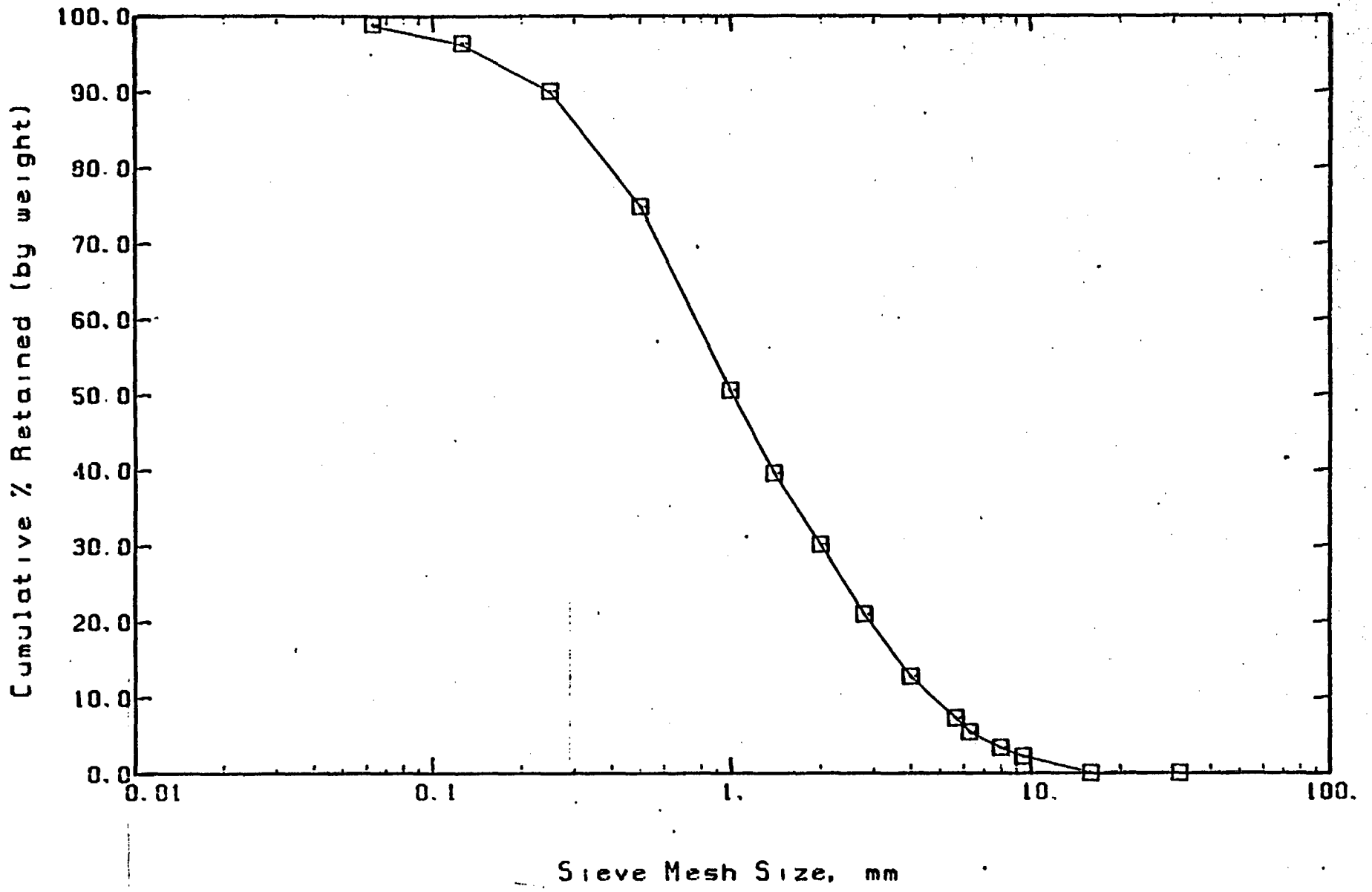

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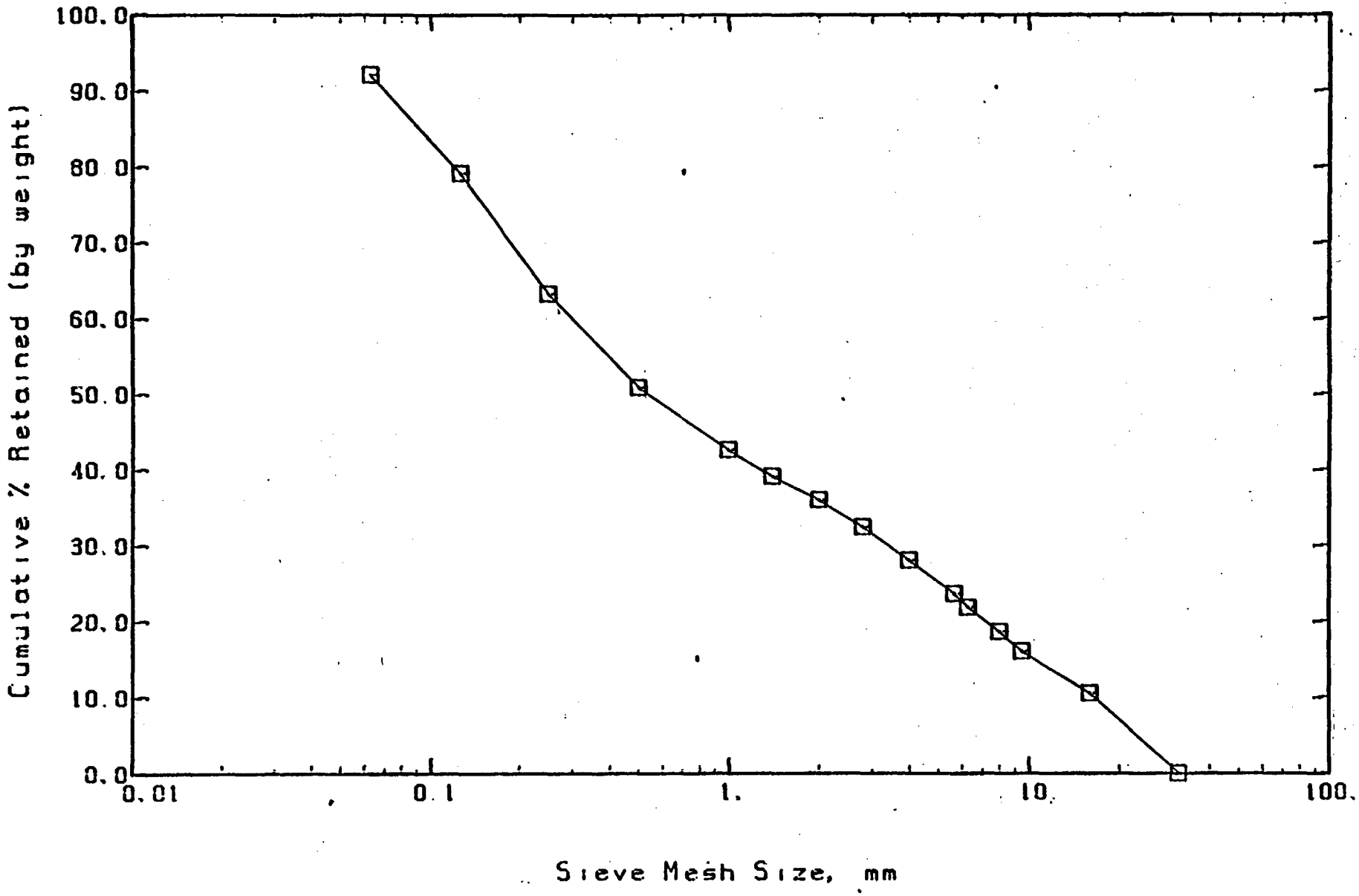

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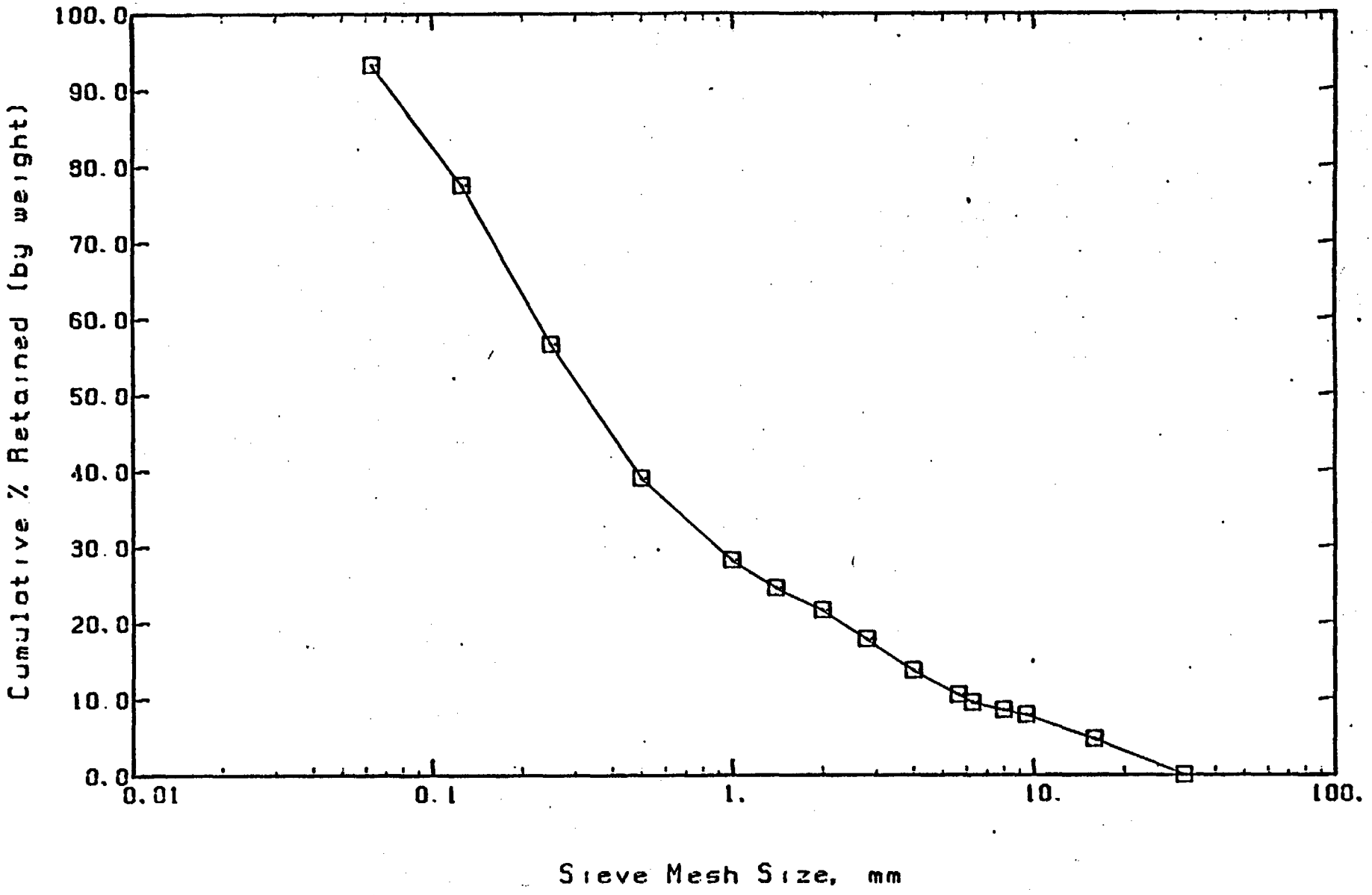

