FORTRAN Computer Program for
Seismic Risk Analysis

By
Robin K. McGuire

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FORTRAN COMPUTER PROGRAM FOR SEISMIC RISK ANALYSIS

By ROBIN K. McGUIRE

Abstract

A program for seismic risk analysis is described which combines generality of application, efficiency and accuracy of operation, and the advantage of small storage requirements. The theoretical basis for the program is first reviewed, and the computational algorithms used to apply this theory are described. The information required for running the program is listed. Published attenuation functions describing the variation with earthquake magnitude and distance of expected values for various ground motion parameters are summarized for reference by the program user. Finally, suggestions for use of the program are made, an example problem is described (along with example problem input and output), and the program is listed.
Introduction

This computer program for seismic risk analysis accomplishes several objectives:

1. It allows specification of source-area geometry in a general and convenient manner, independent of the sites at which seismic risk is to be calculated;
2. It performs risk analysis at different sites sequentially and, hence, incurs no computer storage penalty for mapping problems where a large grid of sites is considered;
3. It allows a very general specification of attenuation functions; and
4. It enables the user to make a simple and intelligent trade off between efficiency and accuracy, if necessary.

For calculation of seismic risk at a site, the analyst needs (1) a description of local and regional seismicity, (2) an attenuation function for the ground-motion-intensity measure of interest, and (3) a means of performing the calculations. The first requirement is somewhat site dependent and involves the synthesis of seismic history, and geologic and tectonic evidence. The second requirement is less site specific; attenuation functions are often assumed to apply on regional scales. (A summary of published attenuation functions is listed in the section
on "Summary of published attenuation functions" to aid the user in finding a suitable function or to provide a means to compare a newly proposed attenuation law.) The third requirement above is fulfilled by the present program. It is published in the belief that the major time and effort in seismic risk assessment should go into examination and evaluation of alternate seismicity assumptions and ground-motion-intensity parameters, rather than into merely performing the calculations.
Theoretical background

The theory on which this seismic-risk-analysis program is based has been developed over several years (Cornell, 1968, 1971; Merz and Cornell, 1973). A brief description is given here.

Calculations in this program can be represented in the most basic form by the "total probability theorem":

$$ P[A] = \int \int P[A|S \text{ and } R] f_S(s) f_R(r) ds dr $$

where $P$ indicates probability, $A$ is the event whose probability is sought, and $S$ and $R$ are continuous, independent random variables which influence $A$. In words, the probability that $A$ occurs can be calculated by multiplying the conditional probability of $A$ given events $s$ and $r$, times the (independent) probabilities of $s$ and $r$, and integrating over all possible values of $s$ and $r$.

In this program, $A$ represents the event that a specific value of ground-motion intensity is exceeded at the site of interest during an earthquake. As discussed below, the term "intensity" is used here in a general sense and can mean Modified Mercalli intensity, peak ground acceleration, spectral velocity, or other parameters.

Variables $s$ and $r$ represent earthquake size (magnitude or epicentral Modified Mercalli intensity) and distance from the site of interest. Random size and location of events are accounted for as discussed below.
Under the principal option for which this program was written, the conditional probability of (random) intensity $I$ exceeding value $i$ at the site given $s$ and $r$ is evaluated using the normal distribution; this distribution has been used for a variety of ground-motion-intensity measures by various investigators, for example, Esteva (1970); Donovan (1974), and McGuire (1974). The mean of the (conditional) distribution of intensity is taken as

$$m_I(S,R) = c_1 + c_2 S + c_3 \ln(R + r_o)$$

(2)

where $c_1$, $c_2$, $c_3$, and $r_o$ are constants, $S$ is earthquake size, and $R$ is epicentral or hypocentral distance. The majority of analytical attenuation functions reported in the section on "Summary of published attenuation functions" are of this form or can be converted to this form by logarithmic transformation (see below). As will be seen, the program calculates integrations over distance numerically; hence the form of the distance term in the above equation is not critical. By means of slight modifications the program can easily handle mean-intensity functions of the form

$$m_I(S,R) = c_1 + c_2 S + c_3 \ln(R + r_o) + c_4 (R + r_o)$$

(3)

This form has been examined by several investigators, for example, Gupta and Nuttli (1975) and Howell and Schultz (1975). (See section on "Summary of published attenuation functions."
The standard deviation of intensity \( \sigma_I \) is generally taken to be constant, that is, independent of \( S \) and \( R \). Using the normal distribution and equation 2, we have

\[
P[A|s \text{ and } r] = P[I > i|s \text{ and } r] = \Phi^*(\frac{i - c_1 - c_2 s - c_3 \ln(r + r_0)}{\sigma_I})
\]

where \( \Phi^* \) is the complementary cumulative of the standardized normal distribution.
Peak ground motion and spectral intensity measures

When peak-ground-motion values (acceleration, velocity, or displacement) or spectral velocity are used as ground-motion-intensity measures, these variables are generally assumed to be lognormally distributed. Thus, the logarithms of these variables are normally distributed. The mean of, for example, peak ground acceleration $A_g$ as a function of Richter-magnitude $M$ and hypocentral-distance $R$ is often reported as

$$m_A^\text{g} (M,R) = c_1^\text{I} \cdot e^{(R+r_0)}.$$  \hspace{1cm} (5)

In this case the intensity $I$ discussed above is obtained as the natural logarithm of $A_g$, $S$ is equivalent to $M$, and equation 2 is obtained by a logarithmic transformation of equation 5. Parameter $\sigma_I$ is now the standard deviation of the logarithm of peak ground acceleration. If (as is usual) $c_1$, $c_2$, and $c_3$ are calculated by least-squares regression on the logarithm of the ground-motion or spectral-velocity measure, $c_1'$ is often reported as simply the anti-logarithm of $c_1$, in which case $c_1$ is calculated as the logarithm of $c_1'$. More rigorously, from the relationship between the mean and variance of a normally-distributed variable, and the mean of the corresponding lognormally-distributed variable, $c_1'$ can be estimated as
\[ c'_1 = \exp(c_1 + \frac{1}{2} \sigma^2_i) \] (6)

from which \( c_1 \) can be obtained from \( c'_1 \) and \( \sigma_i \). Equation 6 gives a less (but still slightly) biased estimate for \( c'_1 \) (Goldberger, 1968) than simply taking the anti-logarithm of \( c_1 \).

The distribution of magnitude, \( f_M(m) \), is considered next. The number \( n_M \) of earthquakes having magnitude greater than \( M \) occurring in a source area is assumed to conform to the relation (Richter, 1958),

\[ \log_{10} n_M = a - bM \] (7)

where \( a \) and \( b \) are constants characteristic of the source area examined. Constant \( b \) describes the relative distribution of small and large-magnitude events; larger values of \( b \) imply relatively fewer large shocks, and vice versa. Values for \( b \) are relatively constant for different areas, ranging from 0.67 to 1.29 for the continental United States (Evernden, 1970). A value of 0.88 is typical of southern California (Allen and others, 1965).

Assuming that sizes of successive events in the source area are independent, it follows from equation 7 that the cumulative distribution of magnitude for each event is given by

\[ F_M(m) = k \left[ 1 - \exp(-\beta(m-m_0)) \right] m_0 < m < m_1 \] (8)
where \( m_0 \) is a lower-bound magnitude (discussed below), \( m_1 \) is the maximum magnitude which can originate from the source area, and constants \( \beta \) and \( k \) are given by

\[
\beta = b \ln 10
\]

\[
k = \left[ 1 - \exp(-\beta(m_1-m_0)) \right]^{-1}
\]

(9)

It follows from equation 8 that the density function on magnitude is given by

\[
f_M(m) = \beta k \exp(-\beta(m-m_0)) \quad m_0 \leq m \leq m_1
\]

(10)

Postponing, for the moment, consideration of the density function on distance in equation 1, we can substitute equations 4 and 10 in 1, equate \( s \) to \( m \), and obtain the probability that intensity \( i \) is exceeded at the site:

\[
P[I>i] = \int \int_{m_0}^{m_1} \phi\left( \frac{i-c_1-c_2m-c_3\ln(r+r_0)}{\sigma_I} \right)
\]

\[
\beta k \exp(-\beta(m-m_0)) f_R(r) \, dm \, dr
\]

(11)

Through algebraic manipulation (Cornell, 1971; Merz and Cornell, 1973), the integration on magnitude in equation 10 may be performed analytically (derivation is given in "Appendix A, Derivation of equation 11"), resulting in

\[
P[I>i] = \int \left\{ (1-k) \phi\left( \frac{z}{\sigma_I} \right) + k \phi\left( \frac{z'}{\sigma_I} \right) \right\}
\]

\[
+ k(r+r_0) \exp\left( -\frac{\beta c_3}{c_2^2} + \frac{\beta c_1}{c_2} + \beta m_0 + \frac{\beta^2 \sigma_I^2}{2c_2^2} \right)
\]

\[
\left[ \phi\left( \frac{z-\beta \sigma_I^2/c_2}{\sigma_I} \right) - \phi\left( \frac{z'-\beta \sigma_I^2/c_2}{\sigma_I} \right) \right] f_R(r) \, dr
\]

(12)
where constants \( z \) and \( z' \) are defined in "Appendix A, Derivation of equation 11." The density function on distance, \( f_R(r) \), depends on the spatial relationship between the source and site. As discussed in the next section, the program calculates risk associated with intensity \( i \) by evaluating the integral in equation 12 numerically.

