Frequency/Magnitude Relationship of Avalanches in the Chugach Range, Alaska

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ABSTRACT

Since 1946, the Alaska Railroad has systematically recorded natural avalanche activity to the train track level. Parameters recorded include date, location, and apparent volume computed by length and width on the train track.

This relatively long term record shows a significant relationship between frequency and magnitude on individual avalanche paths and the Chugach Range as a whole. For each avalanche path, the distance between Beta and Alpha angles are calculated and the train track position expressed as a percentage of Beta in order to normalize the runout distance expression. The % Beta term standardizes avalanche runouts so that a significant data set can compare frequency and magnitude for a large number of avalanche paths in a single area. A regression analysis defines the overall frequency relationship for all avalanche paths at any given location relative to the measured Beta angle.

This information can be used in the design of fixed facilities in runout zones to determine the likely frequency of major avalanche events at any location. A more refined analysis of risk levels in these locations is thus possible.

INTRODUCTION

Avalanche workers throughout the world are intrigued by large avalanches associated with periodic avalanche cycles. A strategy in engineering avalanche defenses is to use a 10 year or 100 year avalanche event return period and model the forces associated with these unusually large avalanches as well as maximum runout distance (Bovis and Mears, 1976; Lied and Bakkehoi, 1980; Bakkehoi, et. al., 1983; McClung and Lied, 1984; Lied and Toppe, 1988; Mears et.al., 1988; Mears, 1992). Field workers are constantly trying to recognize circumstances that produce such large events and cycles.

Since 1991, the Chugach Mountains on the southern coast of Alaska have been the location of the annual World Extreme Ski Championships. Many recent ski media articles have characterized the Chugach snowpack as stable. However, the Chugach Range is subject to both extreme maritime and continental climatic influences which combine to produce one of the most complex snowpacks in North America. At different times throughout the winter, each climates regime dominates. The result is a complex, stratified snowpack that produces avalanche cycles which are not easily characterized. To characterize the snowpack as stable is not founded. As in every mountain range, there are extended periods of relative stability, followed by extreme instability.

It is helpful for both practitioners and scientists to look at historical influences to try and extract the pertinent information to solve their particular problems. Data on avalanche occurrences are of particular interest in establishing the periodicity and magnitude of avalanche events. In an area as remote and unpopulated as the Chugach Range, relevant data is mostly anecdotal. The two exceptions to this are the systematic avalanche occurrence records available from the Alyeska Ski Resort and the Alaska Railroad. Events have been so recorded at Alyeska Resort since 1976, and on the Railroad since 1946.

This paper uses this data set to describe the relationship between the frequency and magnitude of avalanches in the Chugach Range.

METHODS

The Alyeska data base was used to describe events uphill of Point P (the 10 degree point) with a periodicity of less than 10 years. In 1985, the resort began recording runout distance on avalanche paths by percentage with 100% being maximum runout distance according to existing vegetative parameters. We have analyzed this data using moving averages to derive the average number of events at given locations in the avalanche track and runout zone.

Since 1946, the Alaska Railroad has systematically recorded all avalanche occurrences that reached the railroad track. We have sorted the data according to various parameters. The analysis conducted on this data base is more relevant to long term, large magnitude events. The Railroad data parameters analyzed include:

- Frequency by avalanche path
  A distribution of events sorted by milepost or location
- Apparent Volume of selected paths
  Apparent volume of all avalanche paths was sorted by size, then characteristic volume curves were selected for regression analysis.
- Analysis of largest 5 events on each path
  The largest 5 events for each path were selected, then the volume of the largest event in each path was divided by the volume of the smallest of the 5 event sample to produce a ratio. The average ratio was derived in order to isolate those paths that produced unusually large events.
- Analysis of largest 2 events
  The same analysis as in # 3 except with only the top two events.
- Volume curves of 5 largest events on select paths
  A similar analysis to #2 but with only the largest 5 events included.
- Chronological distribution of 5 largest events

- The largest 5 events were sorted according to chronological order.
- Spatial distribution of multiple events in a single cycle

  Those avalanche cycles which produced more than one avalanche in the largest 5 list were isolated. This data would thus represent the most severe avalanche cycles which have occurred in the 50 year data base. The geographical distribution of these events was then graphed.
- Frequency by % of Beta Angle

  The Beta angle of each avalanche path was measured and the railroad track location expressed as a percentage of the Beta angle. This normalized all paths regardless of their topographic characteristics. A regression analysis was computed on frequency compared with percentage (%) of Beta angle.