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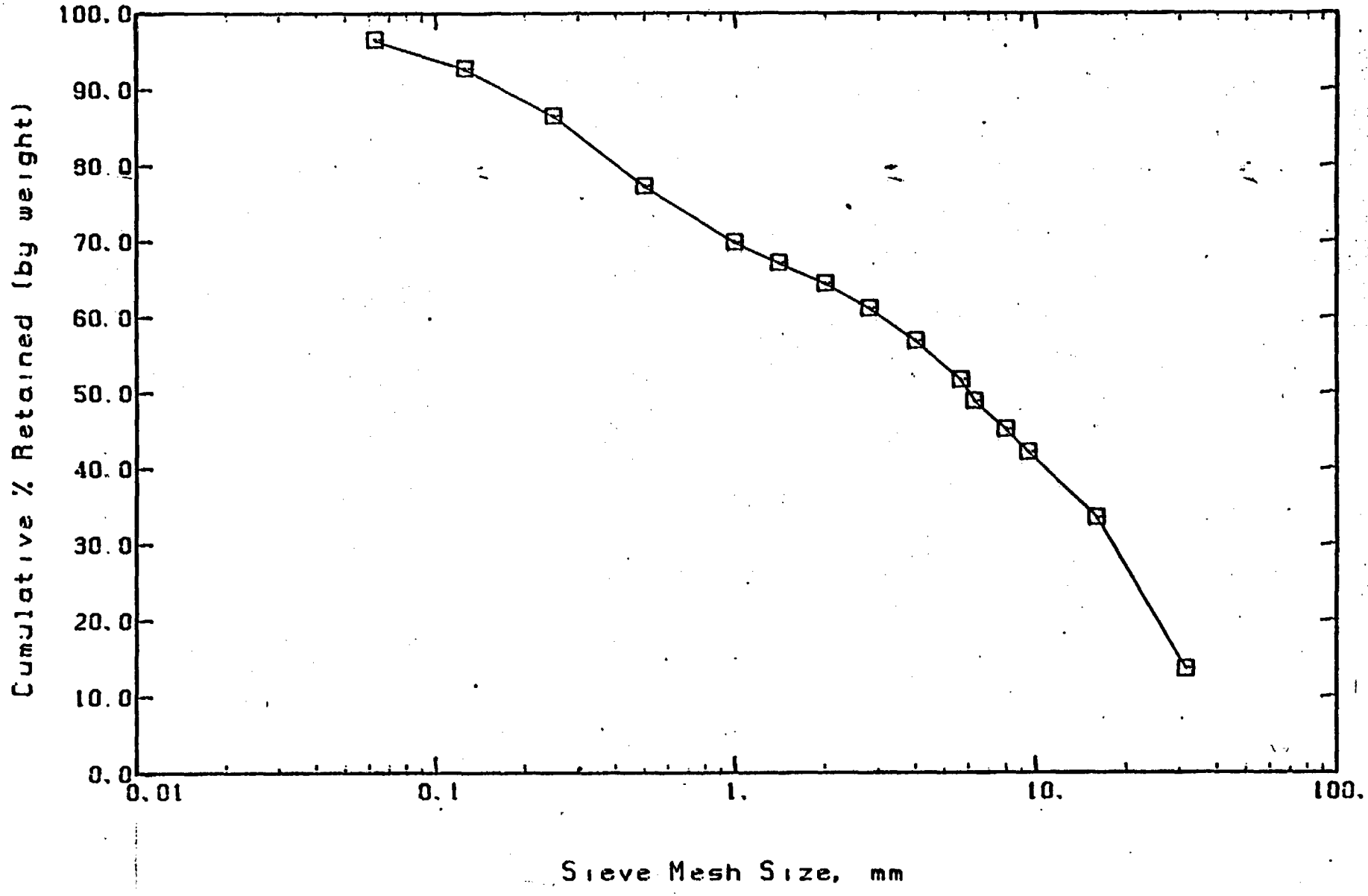

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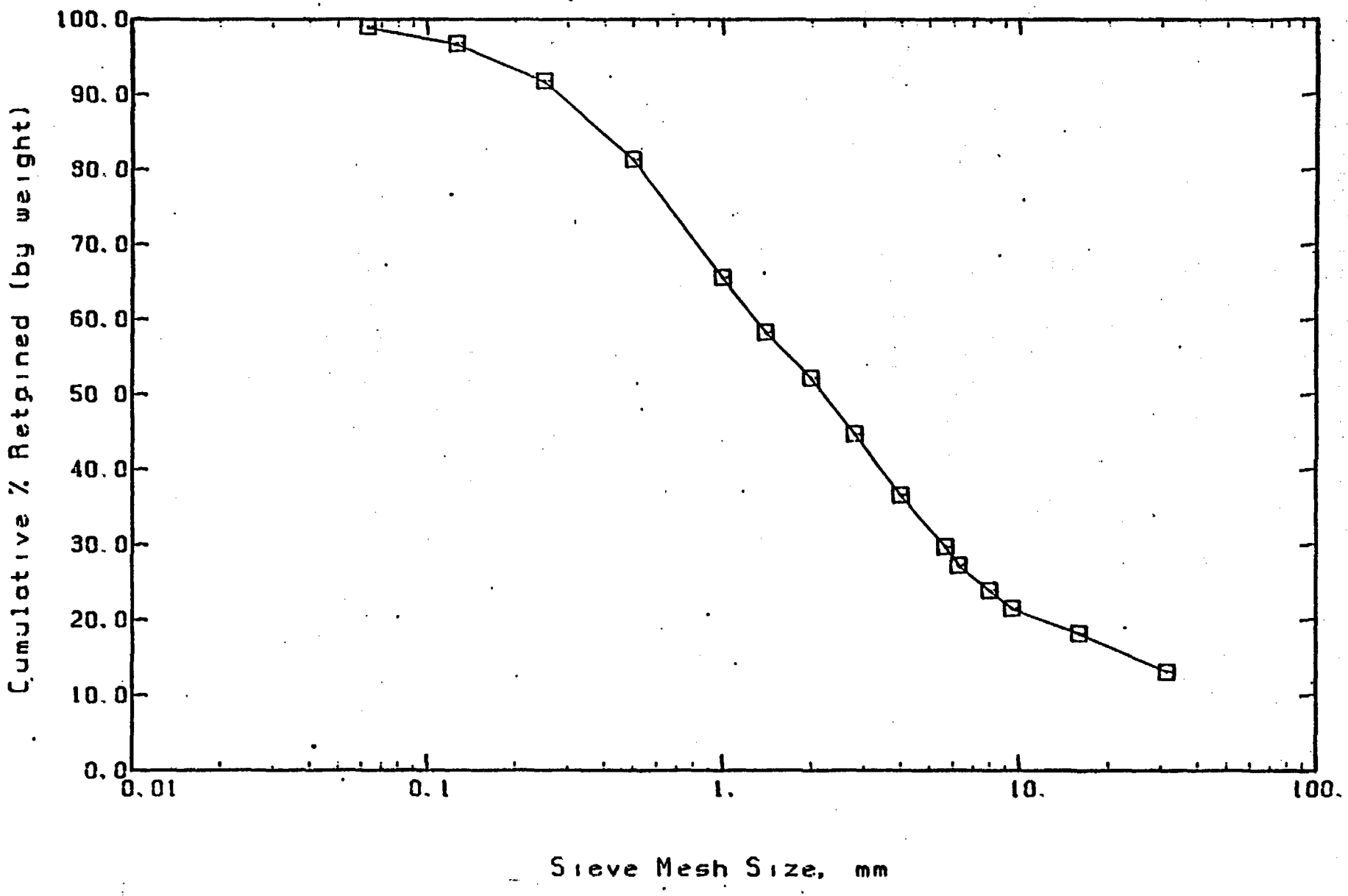

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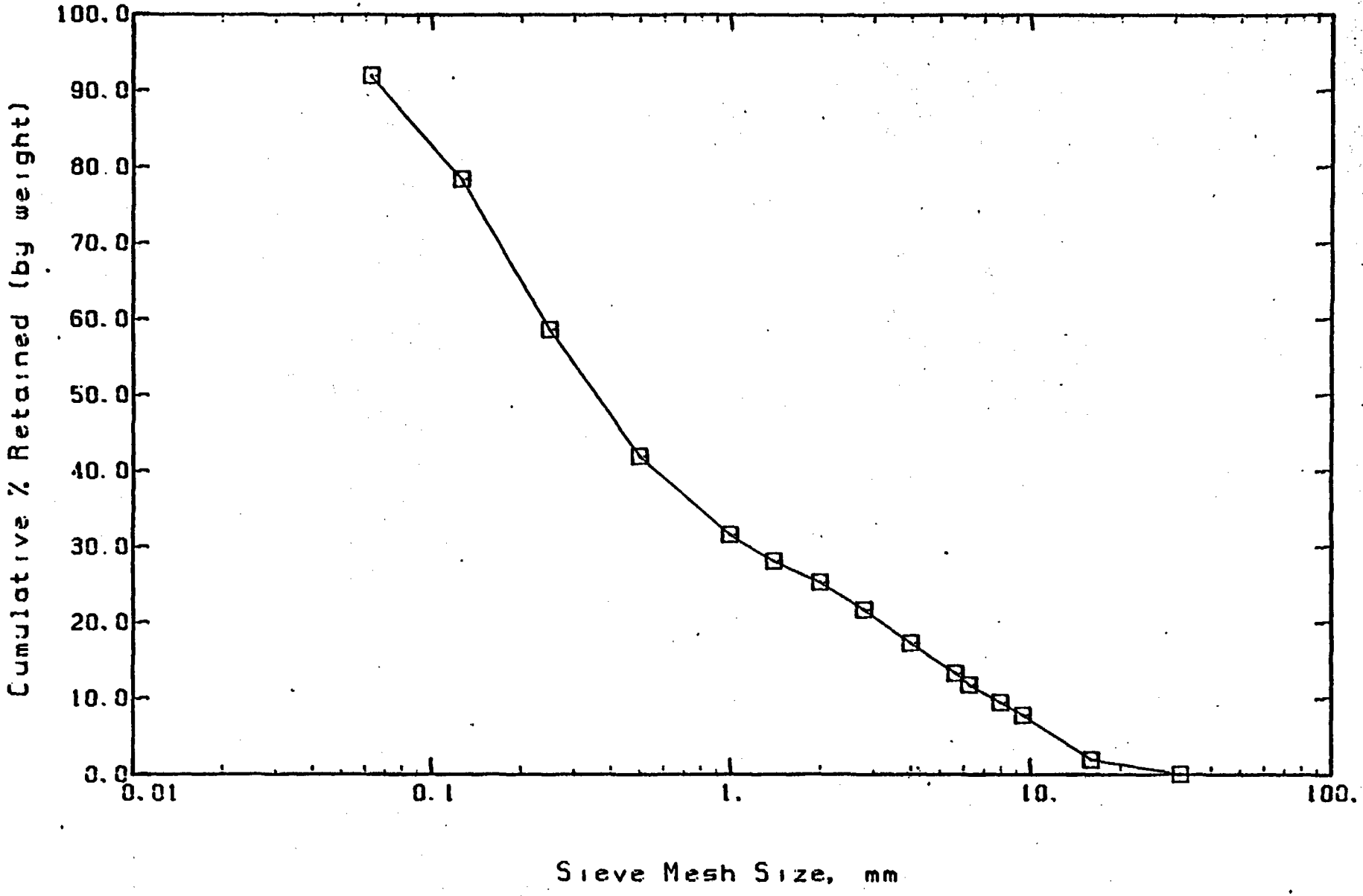

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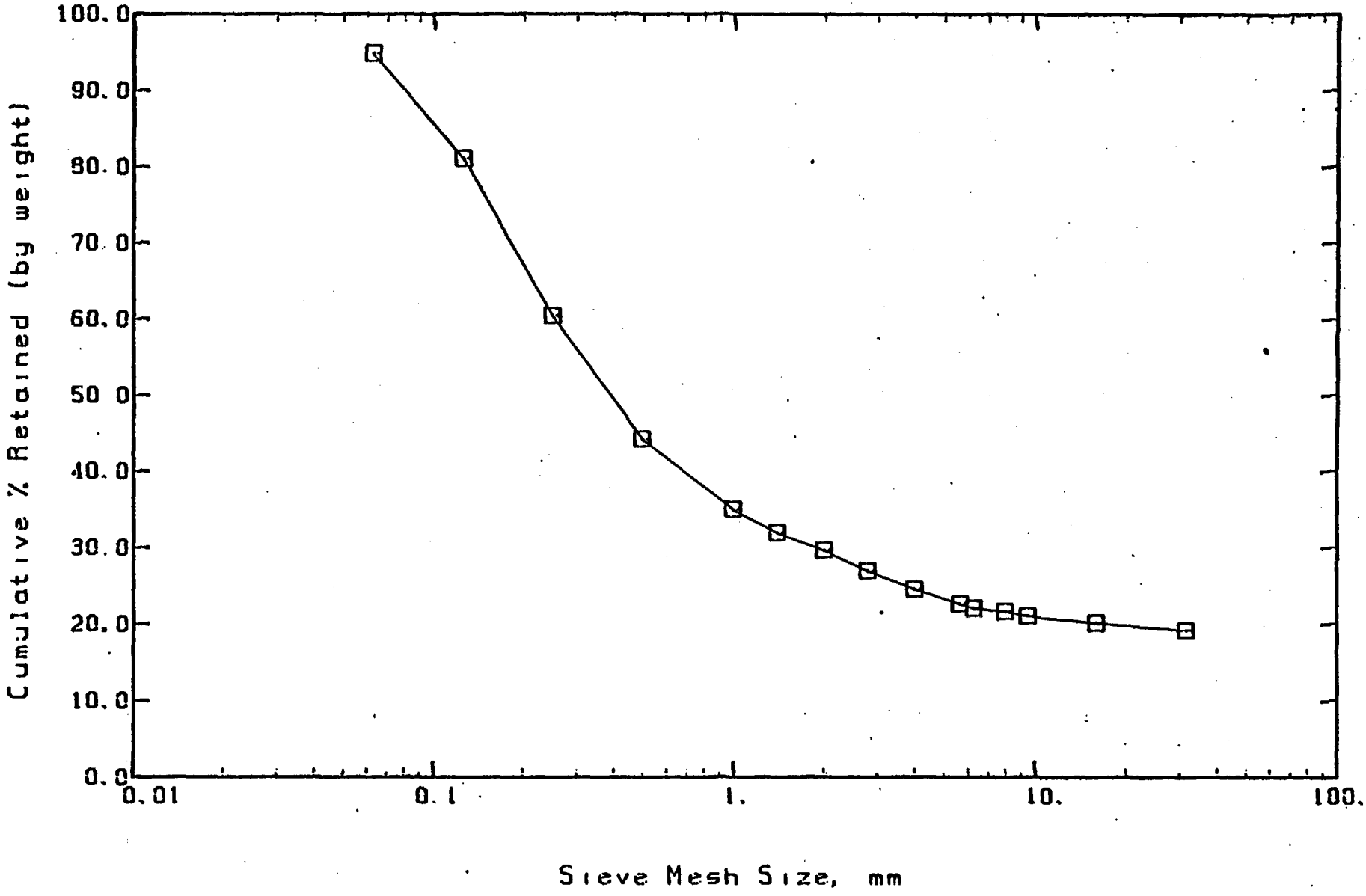