Once the risk associated with an intensity-level \( i \) at a site has been calculated for the occurrence of one earthquake of arbitrary magnitude and location in a source area, the annual expected number of events from that source area that cause intensity \( i \) or greater, is obtained by multiplying the single-event risk by the expected number of events during 1 year. The total expected number of events causing intensity \( I \geq i \) at the site is obtained by summing the expected number from each source area. If this total is less than about 0.1, this expected number is also an accurate (and conservative) approximation to the risk associated with that intensity level. (This is true for a wide range of mathematical models which could be used to represent successive earthquake occurrences.) In this program, both expected numbers and risks are output; risks are calculated assuming that earthquakes occur as Poisson arrivals, that is, \( \text{risk} = 1 - \exp(-\text{total expected number}) \).
The lower-bound magnitude, \( m_0 \), can be used in one of two ways in the program. First (and most commonly), it can be used as a "loose" lower bound (in the terminology of Cornell, 1974), meaning that it is simply a convenient magnitude used to express the activity rate (rate of occurrence of events greater than or equal to that magnitude). Earthquakes of lesser magnitude are assumed to occur, at a rate consistent with that for magnitudes \( m_0 \) and greater (that is, the exponential distribution on magnitude is extrapolated to lower magnitudes, using a corresponding and consistent increase in activity rate). In the program, extrapolation is made to magnitude zero, and risk calculations are performed from magnitude zero to \( m_1 \). (The choice of magnitude zero for the lower bound of calculations is not critical.)

The second option in the program for use of \( m_0 \) is as a "strict" lower bound (again in the terminology of Cornell, 1974). Risk calculations are made only from magnitude \( m_0 \) to \( m_1 \). This option is useful, for instance, for modeling a piecewise linear \( \log n_M \) versus \( M \) curve (as described in "Guidelines for program use").

The choice of lower-bound option for each source is controlled by the value input for variable LORS, as described in the section on "Required input."
Modified Mercalli intensity.--Site analysis can be performed using Modified Mercalli intensity (MMI) as the intensity measure. In the program, there is no loss of generality in taking MMI to be a continuous random variable. The user must take care, however, in interpreting discrete MMI data for input as a continuous variable, particularly in defining the lower bound and in reinterpreting intensities (from continuous to discrete values) after risks have been calculated.

The equations presented above apply for use of MMI, except that earthquake size is designated by epicentral MMI, $I_e$. Event size may also be designated by the maximum MMI, and the user should be aware that the epicentral MMI of an earthquake is not always the maximum MMI observed. This may result because of such effects as mislocated epicenters, misreported intensities, and propagation path or site geology. For events documented without instrumental data (and thus without an instrumentally determined epicenter) the epicentral MMI is often taken to be the maximum MMI reported. If these data are used to represent earthquake size for the program, the user should be aware of potential inconsistencies arising because, for a given earthquake, the program will compute nonzero probabilities of site intensities which are greater than the maximum intensity defining the event.
Similarly, nonzero probabilities will be calculated for site intensities greater than the maximum intensity allowable in the surrounding source areas.

Using epicentral MMI $I_e$, the mean site intensity (equation 2) becomes

$$m_I (I_e, R) = c_1 + c_2 I_e + c_3 \ln (R + r_0)$$

(13)

where $R$ is now epicentral distance and other parameters are as previously defined. Standard deviation $\sigma_I$ is now that of MMI about its predicted value. The density function on magnitude, equation 10 becomes a density function on epicentral intensity:

$$f_{I_e} (i_e) = \beta k \exp (-\beta (i_e - i_0)) \quad i_0 \leq i_e \leq i_1$$

(14)

where the constants $\beta$ and $k$ are analogous to the previous definitions.

It is possible to perform an analysis for site MMI using Richter magnitude as the measure of earthquake size. An attenuation equation for site MMI as a function of Richter magnitude and distance is reported by Howell and Schultz (1975). Whichever event-size parameter (magnitude or MMI) is used in the right-hand side of the attenuation function must also be used for the earthquake density function (equation 10 or 14).

The previous comments regarding loose and strict lower bounds for sources apply also to MMI. For loose lower
bounds, extrapolation is made to MMI equal to zero, using an occurrence rate consistent with that indicated for \( i_e = i_0 \).

**Limits on attenuation equations**.--Several options are available in this program to introduce limits on the attenuation equation 2. The first of these is a limiting radius (denoted as variable RONE in the program) inside of which there is no attenuation of motion. Operationally, the program computes mean intensities for distances less than RONE by substituting RONE for \( R \) in equation 2. Mean intensities for earthquakes at greater distances than RONE are not affected. This option is often used when MMI is the intensity measure and the user wishes the mean intensity within radius RONE to be constant (and ordinarily equal to the epicentral intensity). Dispersion of intensities within radius RONE is taken to be the same as dispersion outside this radius; this implies that a particular site might experience a higher MMI than that at the epicenter. Such higher than epicentral intensities might represent local soil conditions or propagating (focusing) effects. If the user wishes the standard deviation of intensities within RONE to be different from the standard deviation outside that radius (particularly if he wishes \( \sigma_I \) to be zero), comment cards in subroutines RISK1 and RISK2 indicate the method of modifying the program to achieve this result.
The second option for limiting the mean values calculated by attenuation equation 2 involves describing a maximum mean intensity as a function of magnitude. Operationally, the equation

$$\text{maximum } m_I(S) = \text{AAA} + \text{BBB} \times S$$

(15)

(where the symbol * indicates multiplication) is used to calculate a maximum mean intensity for any earthquake size S. Variables AAA and BBB are input by the user. Equation 15 implicitly defines a radius for each earthquake size S inside of which equation 15 yields a constant mean intensity and outside of which equation 2 governs the mean intensity (fig. 1). Equation 15 is most often used when the intensity measure is (the logarithm of) peak ground acceleration, and when the user wishes to specify a lesser dependence of acceleration on magnitude at close distance than at far distances (this may also be done by specifying a set of tabulated attenuation functions, as is explained below). Note that a limiting mean intensity for all earthquake sizes can be designated with equation 15 by specifying AAA as the absolute limit and BBB as zero. (In this case the limiting equation in figure 1 would become a horizontal line.)

The use of limits RONE and equation 15 is best illustrated by showing the effect of these limits on a typical attenuation equation (of the type given by equations 2 or
FIGURE 1

EFFECTS OF EQUATION (14) AND PARAMETER RONE ON MEAN INTENSITY ATTENUATION CURVES
5.) Figure 1 shows mean intensity as a function of distance for earthquakes of several different magnitudes, when both RONE and equation 15 are used as limits on the mean intensity. When both limiting options are used, the lower of the two resulting limit intensities governs.