DESCRIPTION OF THE DATA BASE

Alyeska Resort

Alyeska's recording of avalanche runout by percentage allows us to analyze the runout distance of more frequent avalanche events. In general, the avalanche starting zone is above the 10% mark, the track or acceleration zone is from 10% to 70%, and the runout zone is below 70%. Point P, the point at which the runout zone angle first drops to 10 degrees, is at the 80% mark.

The majority of occurrences represent results from explosive control efforts conducted during or after every significant storm. While there are few natural avalanches in the data base, we feel it is still representative of the periods of instability in the Chugach Range.

Our analysis has excluded inbounds areas that receive heavy skier compaction and other non-representative sites. The remaining 29 avalanche paths are above areas of skier traffic and receive little skier compaction. Almost all avalanche paths in the data base fall over 200 meters vertically before crossing the first percentage line of 10%. The smallest avalanche path in the data base is 600 vertical meters and the largest is over 1,200 vertical meters at full runout.

Alaska Railroad

Since 1946, the Alaska Railroad has systematically recorded avalanche activity on the daily dispatcher's log. These events have been recorded in the log by date, milepost, length, and depth on the centerline. The length and depth can be multiplied to produce "apparent volume", a two dimensional figure. The systematic recording of volume at a given point allows us to analyze the relationship between frequency and volume (magnitude) on these paths.

Explosive control efforts on the Railroad began in 1987 but are not employed on every storm. With low traffic volumes and management of personnel activities, the Railroad is able to achieve significant risk reduction with occasional use of artillery. The ratio of natural events to artificial releases that reach the railroad track has been reduced since 1987 to approximately 1 natural per 5 events. Therefore, the Alaska Railroad data set predominately represents natural avalanche occurrences of large magnitude.

There are a total of 22 avalanche paths in the Railroad data base which range from the smallest at 600 vertical meters to a high of 1,300 vertical meters. Each path is designated by the milepost where it reaches the tracks.

RESULTS AND DISCUSSION

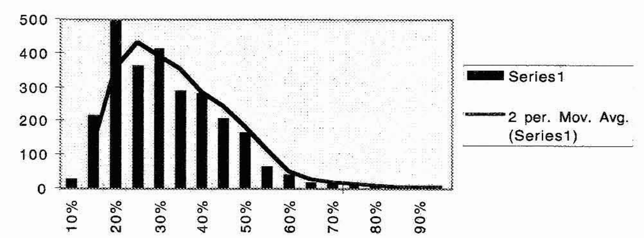
Alyeska Resort Data

The Alyeska data base totals 2619 events recorded over a ten year period. Figure 1 shows these events according to runout percentage with a moving average.

Alaska Railroad Data

There were 414 events that reached the track in the 50 period of record. Design criteria commonly use 10 and 100 year return intervals. With our 50 year period of record, there is a 39% probability that a given avalanche path would have recorded a 100 year event. With a 100 year record that probability goes to 63% (McClung and Shaerer, 1993).

Figure 1-Alyeska Frequency by %



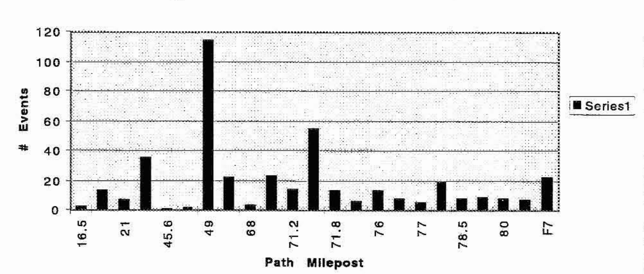
Total Avalanche Events by Path

Figure 2 shows the distribution of avalanche events by milepost. The frequency of individual paths at the railroad track is highly variable. This information was relevant when originally setting up the avalanche program and is still used to help define priorities of the operational program. It is presented here to identify those paths that produce the most events.