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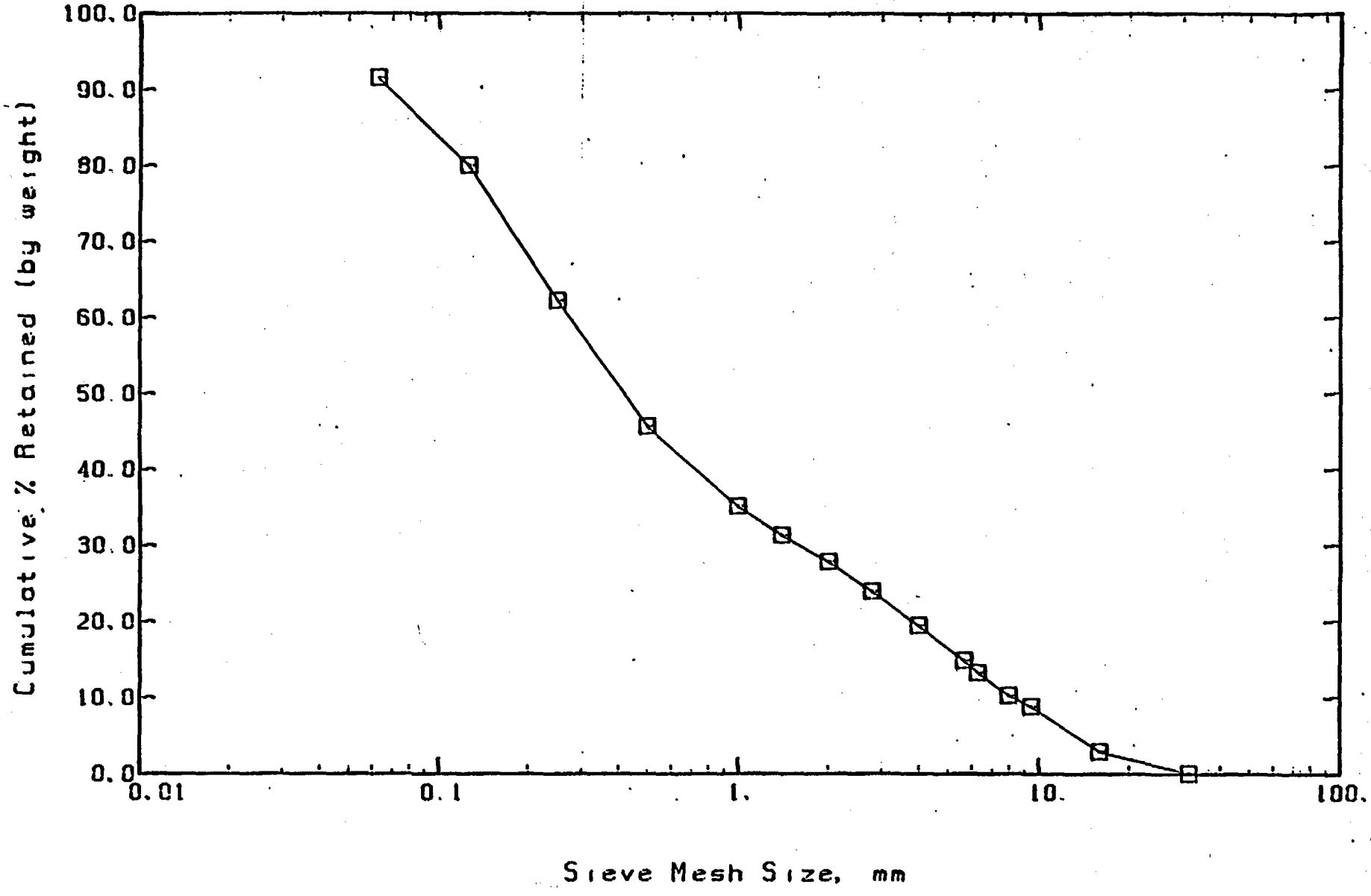

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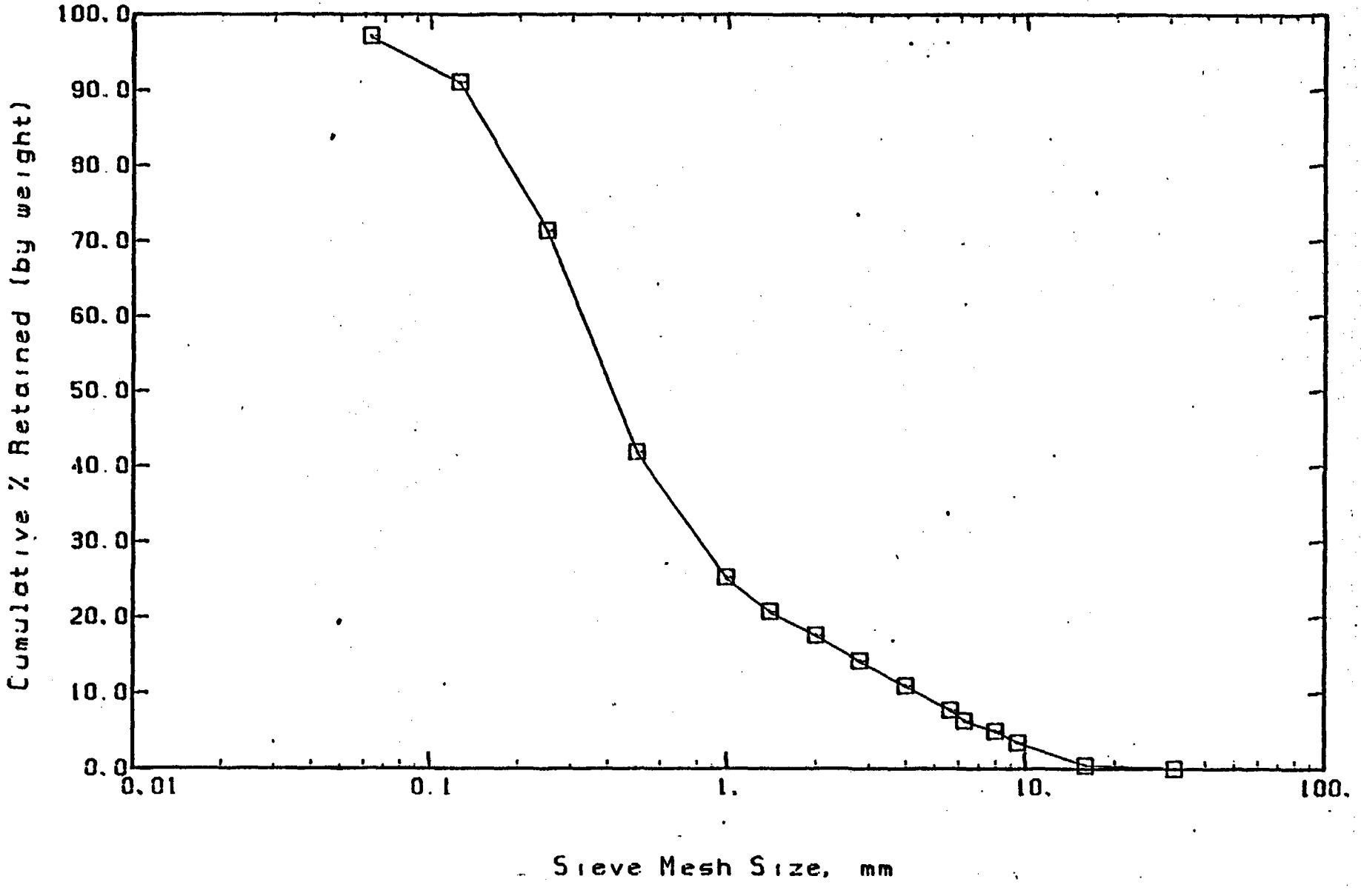

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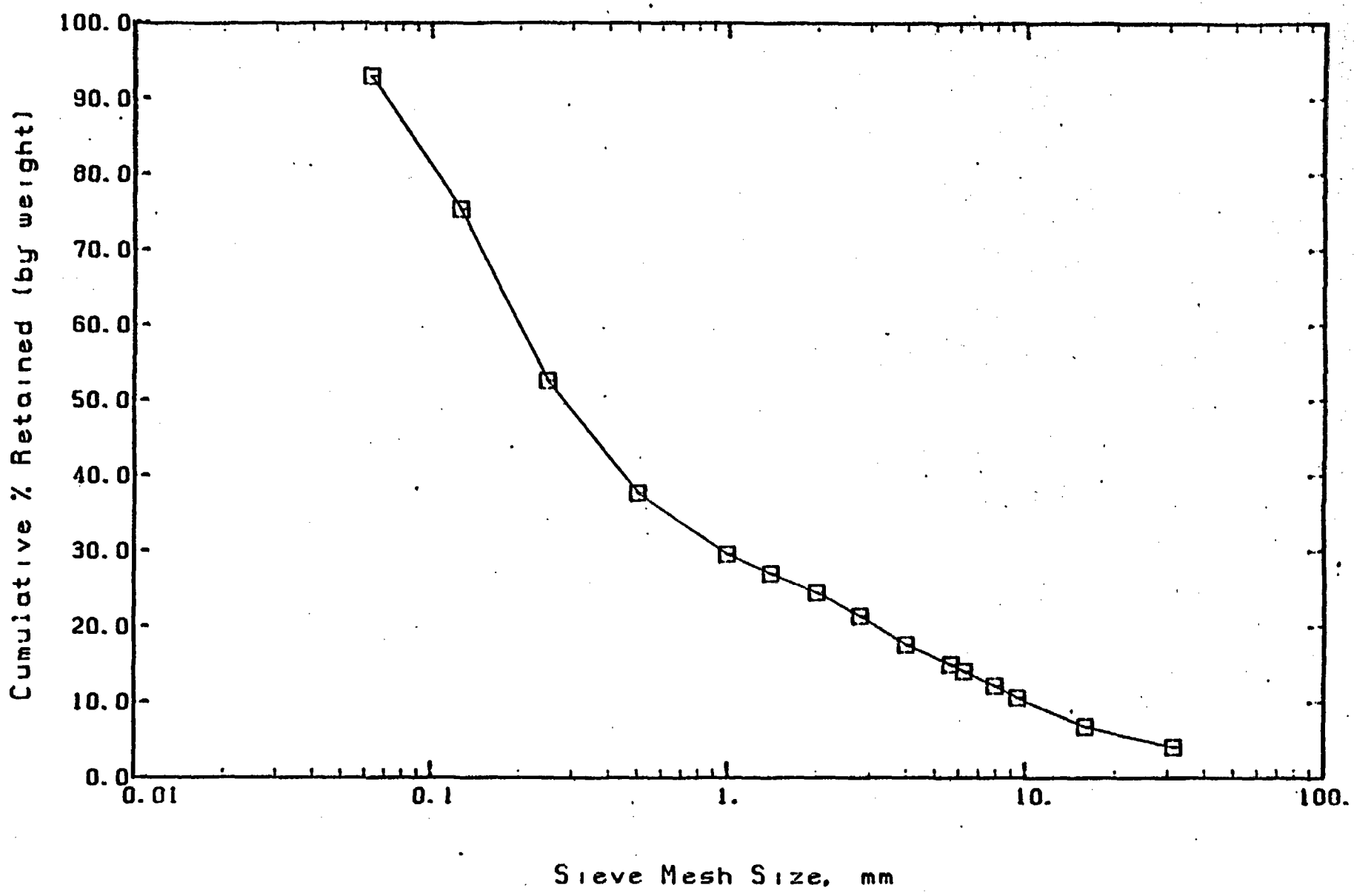