The form of equation 15 was chosen because it is consistent with the dependence of intensity on magnitude in the attenuation equation 2. Choice of parameters AAA and BBB must be made using judgment and physical arguments because of the dearth of quantitative ground-motion data at small epicentral distances. It is strongly suggested that the user plot his attenuation relationship along with the limiting options used, as in fig. 1, before proceeding with site analysis. The equation of the dashed line in fig. 1 representing limiting equation 15 is

\[ m_I = \frac{BBB \times c_1 - AAA \times c_2}{BBB - c_2} + \frac{BBB \times c_3}{BBB - c_2} \ln(R + r_0) \]  

(16)

As an alternative to specifying AAA and BBB directly, it may be more convenient for the user to plot his attenuation function for several magnitudes, as in fig. 1, decide on a limiting line such as the dashed line in fig. 1, determine the intercept \( \alpha \) and slope \( \gamma \) of this line, and calculate AAA and BBB for program input by the relations:
Alternate attenuation functions.—Mean attenuation functions of a form other than equation 2 can easily be handled by this program. Similarly, distributions of intensity residuals other than the normal distribution may be specified. Changes required are that the value of switch JCALC be input as 1 (see the section on "Required input"), and the user's mean-intensity-attenuation function and distribution of residuals be specified in subroutine RISK2 following the comment cards in that subroutine. Under this option a double numerical integration is carried out over magnitude and distance, evaluating equation 1 directly. Program calculations are less efficient than if attenuation equation 2 and a normal distribution of residuals is used, allowing analytical integration over magnitude as described previously. At present (1975) subroutine RISK2 is programed for demonstration purposes to use a mean-intensity-attenuation function identical with equation 2, and a normal distribution of residuals; comment cards indicate the modifications necessary to incorporate changes in the attenuation function and residual distribution.
Program operation

The program evaluates risk for each site-source combination and intensity level by integrating equation 12 numerically, and calculates the total annual expected number of occurrences of intensity greater than those levels of interest at a site by summing the expected numbers from all sources. The total annual risk is calculated assuming that earthquakes occur as Poisson arrivals. To make intelligent choices for such operational parameters as the number of integration steps, and to construct program input for a problem in order to achieve most efficient operation, the program user must understand the operation of the program.

Seismic source areas are specified as a set of arbitrarily shaped quadrilaterals (fig. 2). For ease of input, gross sources may be divided into subsources which are a string of quadrilaterals, each two adjacent subsources having two common corners (the method of source-area specification is described in the following section). A Cartesian coordinate system is used; the location of the origin is arbitrary. The program is easily modified to use a latitude-longitude coordinate system, as explained by comment cards in the main program. Activity rates (yearly number of earthquakes having magnitudes \( \geq m_0 \)) and
FIGURE 2
TYPICAL SOURCE AREAS
values of $\beta$ (equation 9) are input for each gross source. The only restrictions on specification of the quadrilaterals are that (1) two sides cannot be colinear, and (2) no reentrant figures (those having a concavity) may be used. A triangular source can be prescribed by using a quadrilateral having one short side (for example, gross-source 2 in fig. 2). Quadrilateral sources, whether in the same or different gross sources, may overlap and may have coincident corners.

Sites to be examined are specified by inputting the (Cartesian) coordinates of each site. As an option, a grid (or grids) of sites may be specified by inputting the $X$ and $Y$ distance between sites in the grid and the number of sites in the $X$ and $Y$ directions (that is, the number of columns and rows in the grid). In this case the coordinates of the first site represent the lower-left corner of the grid. Risks for sites are calculated and are output sequentially in the order specified.

For each site and quadrilateral source, the program computes the closest and farthest distances of the source from the site (fig. 3). The difference between these distances is divided into NSTEP intervals (this parameter being specified in program input), and the distance variable in equation 12 is increased sequentially, starting with the distance from the site to the midpoint of the first interval. For each interval (each distance value) the intersection of
FIGURE 3

ARC AREAS GENERATED BY PROGRAM TO ASSIGN SEISMICITY WITHIN QUADRILATERAL SOURCE AREA AS A FUNCTION OF DISTANCE FROM SITE
an arc of constant radius, centered at the site, and the
sides of the quadrilateral are computed, and the arc area
(the arc length times the interval width) is calculated.
Seismicity is assigned to each arc area in the proportion
that its area has to that of the entire quadrilateral.

The sum of the arc areas will not exactly equal the
area of the quadrilateral because of the approximate method
of calculating each arc area (fig. 3). Whenever the
difference is more than 5 percent of the true quadrilateral
area, a warning message is printed. This situation is
generally caused by too few intervals (too small a value
for NSTEP), although in some cases increasing NSTEP through
a small range will increase the calculated error. Guide­
lines for choice of values for NSTEP are given in the
section on "Guidelines for program use."

Several cases deviate from this basic analysis. When
the closest distance from site to quadrilateral source area
is between 100 and 250 km, the number of steps used is one­
half of NSTEP. When the closest distance is between 250
and 500 km, no numerical integration is done, and all
seismic activity is located at the center of the source
area (determined by averaging the coordinates of the corner
points). Quadrilateral sources farther away than 500 km
are not considered in risk computations. These distances
can easily be altered to suit the user; see the comment
cards referring to this in subroutine OUTSID. For sites located inside quadrilateral source areas, NSTEP circular intervals are considered, from the site to the closest edge (except that the smallest interval width used is 1 km).

The number of steps used for the remainder of the source area (outside the largest circle) is a fraction of NSTEP, the fraction determined by the ratio of the remaining area to the total area of the source. The purpose in devising these algorithms to modify NSTEP for particular cases is to promote calculations which trade accuracy for efficiency in situations where such a trade is desirable.

The relative value of NSTEP for sites inside and outside source areas can be changed or can be input separately. Comment cards giving directions for these changes are included in the main program.

For each arc interval, the contribution to the integral of equation 12 is calculated for each intensity of interest. Computation of the arc lengths takes much of the program's operational time for a large problem; hence, changing NSTEP by a factor of 2 will affect a problem's run time by about a factor of 2. Similarly, for a chosen value of NSTEP the run times of different problems are approximately proportional to the number of (quadrilateral) sources times the number of sites in each problem, for the same number of examined intensities. There is no computational advantage to lumping
subsources under one gross source; the advantage is in the smaller number of coordinates needed to be input. The run time of any particular problem is proportional to the number of intensities for which risks are calculated.

A coefficient for each gross source must be supplied in the program input. After the expected number of occurrences (of intensity greater than those specified) has been computed for a gross source (and site), this number is multiplied by the (gross) source coefficient before adding to obtain the total expected number (from all gross sources). The normal (most common) value for the coefficient is 1.0; however, fractional values may be used to express subjective probabilities on that source. For instance, duplicate sources, each having a coefficient value of 0.5, may be specified to be identical in all respects except for the assigned activity rate, to indicate uncertainty in this parameter. Alternately, coefficient values of -1.0 may be used to "subtract" one gross source from another. (An example is given in "Guidelines for program use.") Note that the coefficient is applied to the expected number from each source, rather than to the risk from each source.

Parameter values to indicate "background seismicity" may also be input to the program. This is seismicity which cannot be associated with a specific source area.
The activity-rate input is that for a 10,000 km² area, and the contribution of background seismicity is calculated for a circle of radius 150 km. This calculation is made once, and the contribution to the expected numbers of occurrences of intensities greater than those in the input list is added to the expected number for each site examined. Note that there is an inconsistency in this procedure, in that the background seismicity is assigned to all areas including source areas having loose lower bounds. Hence, for magnitudes less than the upper-bound-background seismicity magnitude, two specifications of seismicity for loose-lower-bound source areas have been made. For activity rates and upper-bound magnitudes usually associated with background seismicity, the errors will be very small. The errors will be largest for sites near and within loose lower-bound sources that have an upper-bound magnitude and activity rate close to those of the specified background seismicity. To alleviate these errors, the user may wish to specify a gross source identical in geometry to the real gross source but having an activity rate and bounding magnitudes equal to those of the background seismicity and a source coefficient of minus one.

The advantages of the algorithms used in this program over alternatives (Cornell, 1974; Shah and others, 1975) are worth enumerating:
1. Source-area specification is quite general; virtually all possible geometries for source areas may be specified efficiently by the quadrilaterals used here.

2. Source-area specification is independent of the site being investigated; hence, alternate sites may be compared, or grids of sites (for mapping purposes) may be analyzed using one source-area specification.

3. The size of the program is quite small; no storage penalty is incurred by analyzing a grid of sites, as each site is considered and analyzed sequentially. Using a moderate amount of core space, seismic source areas may be specified for a large area (for example, a large section of the United States); sites can then be chosen for later analyses at will.

4. An optimum trade off between accuracy and efficiency is easily approximated through variation of the number of steps used in the numerical integration as a function of site-to-source distance.

5. The program is easily converted to work on a latitude-longitude coordinate system (see comment cards in main program).