Volume of Avalanche Events at Each Path

The number of events ranged from a low of 1 event at 45.6 Mile to a high of 113 events at 49 Mile. It was expected that smaller volume events would be more numerous, with a decrease in frequency as volume increases.

Figure 2- Railroad Total # Events



Regression analysis showed that each avalanche path has a distinctive exponential curve as in the 69.9 Mile path shown in Figure 3 and the 53 Mile path shown in Figure 4. While both cases show a high r^2 value, the highest actual volume value in Figure 3 is very close to the predicted value, while in Figure 4 actual volume is 2 1/2 times higher than predicted. Variations between these two examples are evident throughout the data set, but approximately 40% of all avalanche paths had an unusually large event similar to that shown in Figure 4.

Volume Difference

Figure 5, compares the volume difference between the largest and the fifth largest event at each location. Our reasoning in making this comparison is that in a sample of 22 avalanche paths with 50 year of observation, some paths should show unusually large events which could represent a 100 year return period. Those avalanches with values higher than the average may represent 100 year return periods, or "design magnitude" events. We found that 45% of the avalanche paths produced an unusually large event based on this criteria.

Volume Difference of Largest 2 Events in Each Path.

Using the same approach as with the top 5 events, we analyzed the top 2 events for each path. In this case, 27% of the avalanche paths produced an unusually large event as shown in Figure 6.

Representative 5 Largest Events by Path.

Figure 7 shows the volume of the largest 5 events in selected paths. In the case of the 43 and 49 Mile paths, the r^2 value is high with a flat curve that shows little exponential trend. These paths show a consistent increase in vol-