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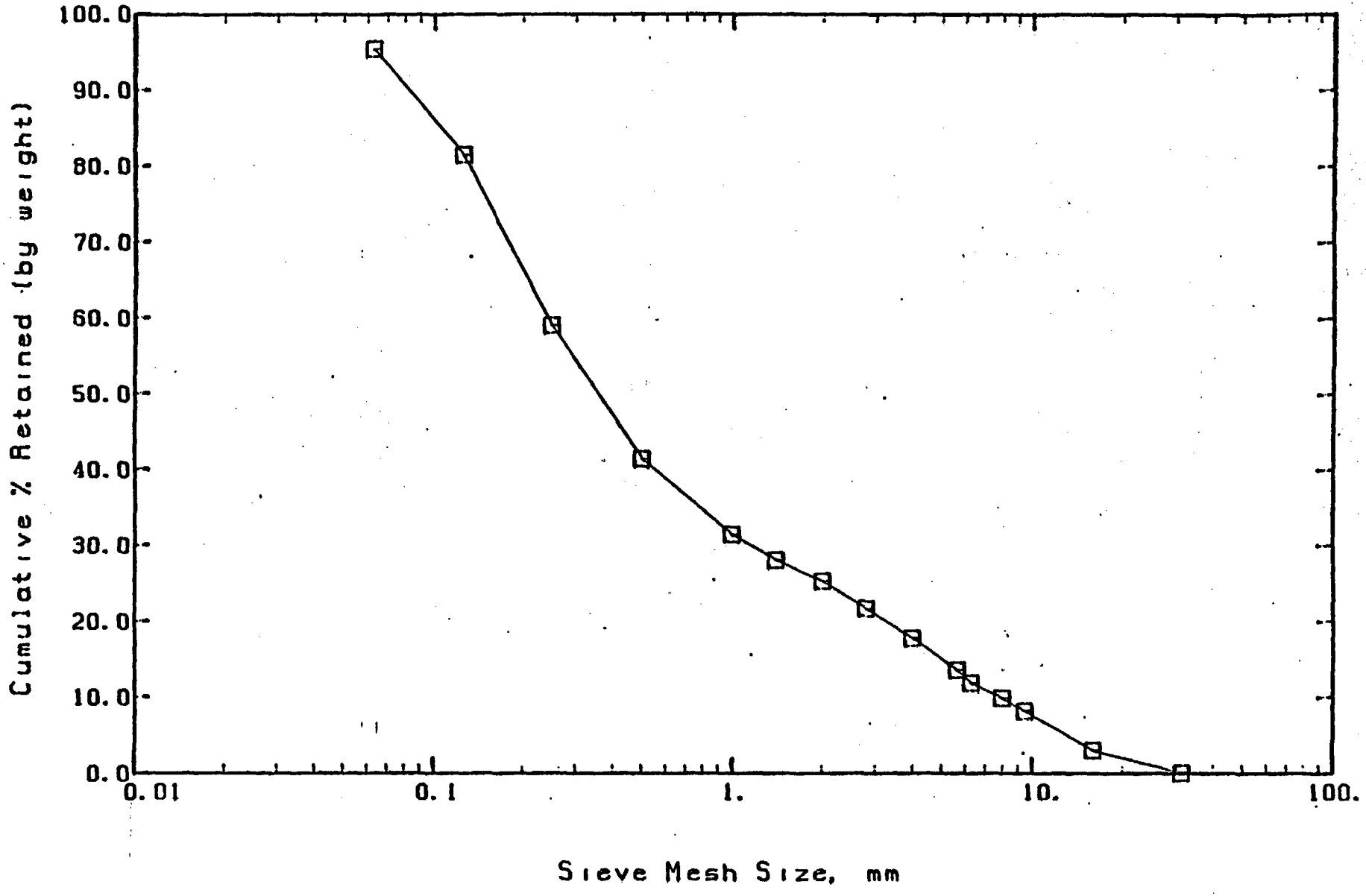

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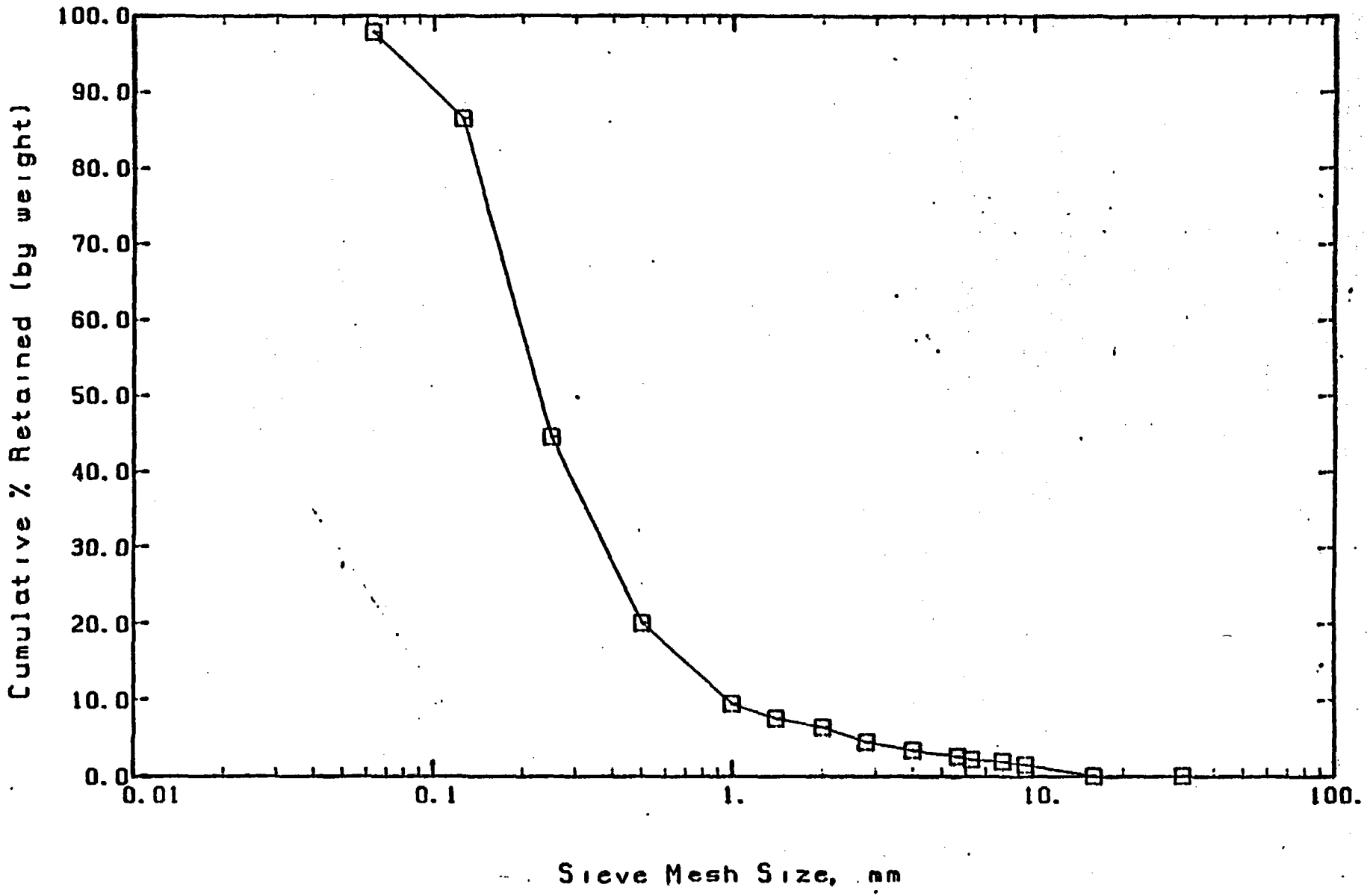

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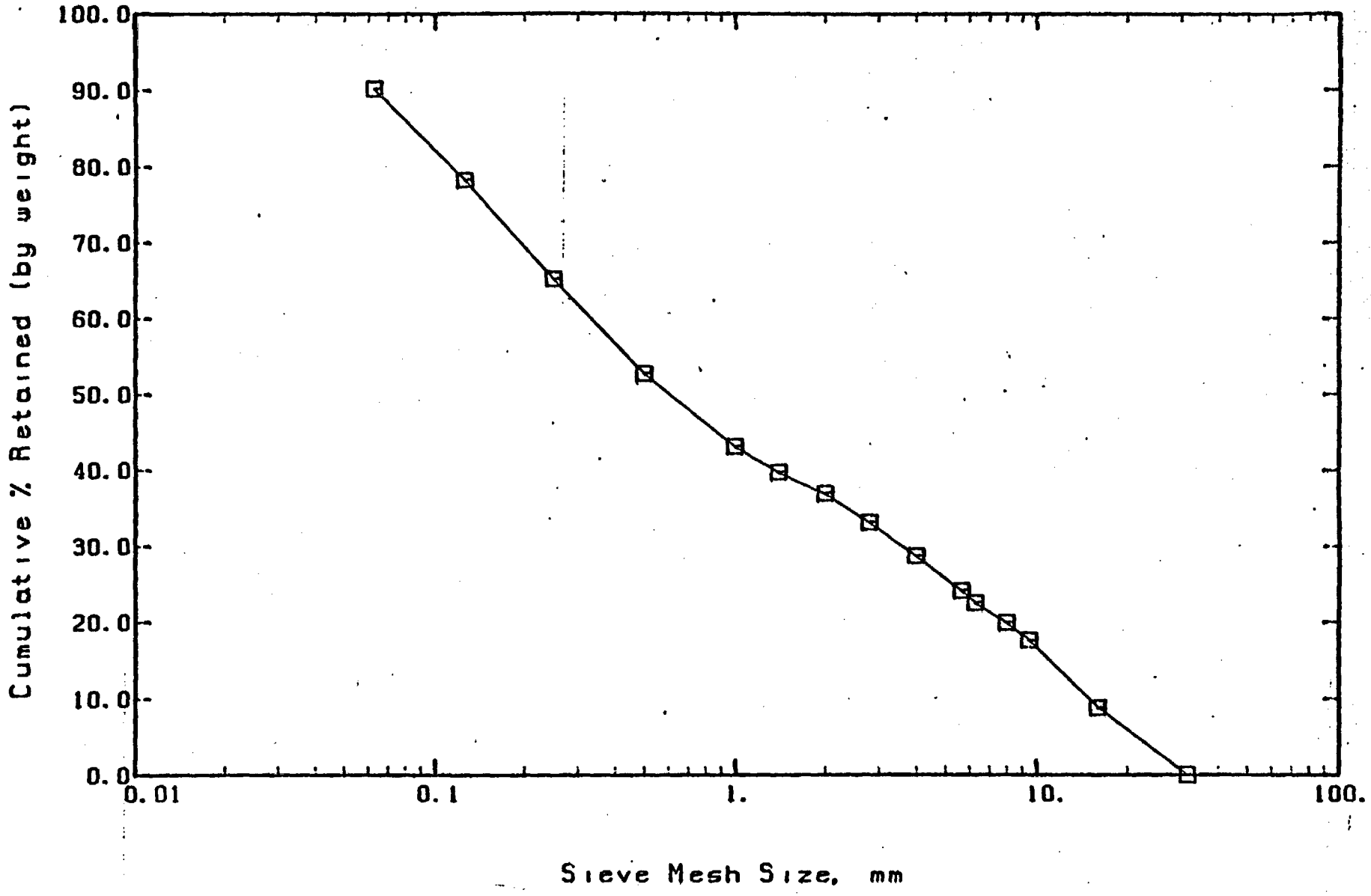

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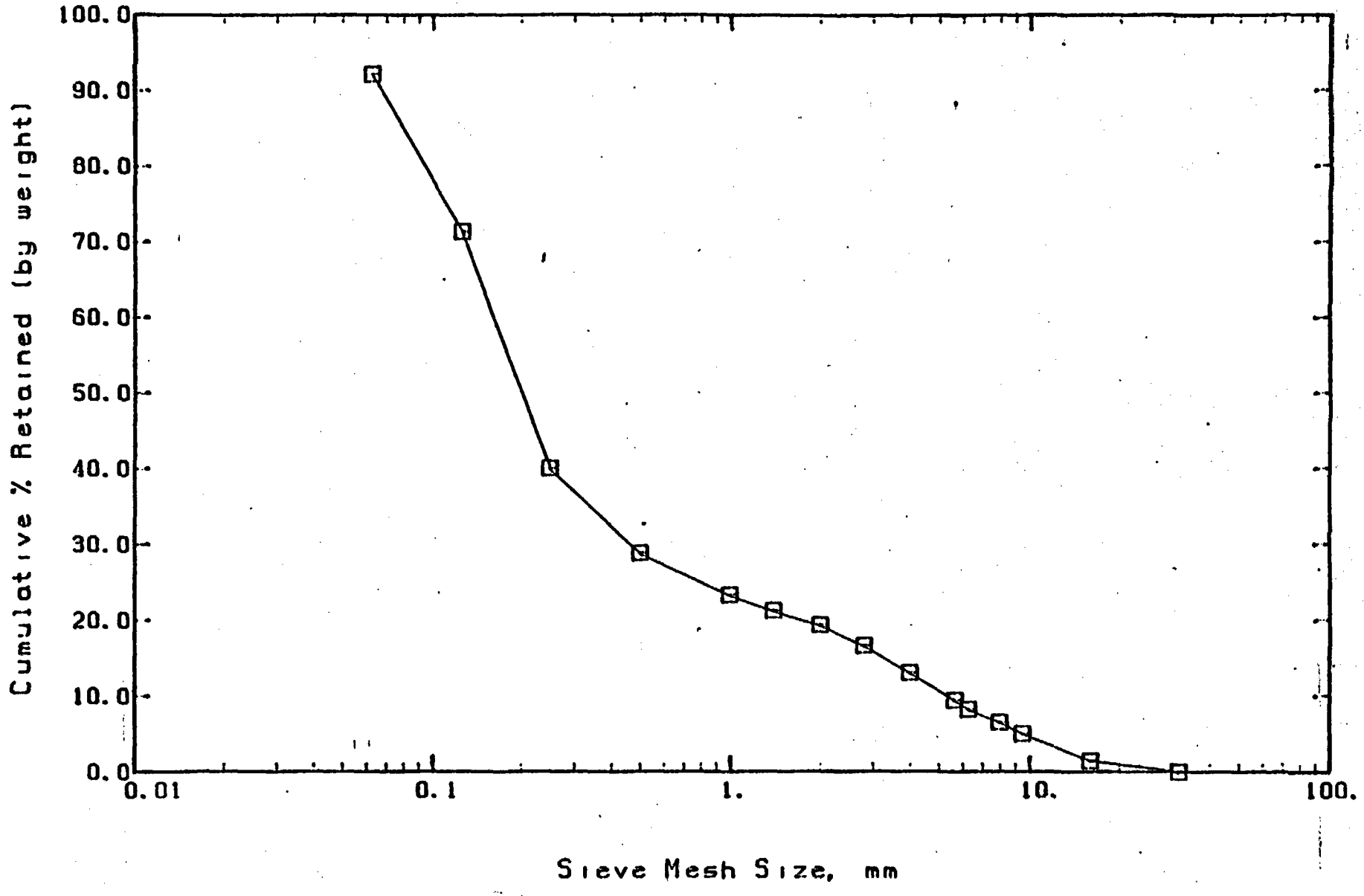