6. An optional variation of the program allows use of any form of attenuation function and residual distribution. Even a tabulated attenuation function may be used.
Present limitations on input are as follows:

- maximum number of gross sources........ 10
- maximum number of subsources (in each gross source)........... 10
- maximum number of intensities to be examined................ 12
- maximum number of risks for which associated intensities are to be calculated............... 8
- number of sites to be examined........ unlimited

These limits can be modified by changing dimension statements as noted in the comment cards of the main program.
Required input

Input required for program operation is described in this section. All input is read in the main program and is echo printed for reference. Because the program does only a minimal amount of data checking, care must be taken in input preparation and review.

Card 1 (Format 20A4): Title

Any 80 characters may be used to describe the problem.

Card 2 (Format 3110): NSTEP, JCALC, JPRNT.

NSTEP is the number of integration steps used in integrating over distance for each site-source combination. Refer to the discussion of this parameter in the section on "Program operation" and "Guidelines for program use."

JCALC is the flag indicating how integration on magnitude is to be performed:

JCALC=0 is used for analytical integration, and the form of the attenuation function is that described in the section on "Program operation."

JCALC=1 is used for numerical integration on magnitude. The user must supply his attenuation function in subroutine RISK2. Refer to comment cards in that subroutine.

JPRNT is the flag indicating desired output:
JPRNT=0 is used to print only total expected numbers and risks at a site (normally used when a grid of sites is being examined).

JPRNT=1 is used to print expected numbers from each site-source combination (normally used when examining a single site).

Card 3 (Format I5, 12F5.3): NLEI, TI(1), TI(2),...TI(NLEI).

NLEI is the number of intensities to be examined.

TI(1), TI(2), and so on, are intensities for which expected numbers and risks are calculated at each site.

Note, as discussed in the section on "Theoretical background," that the values for TI(i) may be Modified Mercalli intensity, or the natural logarithm of ground acceleration, velocity, displacement, or spectral velocity. In printing results, the program prints both TI(i) and its antilogarithm.

Values for array TI must be specified in increasing order.

Card 4 (Format 8F10.2): RISKS(1), RISKS(2),...RISKS(8).

RISKS(1), RISKS(2), and so on are risks (probabilities of exceedance) for which the corresponding intensities are desired. These intensities are calculated by interpolation, on a logarithmic scale, between intensities (in the list of examined intensities, TI) having larger and smaller risks.

Both the corresponding intensity and its anti-logarithm are printed. Values for array RISKS must be specified in order
of decreasing risk. If fewer than eight values are desired, leave succeeding spaces on the card blank. To avoid large errors and subsequent misinterpretation, the program will not extrapolate to calculate intensity values corresponding to risk levels specified; it is the user's obligation to choose values for array TI which will result in risks which bound those specified in array RISKS. This is, of course, a matter of judgment and experience. The user must be cautioned that in a grid site system appropriate values for array TI may vary considerably for the different sites examined. The intensities interpolated for levels specified in RISKS will be most accurate for closely spaced values of TI.

Card 5 (Format 8F10.2): C1, C2, C3, SIG, RZERO, RONE, AAA, BBB.

C1, C2, C3, and RZERO are parameters in the attenuation equation 2 for mean intensity discussed in the section on "Theoretical background":

\[ m_I(S,R) = C1 + C2*S + C3*\text{ALOG}(R + \text{RZERO}) \]

SIG is the standard deviation of residuals about the mean. If no dispersion of residuals is desired, insert a very small value for SIG (rather than exactly 0.0).

RONE is the limiting radius inside of which no attenuation of motion is desired, for values of focal distance
closer than RONE, the mean intensity is calculated using RONE in place of R in the attenuation equation above. If this feature is not desired, insert zero for RONE.

AAA and BBB are parameters in the equation limiting the mean intensity (see the section on "Program operation"):

\[ \max m(s) = AAA + BBB \times S \]

The value specified for BBB must be between zero and C2 for this limiting equation to make sense. If it is not, an error message will result and program operation will terminate.

Card 6 (Format 2413): NGS, NRS(1), NRS(2), ... NRS(NGS).

NGS is the number of gross sources to be specified.

NRS(1), NRS(2), and so on are the number of subsources in gross source 1, 2, etc. See the section on "Program operation" for a general description of the source specification.

Card (Set) 7 (Format I10, 6F10.2): LORS(I), COEF(I), AMO(I), AM1(I), BETA(I), RATE(I), FDEPTH(I).

There must be NGS+1 of these cards, one for each gross source and one for background seismicity.

LORS(I) is a flag indicating whether the source area has a loose or strict lower bound (see the section on "Program operation"): 
LORS(I) = 0 implies a loose lower bound.
LORS(I) = 1 implies a strict lower bound.

COEF(I) is a coefficient modifying the expected number of exceedances from gross-source I (see the section on "Program operation"). Its most common value is +1.0.

AMO(I) is the loose or strict lower-bound magnitude or intensity for gross-source I.

AMI(I) is the upper-bound magnitude or intensity for gross-source I.

BETA(I) is the value of $\beta$ for gross-source I. It is equal to the natural logarithm of 10, times the Richter b value for the source (see equation 6).

RATE(I) is the rate of occurrence of events having magnitudes of intensities greater than AMO(I). If a discrete distribution on intensities has been used to calculate the rate, the user may wish to specify AMO(I) as one-half intensity unit lower than the lowest intensity used to establish the rate. Note that for gross sources RATE(I) is in units of number per year; for background seismicity it is in units of number per year per 10,000 km.

FDEPTH(I) is the focal depth of events in gross-source I, in kilometres. If epicentral distances are required for all sources and for background seismicity for the attenuation function, insert zero for FDEPTH(I).
If no background seismicity is desired, leave the last card in this set completely blank.

Card (Set) 8 (Format 4F10.2): X1, Y1, X2, Y2.

There must be NRS(1) + NRS(2) + ... + NRS(NGS) + NGS of these cards. The first NRS(1)+1 cards specify coordinates of subsources for gross-source 1, the next NRS(2)+1 cards specify coordinates of subsources for gross-source 2, and so on. Internally, the point X1, Y1 is connected to point X2, Y2, as well as to both the previous and subsequent points designated as X1, Y1, as long as these are both in the same gross source. Point X2, Y2 is connected similarly. An example is elucidating. The following points, for two gross sources having two subsources each, designate the source areas of fig. 4:

```
0.0   0.0   10.0   0.0
0.0   5.0   10.0   8.0
-5.0  10.0   6.0   15.0
10.0  20.0  11.0  20.0
15.0  15.0  16.0  15.0
15.0  0.0   16.0  0.0
```

Card (Set) 9 (Format 2I5, 4F10.2): NX, NY, XZERO, YZERO, XDELTA, YDELTA.

There can be any number of these cards, one for each site or grid of sites to be examined.
FIGURE 4

SOURCE AREAS SPECIFIED IN EXAMPLE
NX and NY are the number of grid points in the X (east-west) and Y (north-south) directions; that is, they are the number of columns and rows in the grid of sites to be examined. For specification of a single site, NX and NY must have values of unit. Zero or negative values for NX or NY are meaningless and will cause program termination.

XZERO and YZERO are the coordinates of the site to be examined, or are the lower left corner of the grid if NX and/or NY are greater than one.

XDELTA and YDELTA are the grid spacings in the X and Y directions. When the grid option is not used, these variables may be left blank or set equal to zero.

Final Card:

Insert one blank card at the end of the input deck.
Summary of published attenuation functions

Table 1 lists some published attenuation functions and the data on which they are based. Not included in this summary are functions derived primarily from events on continents other than North America, and functions derived from observations of underground nuclear explosions. Refer to Ambrayses (1974) for a summary of attenuation functions derived from observations on other continents; refer to Environmental Research Corporation (1974) for a summary of attenuation functions derived from nuclear explosions.