Figure 3-Avalanche events at 69.9

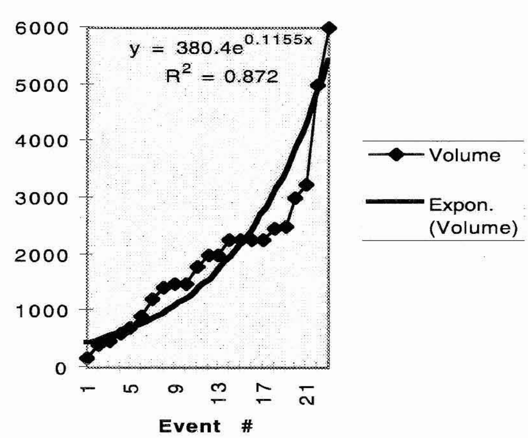


Figure 4-Events at 53 Mile

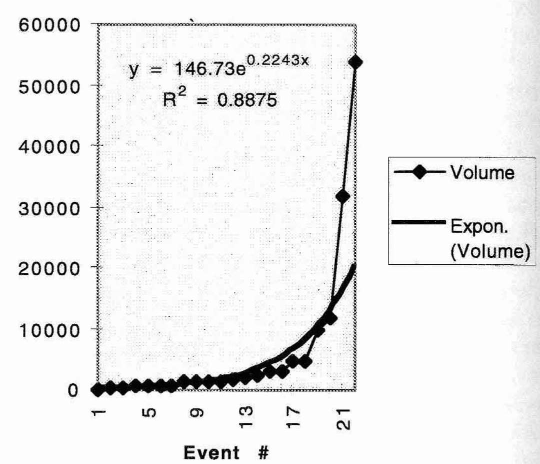
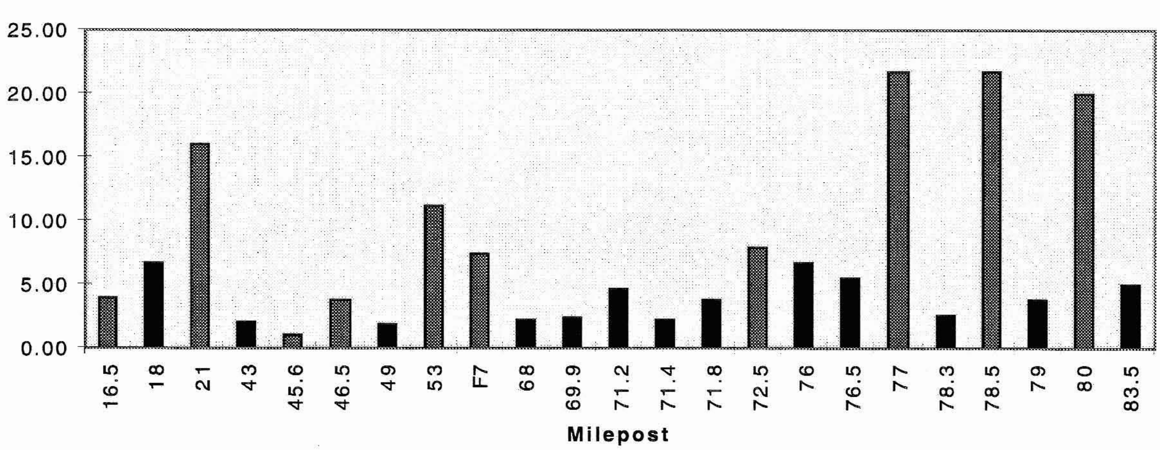
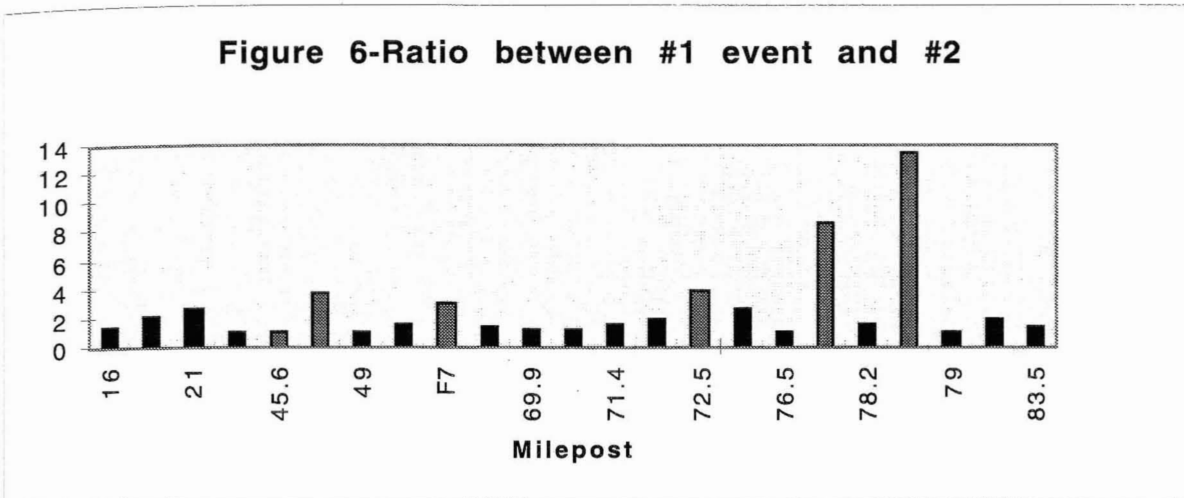


Figure 5-Ratio of #1 event to #5





ume and thus have not had an unusually large event occur in the period of record. A contrast is shown in the 21 and 53 Mile paths which also show a high r^2 value, but show a distinct exponential trend due to at least one unusually large event.

The most outstanding example of unusually large events is at 78.5 Mile where the largest event was 13.5 times greater in volume than the second largest event. This extreme event relative to the others in the data set results in a lower correlation coefficient.

Chronological Distribution of 5Largest Events.

Figure 8, shows the total number of 5 largest events that occurred each year. This gives a chronological look at the largest avalanche cycles. It appears there is a rough periodicity to avalanche cycles in the Chugach of 14 years.

Avalanche workers have observed that the zone of severe instability in a larger mountain range moves around according to the vagaries of local precipitation and snowpack. We have used the data base of the largest two events of each path to demonstrate this variability.