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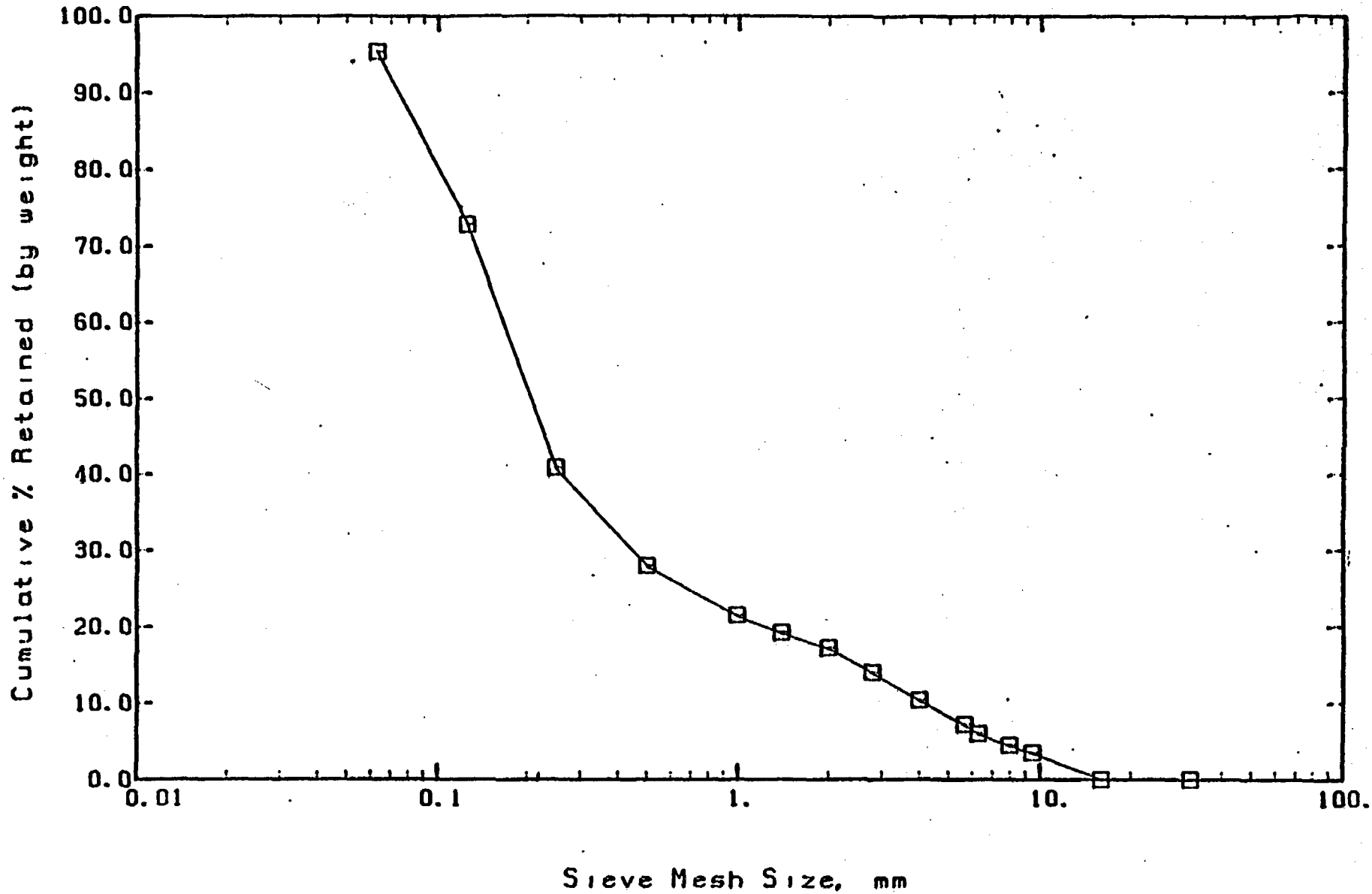

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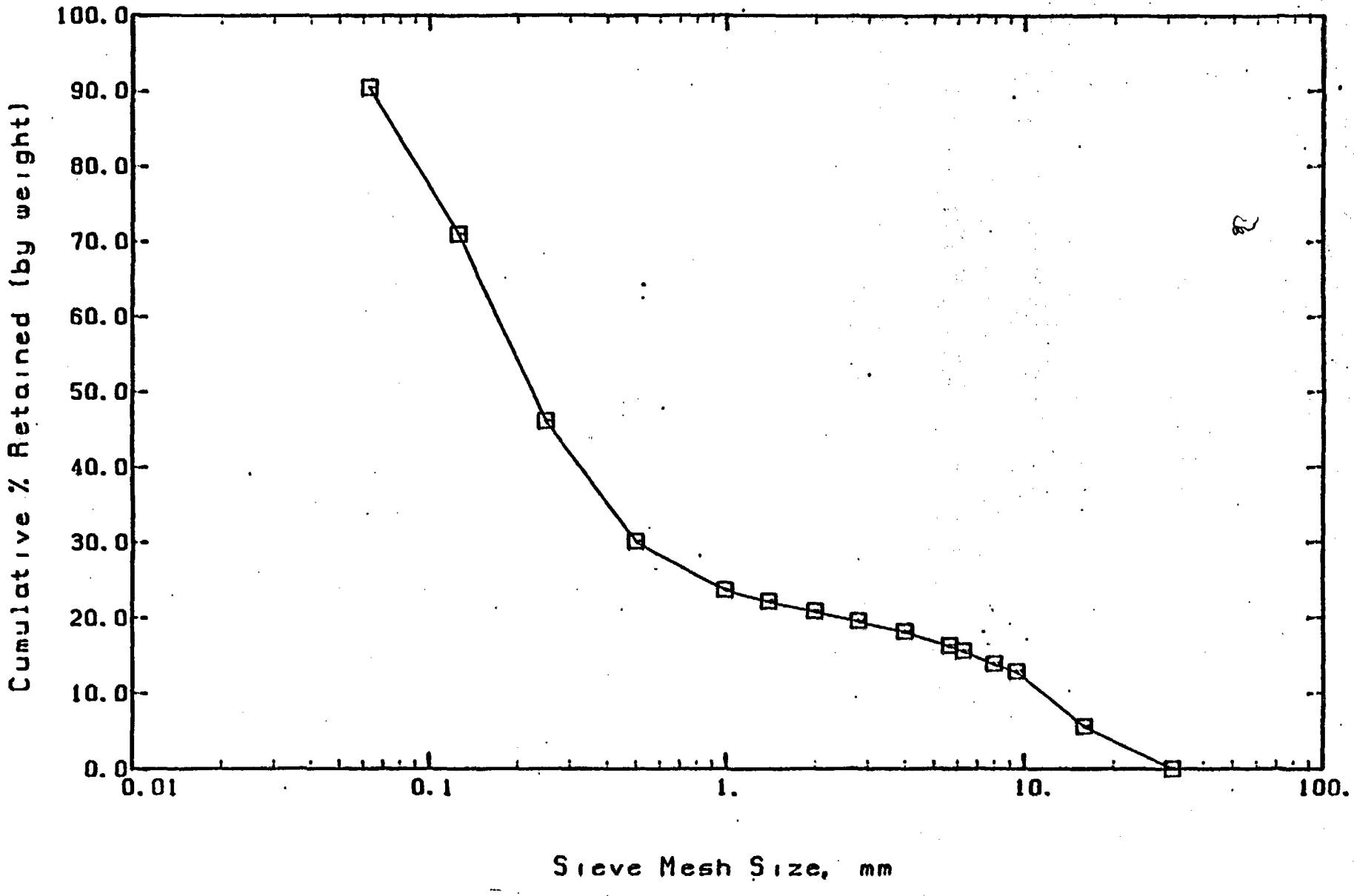

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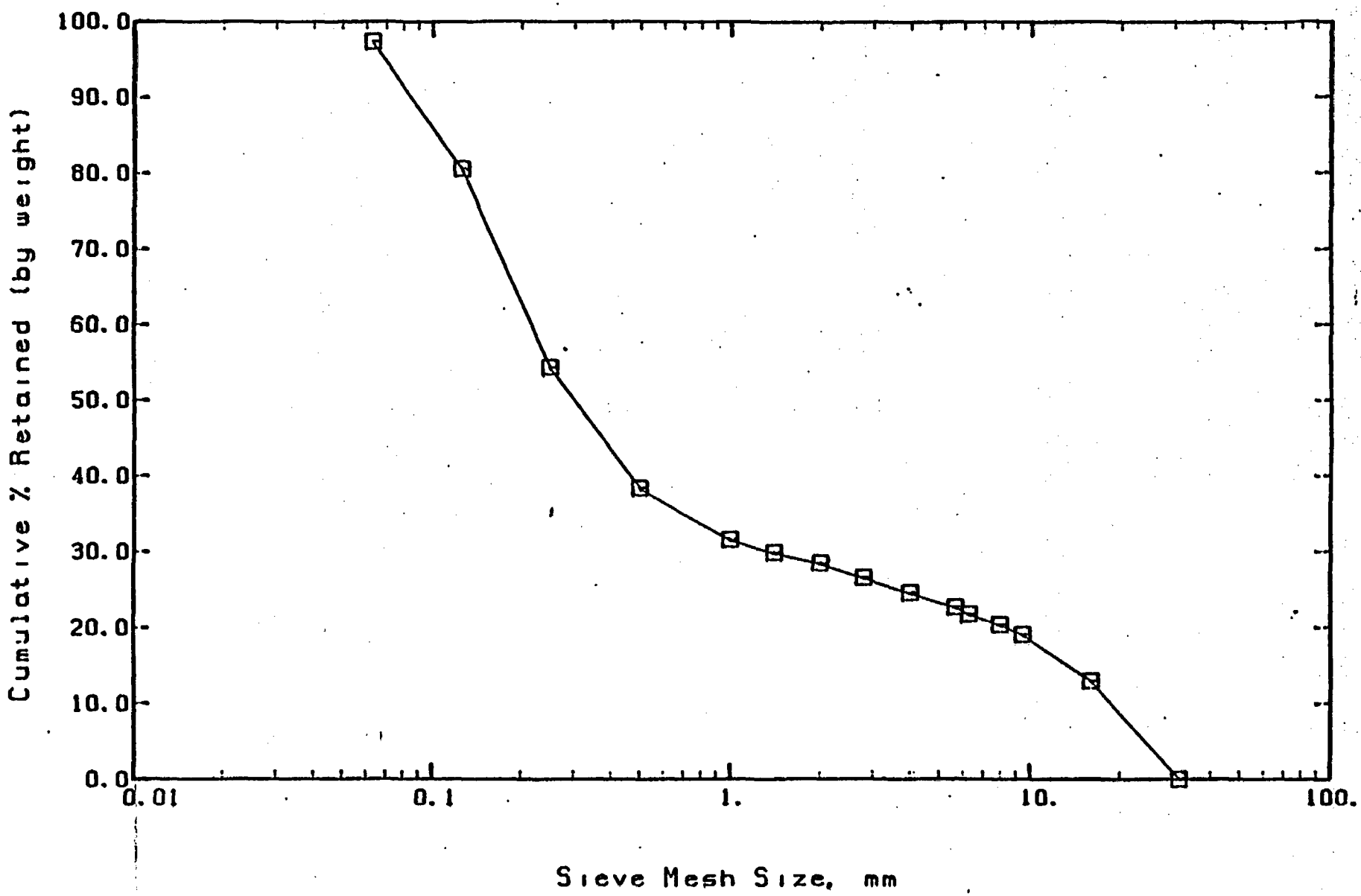