Particular care should be taken when using reported attenuation functions describing Modified Mercalli intensity. For the distance variable in these functions some investigators use epicentral or hypocentral distance to sites where intensities were reported, whereas others use distance to an equivalent circular isoseismal. The two methods are not equivalent, but comparisons are often made in the literature, ignoring the difference.
<table>
<thead>
<tr>
<th>Reference</th>
<th>Data source</th>
<th>Distance parameter</th>
<th>Dependent variable</th>
<th>Equation</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blume (1966)</td>
<td>Southern California</td>
<td>Epicentral distance ( d ) (mi)</td>
<td>Peak ground acceleration ( a_g ) (g)</td>
<td>( a_g = \frac{a_0}{1 + (d/h)} )</td>
<td>Not reported</td>
</tr>
<tr>
<td>Brazee (1972)</td>
<td>United States east of long. 106°W</td>
<td>Epicentral distance ( d ) (mi)</td>
<td>Distance over which a Modified Mercalli intensity is felt</td>
<td>( \log a_g = b_1 I_e )</td>
<td>Not reported</td>
</tr>
<tr>
<td>Cloud and Perez (1971)</td>
<td>North and South America</td>
<td>Epicentral distance ( d ) (mi)</td>
<td>Maximum single component ground acceleration ( a_g ) (g)</td>
<td>( a_g = 3.0 - 2 \log (d/80) )</td>
<td>Not reported</td>
</tr>
<tr>
<td>Cornell and Hess (1974)</td>
<td>Northeastern United States, rock sites</td>
<td>Hypocentral distance ( R ) (km)</td>
<td>Modified Mercalli intensity</td>
<td>( I = 2.6 + I_e - 1.3 \ln \delta )</td>
<td>( \delta &gt; 10 )</td>
</tr>
<tr>
<td>Donovan (1974)</td>
<td>San Fernando, rock sites</td>
<td>Distance to energy center ( R ) (km)</td>
<td>Peak ground acceleration ( a_g ) (gals)</td>
<td>( a_g = 12.783 \times 10^6 (R+25)^{-2.77} )</td>
<td>Not reported</td>
</tr>
<tr>
<td>Donovan (1973)</td>
<td>Worldwide</td>
<td>Hypocentral distance, epicentral, or distance to fault ( R ) (km)</td>
<td>Peak ground acceleration ( a_g ) (gals)</td>
<td>( a_g = 1.3 \times 10^8 (R+25)^{-1.52} )</td>
<td>( \ln a_g = 0.84 )</td>
</tr>
<tr>
<td>Duke and others (1972)</td>
<td>San Fernando, soil sites</td>
<td>Distance to energy center ( R ) (km)</td>
<td>Peak ground acceleration ( a_g ) (g)</td>
<td>( a_g = 6.68 R^{-0.0097} )</td>
<td>( \ln a_g = 0.052 )</td>
</tr>
<tr>
<td>Esteva (1970)</td>
<td>See reference</td>
<td>Hypocentral distance ( R ) (km)</td>
<td>Peak ground acceleration ( a_g ) (gals)</td>
<td>( a_g = 1.3 \times 10^8 (R+25)^{-2} )</td>
<td>( \ln a_g = 1.2 )</td>
</tr>
<tr>
<td>Esteva and Rosenblueth (1968)</td>
<td>West Coast of United States, distance ( R ) (km)</td>
<td>Peak ground acceleration ( a_g ) (gals)</td>
<td>Peak ground velocity ( v_g ) (cm/sec)</td>
<td>( v_g = 1.5 \times 10^8 (R+0.17 R^{-0.58})^{-1.7} )</td>
<td>( \ln v_g = 0.84 )</td>
</tr>
<tr>
<td>Esteva and Villaverde (1974)</td>
<td>Western United States, distance ( R ) (km)</td>
<td>Peak ground acceleration ( a_g ) (gals)</td>
<td>Peak ground velocity ( v_g ) (cm/sec)</td>
<td>( v_g = 32 \times 10^8 (R+25)^{-1.7} )</td>
<td>( \ln v_g = 0.74 )</td>
</tr>
<tr>
<td>Reference</td>
<td>Data source</td>
<td>Distance parameter</td>
<td>Dependent variable</td>
<td>Equation</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------------------------</td>
<td>----------------------------------</td>
<td>-------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>Esteva and Villaverde (1974)</td>
<td>Western United States</td>
<td>Hypocentral distance R (km)</td>
<td>Maximum average spectral</td>
<td>$X=69600 e^{0.8M(R+70)^{-2}}$</td>
<td>$\ln X = 0.75$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>acceleration A (gals)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Maximum average spectral</td>
<td>$\Upsilon=250 e^{M(R+60)^{-1.7}}$</td>
<td>$\ln \Upsilon = 0.64$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>velocity $\Upsilon$ (cm/sec)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gupta and Nuttli (1975)</td>
<td>Central United States</td>
<td>Epicentral distance to</td>
<td>Modified Mercalli intensity</td>
<td>$I=1.7+0.7-0.0011 A$</td>
<td>Not reported</td>
</tr>
<tr>
<td></td>
<td></td>
<td>isoseismal A (km)</td>
<td></td>
<td>$-2.7 \log A$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$I$ is epicentral intensity</td>
<td></td>
</tr>
<tr>
<td>Gutenberg and Richter (1956)</td>
<td>California</td>
<td>Epicentral distance</td>
<td>Peak ground acceleration</td>
<td>Graphical</td>
<td>Not reported</td>
</tr>
<tr>
<td></td>
<td></td>
<td>to isoseismal A (km)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Housner (1965)</td>
<td>Western United States, and Central</td>
<td>Distance to fault</td>
<td>Peak ground acceleration</td>
<td>Graphical</td>
<td>Not reported</td>
</tr>
<tr>
<td></td>
<td>and South America</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Howell and Schultz (1975)</td>
<td>California coast</td>
<td>Epicentral distance to isoseismal</td>
<td>Modified Mercalli intensity</td>
<td>$I=1.8-0.874-0.422 \ln A$</td>
<td>$\sigma_I = 0.64$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A (km)</td>
<td></td>
<td>$-0.0186 A$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Logarithm of Modified</td>
<td>$\ln I = \ln I + 0.16 - 0.1563 \ln A \quad \sigma_i = 0.44$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mercalli intensity</td>
<td>$-0.0023 A$</td>
<td></td>
</tr>
<tr>
<td>Rocky Mountains, Washington,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Modified Mercalli intensity</td>
<td>$I=1.8+1.802-0.628 \ln A \quad \sigma_I = 0.61$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$-0.009 A$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Logarithm of Modified</td>
<td>$\ln I = \ln I + 0.322 - 0.1098 \ln A \quad \sigma_i = 0.47$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mercalli intensity</td>
<td>$-0.0012 A$</td>
<td></td>
</tr>
<tr>
<td>Central and Eastern</td>
<td></td>
<td></td>
<td>Modified Mercalli intensity</td>
<td>$I=1.8+3.278-0.589 \ln A$</td>
<td>$\sigma_I = 0.64$</td>
</tr>
<tr>
<td></td>
<td>United States and Canada</td>
<td></td>
<td></td>
<td>$-0.0029 A$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Other forms of equations</td>
<td>$\ln I = \ln I + 0.480 - 0.0139 \ln A \quad \sigma_i = 0.43$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>examined and reported also)</td>
<td>$-0.06075 A$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$I$ is epicentral intensity</td>
<td></td>
</tr>
<tr>
<td>McGuire (1974)</td>
<td>West Coast of United States</td>
<td>Hypocentral distance R (km)</td>
<td>Peak ground acceleration A g</td>
<td>$a=472x10^{0.28M(R+25)^{-1.3}}$</td>
<td>$\sigma_a = 0.222$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(gals)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Peak ground velocity V g</td>
<td>$v=5.64x10^{0.4M(R+25)^{-1.2}}$</td>
<td>$\sigma_v = 0.273$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(cm/sec)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Peak ground displacement d g</td>
<td>$d=0.393x10^{0.4M(R+25)^{-0.8}}$</td>
<td>$\sigma_d = 0.330$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Spectral velocity</td>
<td>$s=0.428x10^{0.3M(R+25)^{-0.59}}$</td>
<td>$\sigma_s = 0.274$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(T=1 sec, &lt;0.02)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mickey (1971)</td>
<td>See reference</td>
<td>Hypocentral distance, R (km)</td>
<td>Peak particle acceleration A g</td>
<td>See reference</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(g)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Peak particle velocity v g</td>
<td>$v=4.06x10^{0.88N-1.5}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(cm/sec)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Peak particle displacement d g</td>
<td>$d=5.66x10^{1.1N-1.2}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(cm)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 1.--Summary of published attenuation functions--Continued