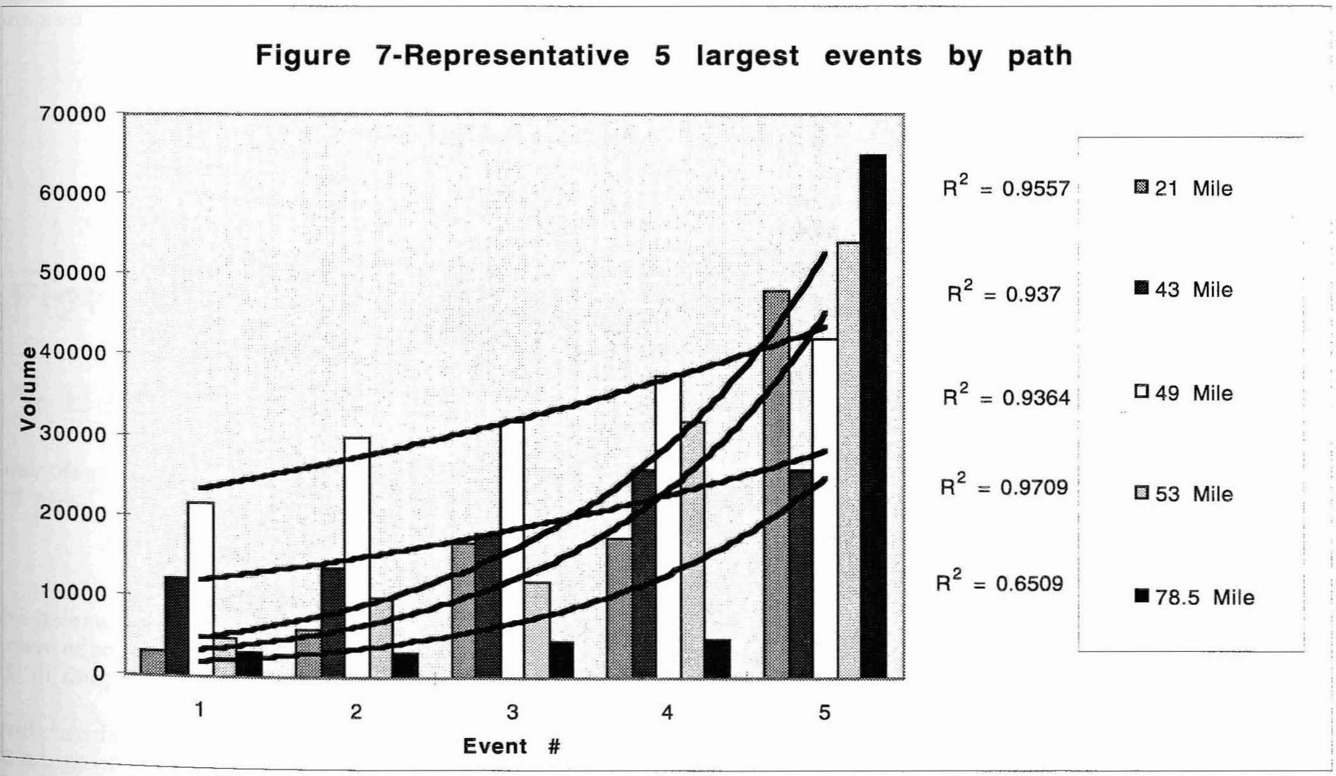


Figure 8-Chronological distribution of 5 largest events

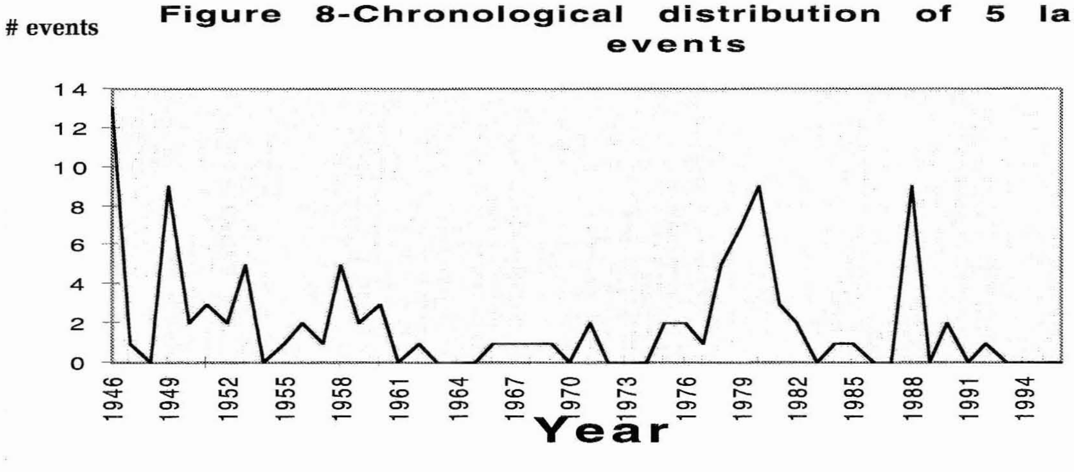


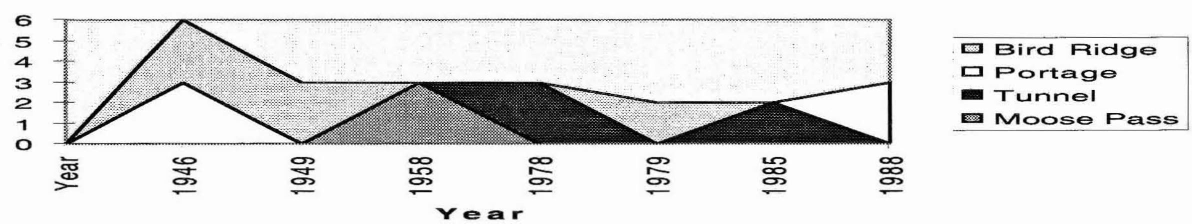
Figure 9 comprises all avalanche cycles in the sample of 5 largest events which produced more than one major event. We have regionalized the avalanche paths into logical groups according to their climate, topography, and geographical location.

There were clear differences in the location of the most severe instabilities. The major cycle of 1946 produced large events in both northern zones. 1949 only produced events on Bird Ridge, and the results continue to shift location from then on. The only year where two geographical regions produced unusually large events was 1946.

Avalanche runout models, cited earlier, commonly state the maximum runout distance as a percentage of frequency of avalanche occurrence at a given point in a typical runout zone in this area.

Figure 10 compares frequency and location or percentage (%) of Beta on three data samples, all Railroad data, Alyeska data which has been normalized to the 50 year period, and the extreme values of the Railroad data. There is good correlation between these two parameters that can be used to help estimate the frequency of large avalanche events at given locations in a runout zone. Figure 11 uses the equations derived by Figure 10 to estimate avalanche frequency according to runout distance as expressed by % of Beta. The Alyeska and Extreme RR data have comparable r^2 values and similar frequency equations. The standard Railroad data has a comparable r^2 value but calculates higher frequencies above the beta angle, and lower frequencies near maximum runout distance.

Figure 9-Spatial distribution of Multiple Large Events



Beta plus or minus a deviation factor. In the Chugach Range, earlier studies (Mears,et.al., 1988) have defined the maximum runout distance or Alpha angle as .78 (78%) Beta $\pm$ 2 degrees.

In every avalanche path, the railroad track can be located as a percentage of the Beta angle. In many cases, this expression is very close to 100% since the track is located at the 10 degree point in the runout zone. In other cases it ranges from 104% or uphill of the Beta angle to 90% or well downhill of the Beta angle. Expressing track position as a percentage of Beta allows us to normalize all avalanche paths in order to calculate the

CONCLUSION

The popular concept that the Chugach Range is relatively stable is not born out by an average of 9 avalanche events produced annually by an average avalanche path in the Alyeska data base.

Avalanche volume records of the Alaska Railroad show that unusually large events have occurred during the 50 year record comparable to the probability of a 100 year avalanche occurring on a single path in the same time span.