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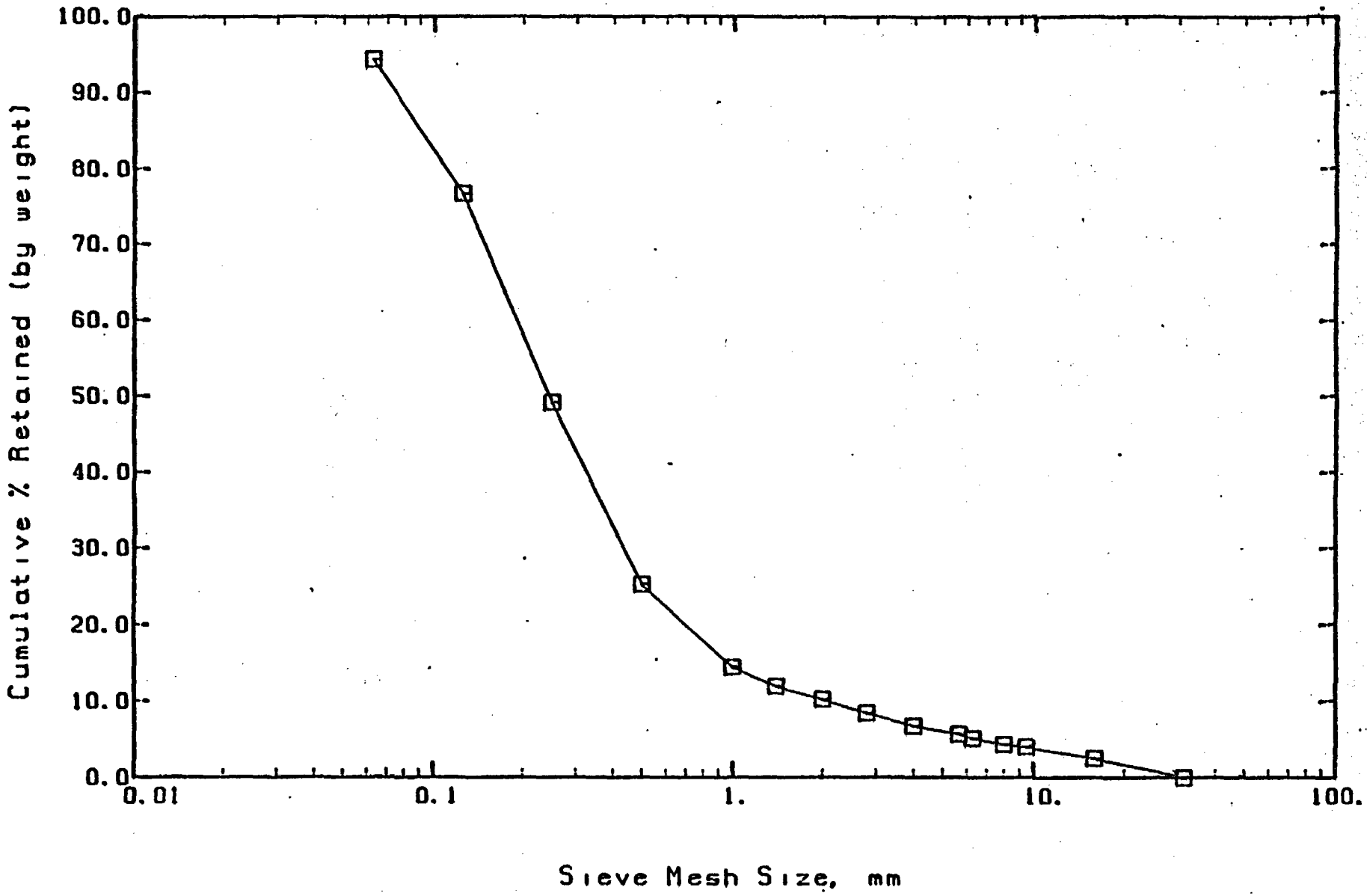

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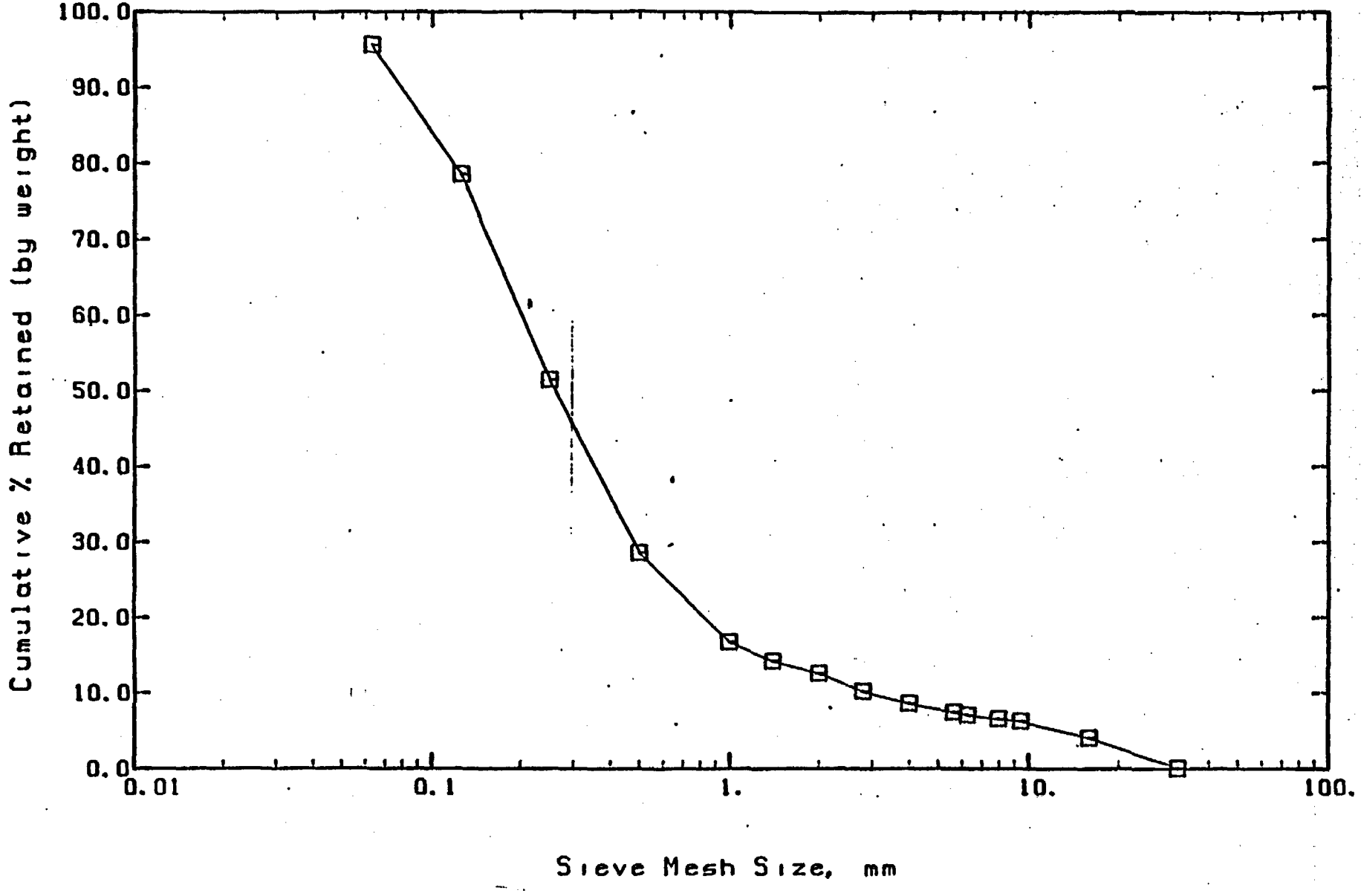

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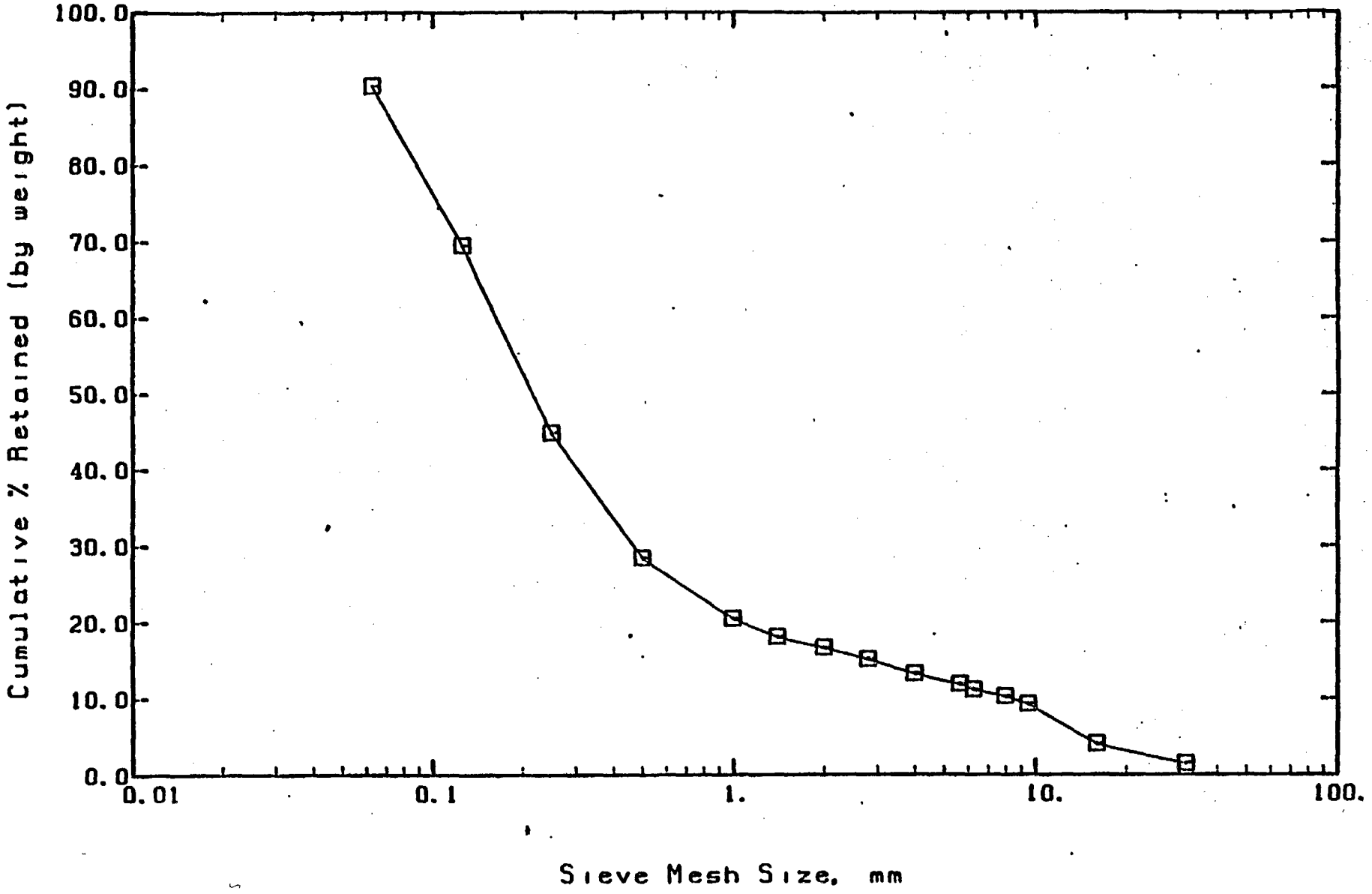