<table>
<thead>
<tr>
<th>Reference</th>
<th>Data source</th>
<th>Distance parameter</th>
<th>Dependent variable</th>
<th>Equation</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milne and Davenport (1969)</td>
<td>Western United States, Central America, Chile</td>
<td>Epicentral distance (d) (km)</td>
<td>Peak ground acceleration (a_g) (g)</td>
<td>(a_g = 0.69 \cdot 10^{-0.64M} \cdot 1.1 \cdot 10^{1.7} \cdot d^0.5)</td>
<td>Not reported</td>
</tr>
<tr>
<td>Neumann (1954)</td>
<td>West Coast of United States</td>
<td>Epicentral distance (d) (mi)</td>
<td>Modified Mercalli intensity</td>
<td>(I = I_e + 0.05 - 3.17 \log R) (R) (\text{R} 1.12 \text{ miles})</td>
<td>Not reported</td>
</tr>
<tr>
<td>Nuttili (1973a)</td>
<td>Central United States</td>
<td>Epicentral distance</td>
<td>Vertical particle acceleration, velocity, and displacement at 3 frequencies for Rayleigh waves</td>
<td>Graphical and tabular for various earthquakes</td>
<td>Not reported</td>
</tr>
<tr>
<td>Nuttili (1973b)</td>
<td>Central United States</td>
<td>Epicentral distance</td>
<td>Sustained ground acceleration, velocity, and displacement at 3 frequencies for surface waves</td>
<td>Graphical and tabular</td>
<td>Not reported</td>
</tr>
<tr>
<td>Orphal and Lahoud (1974)</td>
<td>California</td>
<td>Hypocentral distance (R) (km)</td>
<td>Peak ground acceleration (a_g) (g)</td>
<td>(a_g = 0.066 \cdot 10^{0.4M} - 1.39)</td>
<td>See reference</td>
</tr>
<tr>
<td></td>
<td>California and nuclear explosions</td>
<td>---do---</td>
<td>Peak ground velocity (v_g) (cm/sec)</td>
<td>(v_g = 0.726 \cdot 10^{0.52M} - 1.34)</td>
<td>---do---</td>
</tr>
<tr>
<td></td>
<td>Puget Sound, Washington</td>
<td>---do---</td>
<td>Peak ground displacement (d_g) (cm)</td>
<td>(d_g = 0.0471 \cdot 10^{0.57M} - 1.18)</td>
<td>---do---</td>
</tr>
<tr>
<td>Rasmussen and others (1974)</td>
<td>Puget Sound, Washington</td>
<td>Epicentral distance</td>
<td>Modified Mercalli intensity</td>
<td>Graphical; data and limits given for each earthquake</td>
<td>Not calculated; data shown</td>
</tr>
<tr>
<td>Schnabel and Seed (1973)</td>
<td>Western United States</td>
<td>Distance to fault</td>
<td>Peak ground acceleration</td>
<td>Graphical</td>
<td>Not reported</td>
</tr>
<tr>
<td>Stepp (1971)</td>
<td>Puget Sound, Washington</td>
<td>Hypocentral distance to isoseismal (R) (km)</td>
<td>Modified Mercalli intensity</td>
<td>(I = I_e - 2.017 \log(R/h) - 0.008(R/h))</td>
<td>Not reported</td>
</tr>
</tbody>
</table>

where \(I_e\) is epicentral intensity, \(h\) is focal depth.
Guidelines for program use

In this section, suggestions are given for most efficient and accurate use of this program. In general, more insight is gained for a particular problem by spending effort and computer time calculating approximate and relative risks associated with a range of input assumptions, rather than by calculating highly accurate risks for a single set of assumptions.

**Number of integration steps.**--The effect of the number of integration steps on efficiency was discussed in the section on "Program operation." To illustrate the degree of accuracy associated with various levels of efficiency, two sites affected by a square seismic-source area were examined, as shown in fig. 5.

Using a typical attenuation function for peak ground acceleration and an occurrence rate of once per year, the annual risks associated with various acceleration levels were computed for sites A and B, using various values for NSTEP (the input variable describing the number of integration steps). The largest value examined was 25, representing the most accurate calculation. For acceleration levels corresponding to about 15 percent annual risk at the two sites, the variation in calculated risk as a
FIGURE 5

SITES AND SOURCE AREA USED FOR INTEGRATION ACCURACY STUDY
function of the number of integration steps was determined and is shown in fig. 6. In this illustration a relative error of +1 percent in risk level from the 15 percent annual risk implies an estimated annual risk of 15.15 percent. The lowest detectable error, corresponding to a change in the last significant digit, is +0.6 percent.

As evident in fig. 6, the inaccuracy resulting from fewer integration steps is small, on the order of several percent, for NSTEP values as small as 5 or 10. This conclusion holds for smaller risk levels as well (for example, an annual risk of 0.001). Hence, a value of 10 will not induce great inaccuracies, and is suggested for most problems. Refer also to the discussion on modeling faults as source areas later in this section.

The erratic behavior of relative error in estimated risk with NSTEP for site B results from erratic (but small) errors in the estimated source size as discussed in the section on "Program operation."

Use of source-area coefficient.---The source-area coefficient (variable COEF in the program) is useful for expressing subjective probabilities, as discussed previously in the section on "Program operation." Also, by use of some care and cunning, it can be used to gain efficiency without loss of accuracy.
FIGURE 6

PERCENT ERROR IN RISK LEVEL AS FUNCTION OF NUMBER OF INTEGRATION STEPS
As an extreme example, consider the (perhaps unrealistic) source area shown in fig. 7. This might be represented in program input by four quadrilateral sources defined as rectangles.

Alternately, the source could be designated by one gross source representing the perimeter rectangle and a separate gross source (having coefficient equal to minus one) representing the interior rectangle. In effect, the program would subtract the expected number of exceedances due to the second gross source from the number due to the first, to arrive at the expected number from the "real" source as shown in fig. 7. The rates of occurrence of events for the two gross sources must be correctly calculated before input so that the difference is the rate of occurrence for the real source.

Because run time of the program for large problems is directly related to the number of quadrilateral sources, the run time associated with this simple example would be decreased by about a factor of two if the suggested method of input were adopted. Similar efficiencies may be gained by altering seismicities of sections of large source areas by negative strict-lower-bound sources, rather than by defining many small sources, each only for areas having homogeneous seismicity. For small problems (such as analysis
FIGURE 7

HYPOTHETICAL SOURCE AREA

(SHOWN SHADED)
of a single site) the difference in efficiency between two representations of a source area will be slight; in this case ease of input should govern the selection.

"Piecewise linear" frequency-magnitude relations.--The use of truncated exponential distributions on magnitude is abundant in the seismic-risk literature. With the option of defining sources having strict lower bounds, it is tempting to try to fit two or more truncated exponential distributions to nonlinear cumulative histograms of magnitudes (or epicentral intensities) observed for a hypothesized source area and plotted on logarithmic paper.

The problem is that the complementary cumulative distribution function of a truncated exponential distribution does not plot linearly on logarithmic paper, and the complementary cumulative of two truncated exponential distributions is not continuous. Figure 8 shows the plotted complementary cumulative of a magnitude distribution modeled as two truncated exponentials. In fact, choosing a magnitude distribution and estimating parameters for it is tricky; as thoroughly discussed by Cornell, (1974). Whatever method is used, the data should be compared graphically with calculated points from the chosen distribution, to illustrate the degree to which the chosen distribution models observations.
FIGURE 8

COMPLEMENTARY CUMULATIVE OF TRUNCATED EXPONENTIAL DISTRIBUTIONS
(AFTER CORNELL, 1974)
Modeling faults.--Faults may easily be modeled using this program by specifying them as narrow source areas.

For a site 16 km (closest hypocentral distance) from a fault 100 km long, using an attenuation function describing peak ground acceleration, comparison was made between this program and a separate, very accurate (and inefficient) program that integrates over line sources directly. This comparison showed the following:

1. The trade off between accuracy and efficiency is not circumvented by performing the numerical integration of a fault modeled as a line source.

2. For a value of NSTEP equal to 10, the inaccuracy at all levels of intensity (and risk) is about 9 percent in the estimated risk for the fault modeled as an area 0.1 km wide. As expected, the error decreases as distance increases from the source. Hence, this level of inaccuracy for many problems represents a limit on the expectable error, at least for acceleration. This results because (a) most sites will be greater than 16 km from the nearest fault, particularly when non-zero focal depths of events are specified, (b) limits on the attenuation function, that is, variable RONE and equation 14, may erase the effect of distance (and, hence, errors resulting from the method in which
seismicity is assigned as a function of distance) for sites within 16 km of the source, and (c) faults may, in fact, be more accurately modeled by thin sources rather than by lines.