Even though each avalanche path is unique, the expected frequency of avalanche activity with respect to the terrain parameter Beta can be estimated with reasonable confidence using the regression equations shown in Figure 10. Because the model is based on 50 years of systematic observations, it is a valuable asset to combine with other standard methods for risk assessment problems in the Chugach Mountains. Similar methodology could be used in other mountain ranges to derive a frequency distribution unique to that range or location, most notably on Red Mountain Pass in the San Juan Mountains of Colorado.

Figure 10- Frequency by % Beta

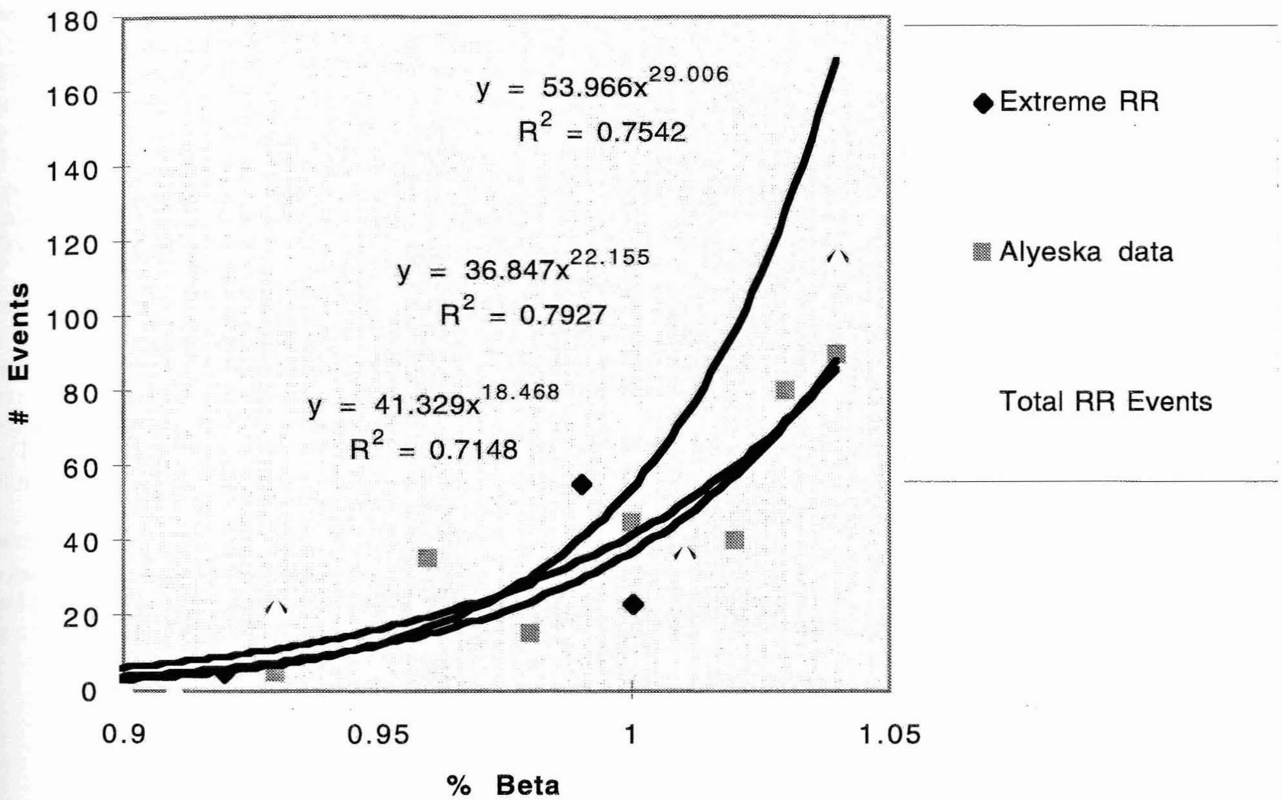


Figure 11-Predicted Frequency in 50 years

% Beta	All RR	Alyeska	Extreme RR
105%	222.22	108.61	101.76
100%	53.97	36.85	41.33
95%	12.19	11.83	16.03
90%	2.54	3.57	5.90
85%	0.48	1.01	2.05
80%	0.08	0.26	0.67
78%	0.04	0.15	0.42
75%	0.01	0.06	0.20

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