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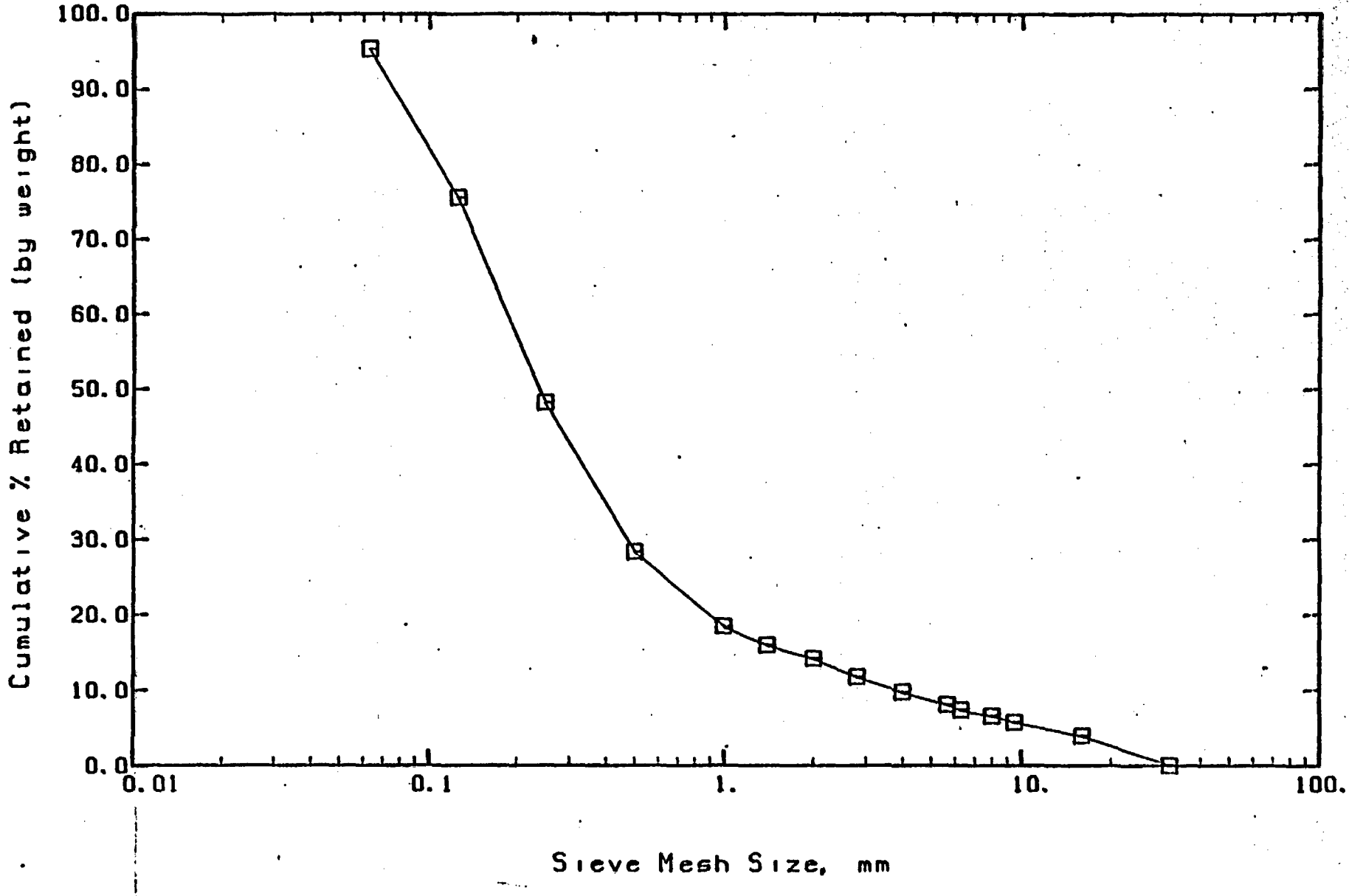

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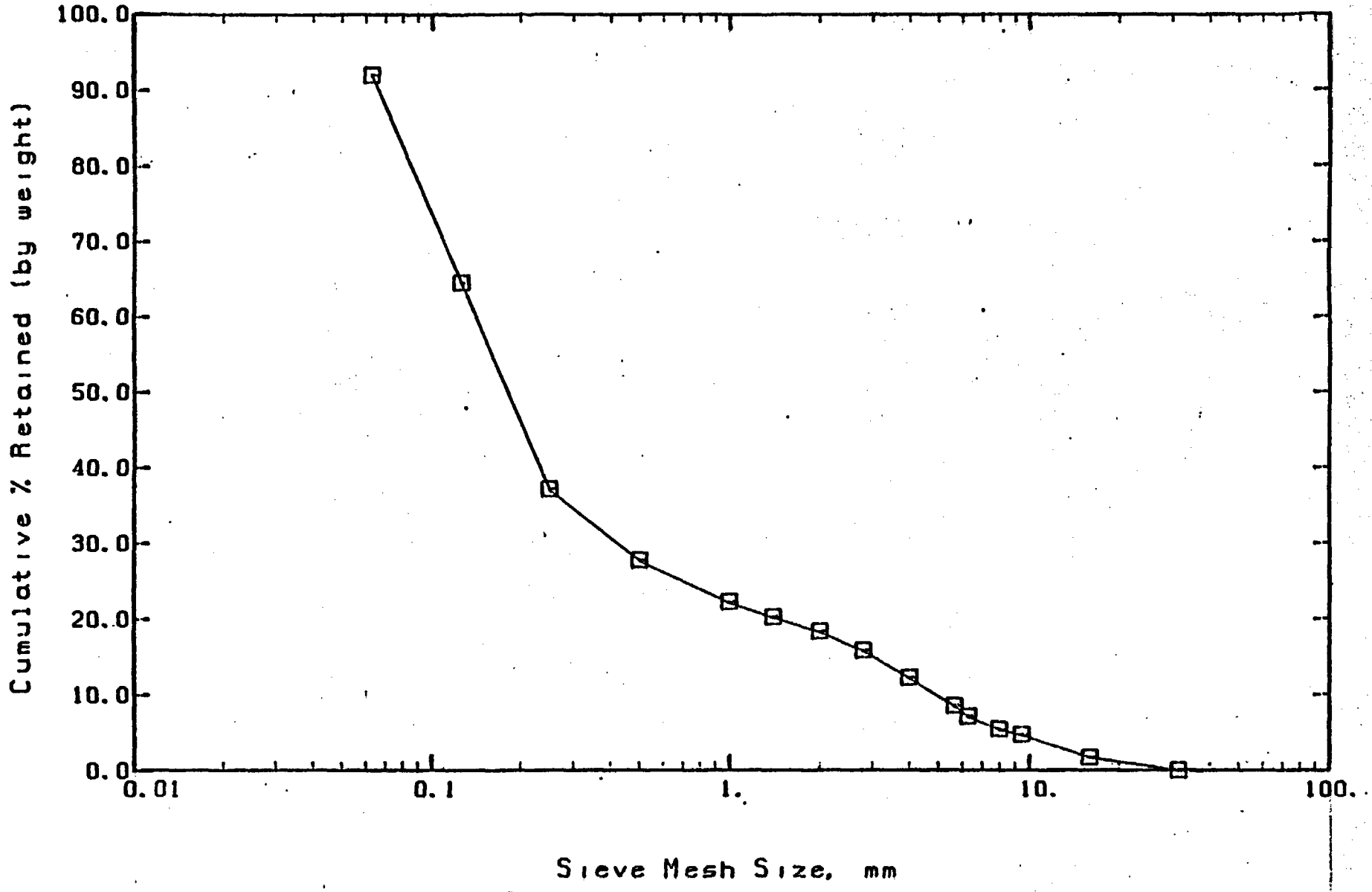

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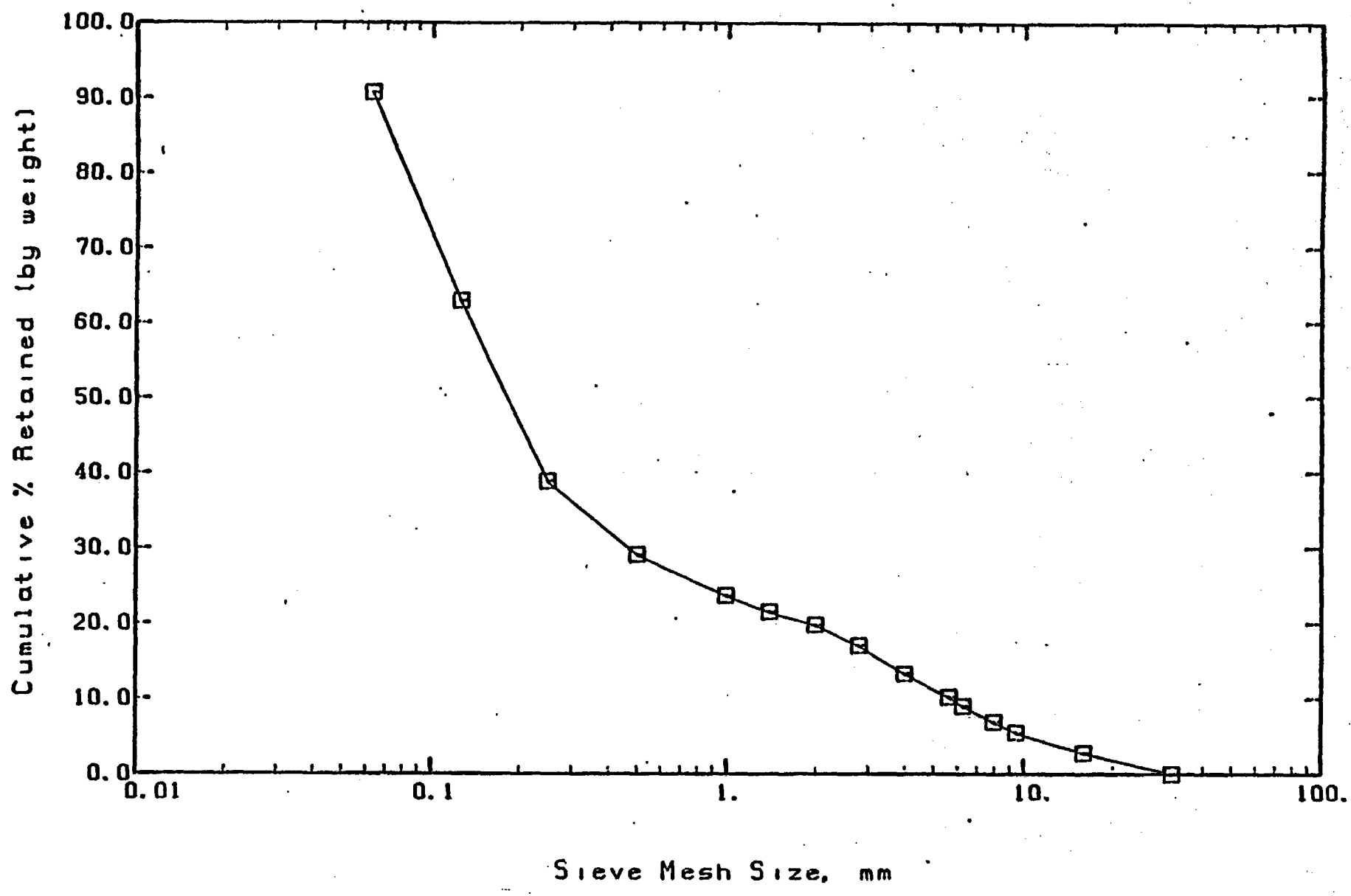

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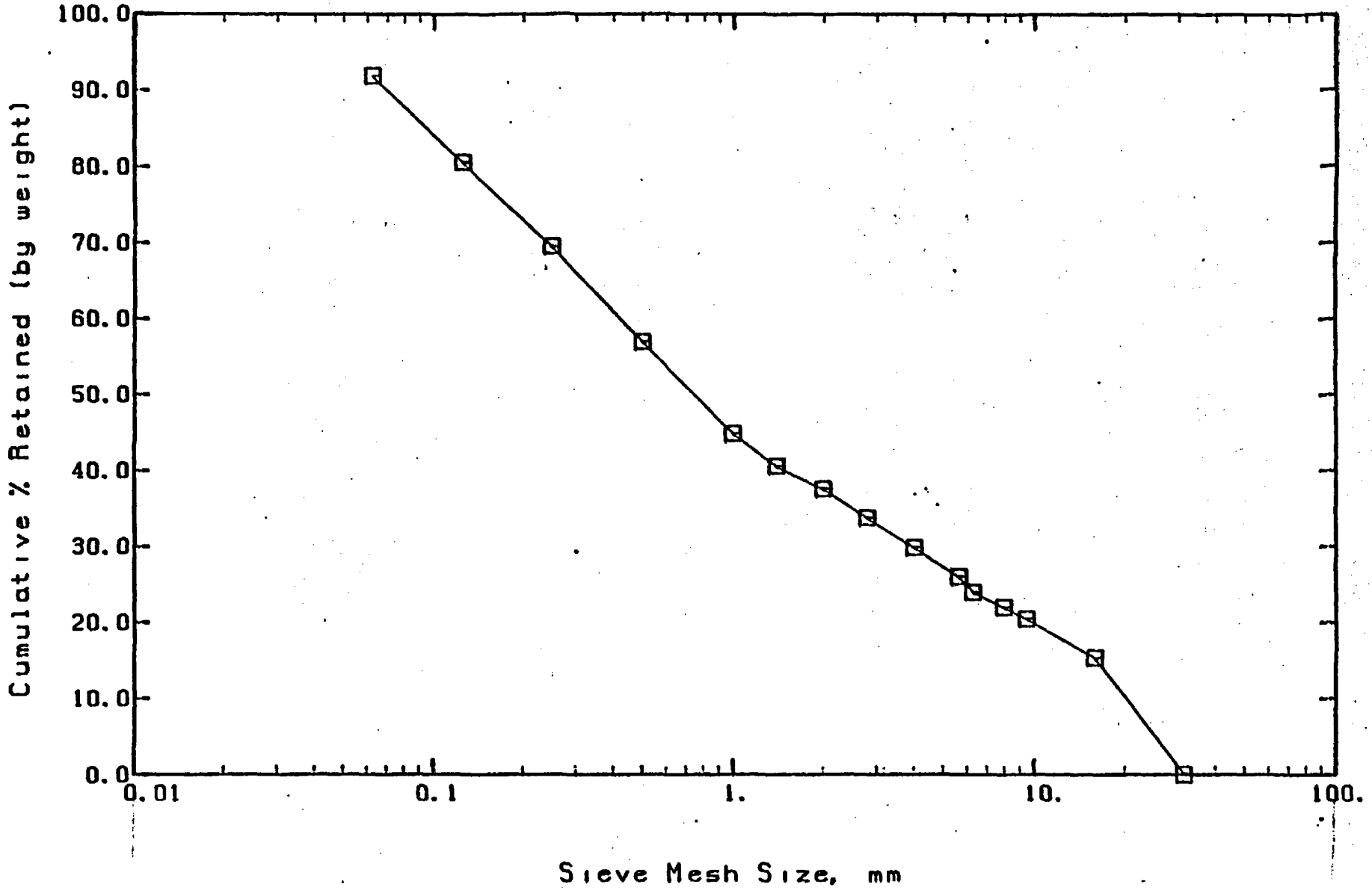