3. The inaccuracy is reduced by increasing the number of integration steps. Using NSTEP=25 decreased errors in estimated risks to 2-3 percent. Interestingly, increasing the width of the source area used to model the fault decreases the error; a source area 2 km wide, using NSTEP=10, results in errors of 2-3 percent in estimated risks.

The tolerable level of inaccuracy ultimately depends on the user. Especially in cases where fault locations are not well known, it may be acceptable to use source areas of 1-2 km wide, using NSTEP=10. For highly accurate risk calculations at sites close to well-located faults, the user should consider very narrow source areas and larger values to NSTEP. This can be achieved easily and efficiently by specifying a large value for NSTEP and modifying the radii in subroutine OUTSID at which NSTEP is decreased (see comment cards in subroutine OUTSID). For sites at 40 km or more hypocentral distance from the modeled fault, errors in estimated risk, using a narrow source area (0.1 km wide) and NSTEP=10, are generally 1 percent or less.
Use of annual risks.--The calculation of risks for any time period from the annual risks output by this program is simple. Assuming the risks in successive years are independent, the risk $R_N$ for a lifetime of $N$ years is obtained from the annual risk $R_A$ by the equation

$$R_N = 1 - (1 - R_A)^N$$

which can be inverted to calculate the annual risk corresponding to a risk $R_N$ in $N$ years.

Alternately, the activity rates specified for the source areas may be the number of events in $N$ years, in which case the program outputs risks for $N$ years corresponding to the intensities specified and assumes that the risks input (for which intensities are desired) are for $N$ years.
Example problem

Input and output from an example problem demonstrating use of the program is given in the section on "Example problem input and output." The source areas used are shown in fig. 9, and parameter values describing these source areas are listed in table 2. The intensity parameter is peak ground acceleration (in gals), and values for the attenuation equation parameters are listed in table 3.

Gross-source 1 represents a general source area within which seismic events are not associated with a well-defined tectonic structure. Gross-source 2 represents a fault zone 1 km wide. Gross-source 3, having a source coefficient of -1, is used to represent an area which is considered aseismic; hence, this "negative" source is used to negate the background seismicity observed elsewhere in the region and specified as background seismicity in the program input.

C.P.U. time for this particular problem is approximately 14 seconds on a DEC-10 computer. Doubling the value of NSTEP (to 20) increases the run time to 26 seconds. Halving the list of examined intensities (to four) and specifying NSTEP=10 decreases the run time to 8 seconds.
GROSS SOURCE 1

GROSS SOURCE 2

GROSS SOURCE 3

SITES INVESTIGATED

FIGURE 9

SOURCE AREAS AND SITES
IN EXAMPLE PROBLEM
### Table 2. -- Source-area parameter values in example.

<table>
<thead>
<tr>
<th>LORS(i)</th>
<th>COEF(i)</th>
<th>AMO(i)</th>
<th>AM1(i)</th>
<th>BETA(i)</th>
<th>RATE(i)</th>
<th>FDEPTH(i)</th>
</tr>
</thead>
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<tr>
<td>Gross source:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-------</td>
<td>0</td>
<td>1.0</td>
<td>5.0</td>
<td>6.0</td>
<td>2.03</td>
<td>0.05</td>
</tr>
<tr>
<td>2-------</td>
<td>0</td>
<td>1.0</td>
<td>5.0</td>
<td>7.5</td>
<td>2.03</td>
<td>0.10</td>
</tr>
<tr>
<td>3-------</td>
<td>0</td>
<td>-1.0</td>
<td>4.0</td>
<td>5.0</td>
<td>2.03</td>
<td>0.10</td>
</tr>
<tr>
<td>Background</td>
<td>0</td>
<td>1.0</td>
<td>4.0</td>
<td>5.0</td>
<td>2.03</td>
<td>0.40</td>
</tr>
</tbody>
</table>

### Table 3. -- Attenuation-function parameter values in example.

<table>
<thead>
<tr>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl</td>
</tr>
<tr>
<td>6.16</td>
</tr>
</tbody>
</table>
References cited


Appendix A, Derivation of equation 11

An observation of I is given by

\[ I = c_1 + c_2 M + c_3 \ln R' + \epsilon \]  

(18)

where \( R' = R + r_0 \) and \( \epsilon \) is a normally distributed variable with mean zero and standard derivation \( \sigma_I \). The cumulative distribution for magnitude is given by equation 7:

\[ F_m(m) = k\left[1 - \exp(-\beta(m-m_0))\right] \quad m_0 < m < m_1 \]  

(19)

where constants have been previously defined. Equation 10, written in the following form:

\[ P[I > i] = \int \int \frac{i-M}{\sigma_I} \quad f_m(m)f_R(r)dm dr \]  

(20)

can be rewritten as:

\[ P[I > i] = \int \int P[M > c_2 (i - c_1 - c_3 \ln R' - \epsilon)|\epsilon, r] \quad f_\epsilon(\epsilon)f_R(r)d\epsilon dr \]  

(21)

For a given value of \( i \) there are two important values of \( \epsilon \), defined by the upper and lower magnitudes:

\[ z = i - c_1 - c_2 m_1 - c_3 \ln R' \]

\[ z' = i - c_1 - c_2 m_0 - c_3 \ln R' \]  

(22)

These two values define three ranges for \( \epsilon \):

1. \(-\infty < \epsilon < z\), in which case

\[ P[M > c_2 (i - c_1 - c_3 \ln R' - \epsilon)|\epsilon, r] = 0 \]
2. \( z < e < z' \), in which case
\[
P[M > c_2 | i - c_1 - c_3 \ln R' - e | e, r] \] can be evaluated by
(the complement of) equation 19

3. \( z < e < \infty \), in which case
\[
P[M > c_2 (i - c_1 - c_3 \ln R' - e | e, r)] = 1
\]
Substituting these and the normal density function on \( e \) into
equation 21 gives

\[
P[I > i] = \int \int (1 - k + k \exp(-\beta(m* - m_0))) \frac{1}{\sqrt{2\pi}} \frac{-\varepsilon^2}{2\sigma^2} d\varepsilon
\]
\[
+ \phi*(z'/\sigma) \] \( f_R(r) dr \) (23)

where

\[
m* = c_2 (i = c_1 - c_3 \ln R' - e) \] (24)

and \( \phi* \) is the complementary cumulative of the standardized
normal distribution. Substituting 24 into 23 and using the
substitution \( \zeta = e - \frac{\beta \sigma^2}{c_2} \), the integral on \( e \) in equation 23
can be transformed into the form of an integral on the
standardized normal distribution, yielding the result

\[
P[I > i] = \int \{ (1-k) \phi* (z/\sigma) + k \phi* (z'/\sigma) \]
\[
+ k (R') \exp \left( - \frac{i \beta}{c_2} + \frac{\beta c_1}{c_2} + \beta m_0 + \frac{\beta^2 \sigma^2}{2c_2} \cdot \right)
\]
\[
\left[ \phi* \left( \frac{z - \beta \sigma^2/c_2}{\sigma_I} \right) - \phi* \left( \frac{z' - \beta \sigma^2/c_2}{\sigma_I} \right) \right] \]
\[
f_R(r) dr \] (25)
APPENDIX B

EXAMPLE PROBLEM INPUT AND OUTPUT
EXAMPLE PROBLEM OF SEISMIC RISK ANALYSIS FOR PEAK GROUND ACCELERATION.