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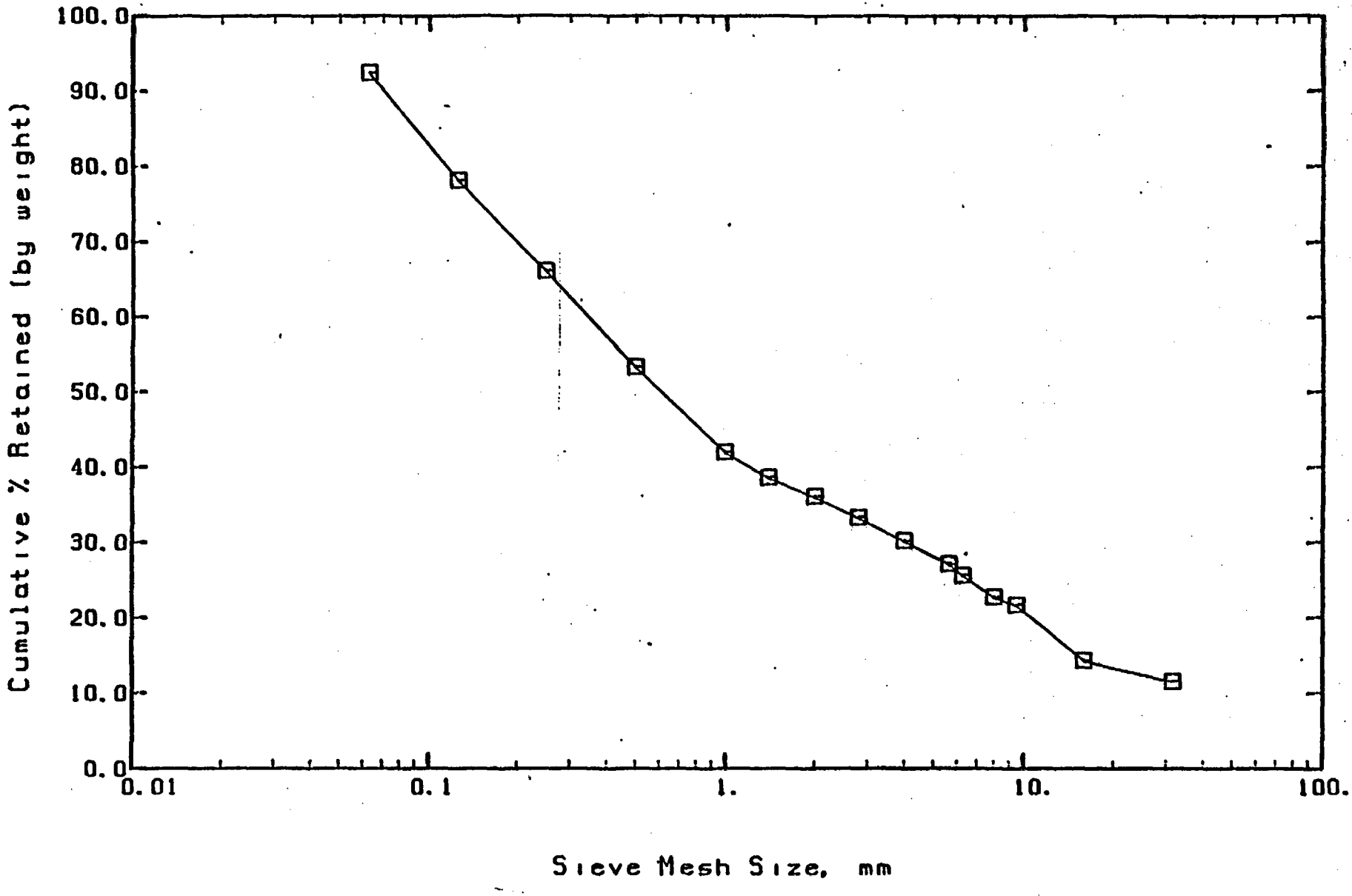

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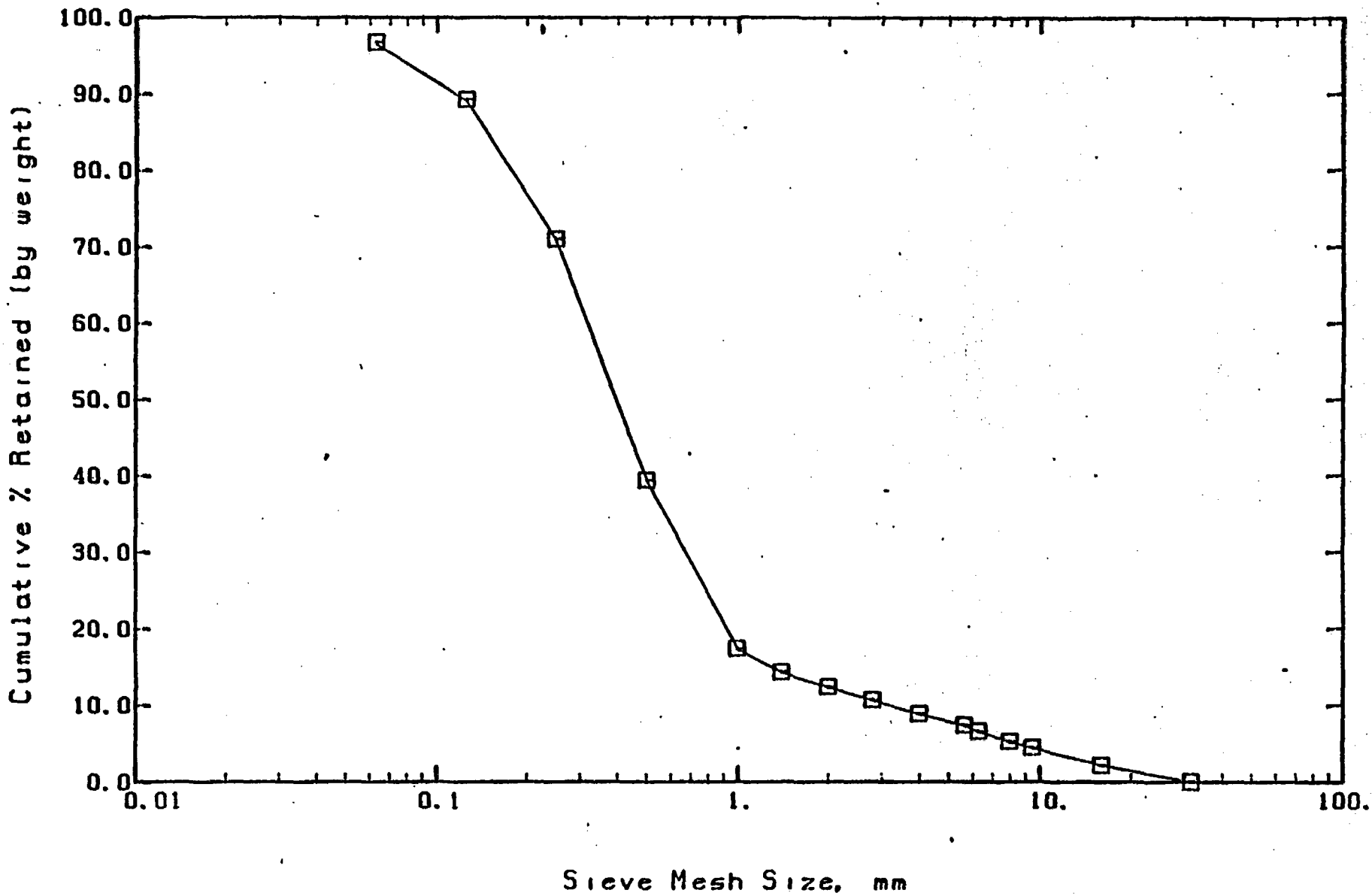

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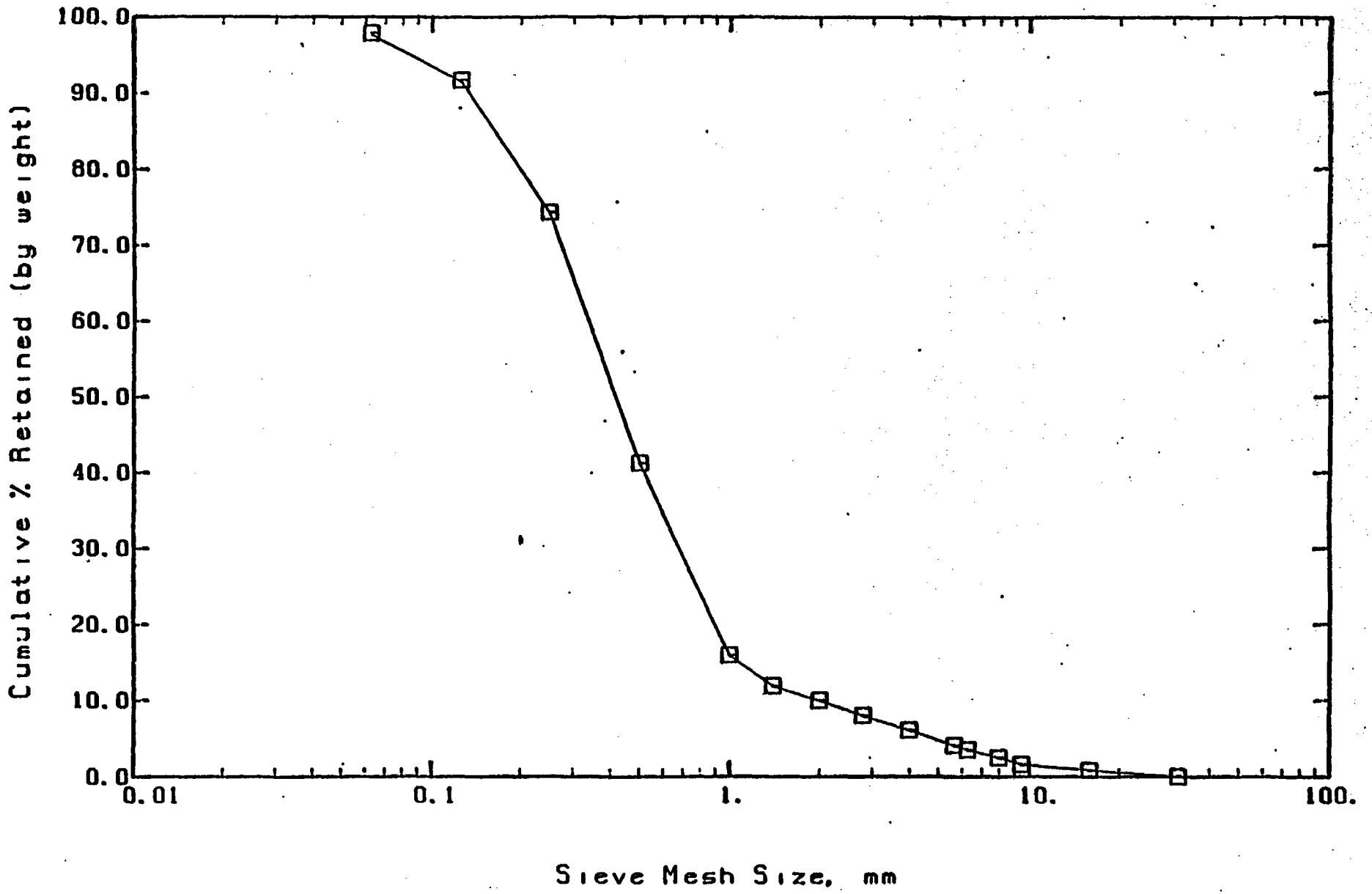

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