<table>
<thead>
<tr>
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<th>0</th>
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</thead>
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<td></td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>0.02 0.01 0.005</td>
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<td>0.645 -1.30 0.511 25. 0.0 100000. 0.</td>
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<td>5 2 1</td>
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<td></td>
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<tr>
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<td>1.0 5.0 6.0 2.03 0.05 10.</td>
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<td></td>
</tr>
<tr>
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<td>1.0 5.0 7.5 2.03 0.10 10.</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>-1.0 4.0 5.0 2.03 0.1 10.</td>
<td></td>
<td></td>
</tr>
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<td>0</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>15.</td>
<td>15. 45. 10.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15.</td>
<td>30. 45. 45.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>65. 30. 60.</td>
<td></td>
<td></td>
</tr>
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<td>100. 45. 110.</td>
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<td></td>
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<td>15.</td>
<td>130. 60. 145.</td>
<td></td>
<td></td>
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<td>25.</td>
<td>155. 45. 155.</td>
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<td></td>
</tr>
<tr>
<td>30.</td>
<td>20. 31. 20.</td>
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<td>15.</td>
<td>65. 16. 65.</td>
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<td>35.</td>
<td>145. 36. 145.</td>
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<td>75.</td>
<td>105. 125. 105.</td>
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<tr>
<td>75.</td>
<td>155. 125. 155.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2 5.0 40. 20. 15.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1 70. 85.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1 95. 125.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**EXAMPLE PROBLEM OF SEISMIC RISK ANALYSIS FOR PEAK GROUND ACCELERATION.**

\[ \text{NSTEP} = 10 \quad \text{JCALC} = 0 \quad \text{JPRNT} = 1 \]

**LIST OF EXAMINED INTENSITIES**

<table>
<thead>
<tr>
<th>Intensity</th>
<th>3.91</th>
<th>4.61</th>
<th>5.01</th>
<th>5.30</th>
<th>5.52</th>
<th>5.70</th>
<th>5.99</th>
<th>6.21</th>
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</thead>
</table>

**RISKS DESIRED**

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<tr>
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<th>0.0200</th>
<th>0.0100</th>
<th>0.0050</th>
<th>0.0000</th>
<th>0.0000</th>
<th>0.0000</th>
<th>0.0000</th>
</tr>
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</table>

**ATTENUATION DATA:**

\[
\begin{align*}
C_1 &= 6.16 \\
C_2 &= 0.65 \\
C_3 &= -1.30 \\
\sigma &= 0.51 \\
\end{align*}
\]

**NO. OF GROSS SOURCES**

<table>
<thead>
<tr>
<th>Source</th>
<th>L/S</th>
<th>COEF</th>
<th>MO</th>
<th>MI</th>
<th>BETA</th>
<th>RATE/YR</th>
<th>FDEPTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1.00</td>
<td>5.00</td>
<td>6.00</td>
<td>2.0300</td>
<td>0.0500</td>
<td>10.0000</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1.00</td>
<td>5.00</td>
<td>7.50</td>
<td>2.0300</td>
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<td>3</td>
<td>0</td>
<td>-1.00</td>
<td>4.00</td>
<td>5.00</td>
<td>2.0300</td>
<td>0.1000</td>
<td>10.0000</td>
</tr>
<tr>
<td>(BACKGROUND)</td>
<td>0</td>
<td>1.00</td>
<td>4.00</td>
<td>5.00</td>
<td>2.0300</td>
<td>0.4000</td>
<td>10.0000</td>
</tr>
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</table>

**GROSS SOURCE 1 SUBSOURCE COORDINATE DATA**

\[
\begin{align*}
\text{MO} &= 5.00 \\
\text{MI} &= 6.00 \\
\text{BETA} &= 2.0300 \\
\text{RATE/YR} &= 0.0500 \\
\text{FDEPTH} &= 10.0000 \\
\end{align*}
\]

**GROSS SOURCE 2 SUBSOURCE COORDINATE DATA**

\[
\begin{align*}
\text{MO} &= 5.00 \\
\text{MI} &= 7.50 \\
\text{BETA} &= 2.0300 \\
\text{RATE/YR} &= 0.1000 \\
\text{FDEPTH} &= 10.0000 \\
\end{align*}
\]

**GROSS SOURCE 3 SUBSOURCE COORDINATE DATA**

\[
\begin{align*}
\text{MO} &= 4.00 \\
\text{MI} &= 5.00 \\
\text{BETA} &= 2.0300 \\
\text{RATE/YR} &= 0.1000 \\
\text{FDEPTH} &= 10.0000 \\
\end{align*}
\]

**RESULTS FOR BACKGROUND SEISMICITY**

<table>
<thead>
<tr>
<th>Intensity</th>
<th>3.91</th>
<th>4.61</th>
<th>5.01</th>
<th>5.30</th>
<th>5.52</th>
<th>5.70</th>
<th>5.99</th>
<th>6.21</th>
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</table>

**ANTILOG(INTENSITY):**

<table>
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<tr>
<th>Intensity</th>
<th>49.90</th>
<th>100.48</th>
<th>149.90</th>
<th>200.34</th>
<th>249.64</th>
<th>298.87</th>
<th>399.41</th>
<th>497.70</th>
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**(BACKGROUND) E(NO/YR):**

<table>
<thead>
<tr>
<th>Intensity</th>
<th>0.469E+00</th>
<th>0.331E-01</th>
<th>0.572E-02</th>
<th>0.136E-02</th>
<th>0.411E-03</th>
<th>0.142E-03</th>
<th>0.216E-04</th>
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64
### RESULTS FOR SITE LOCATION

<table>
<thead>
<tr>
<th>5.00</th>
<th>40.00</th>
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<tbody>
<tr>
<td><strong>INTENSITY:</strong></td>
<td>3.91</td>
</tr>
<tr>
<td><strong>ANTILOG(INTENSITY):</strong></td>
<td>4.90</td>
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<tr>
<td><strong>SOURCE 1 1 E(NO/YR):</strong></td>
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<tr>
<td><strong>SOURCE 1 2 E(NO/YR):</strong></td>
<td>.147E+00</td>
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<tr>
<td><strong>SOURCE 1 3 E(NO/YR):</strong></td>
<td>.479E-01</td>
</tr>
<tr>
<td><strong>SOURCE 1 4 E(NO/YR):</strong></td>
<td>.597E-02</td>
</tr>
<tr>
<td><strong>SOURCE 1 5 E(NO/YR):</strong></td>
<td>.118E-02</td>
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</tbody>
</table>

**CAUTION:** NUMERICAL INTEGRATION ERROR IN AREA IS 9.

### RESULTS FOR SITE LOCATION

<table>
<thead>
<tr>
<th>25.00</th>
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### RESULTS FOR SITE LOCATION

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<tr>
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</tr>
<tr>
<td><strong>ANTILOG(INTENSITY):</strong></td>
<td>4.90</td>
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<tr>
<td><strong>SOURCE 1 1 E(NO/YR):</strong></td>
<td>.756E-01</td>
</tr>
<tr>
<td><strong>SOURCE 1 2 E(NO/YR):</strong></td>
<td>.147E+00</td>
</tr>
<tr>
<td><strong>SOURCE 1 3 E(NO/YR):</strong></td>
<td>.479E-01</td>
</tr>
<tr>
<td><strong>SOURCE 1 4 E(NO/YR):</strong></td>
<td>.597E-02</td>
</tr>
<tr>
<td><strong>SOURCE 1 5 E(NO/YR):</strong></td>
<td>.118E-02</td>
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</table>

**CAUTION:** NUMERICAL INTEGRATION ERROR IN AREA IS 9.
### RESULTS FOR SITE LOCATION

#### RESULTS FOR SITE LOCATION

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<th>INTENSITY</th>
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<th>40.00</th>
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</thead>
<tbody>
<tr>
<td>ANTILOG(1200)</td>
<td>3.91</td>
<td>4.61</td>
</tr>
<tr>
<td>SOURCE 1 E(NO/yr)</td>
<td>0.174E+00</td>
<td>0.157E-03</td>
</tr>
<tr>
<td>SOURCE 1 E(NO/yr)</td>
<td>0.134E+00</td>
<td>0.113E-02</td>
</tr>
<tr>
<td>SOURCE 1 E(NO/yr)</td>
<td>0.403E-01</td>
<td>0.179E-03</td>
</tr>
<tr>
<td>SOURCE 1 E(NO/yr)</td>
<td>0.673E-02</td>
<td>0.823E-03</td>
</tr>
<tr>
<td>SOURCE 1 E(NO/yr)</td>
<td>0.134E-02</td>
<td>0.121E-06</td>
</tr>
<tr>
<td>CAUTION: NUMERICAL INTEGRATION ERROR IN AREA IS 15.94% FOR (OUTSIDE) SOURCE 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOURCE 2 E(NO/yr)</td>
<td>0.415E+00</td>
<td>0.501E-01</td>
</tr>
<tr>
<td>SOURCE 2 E(NO/yr)</td>
<td>0.895E-01</td>
<td>0.308E-03</td>
</tr>
<tr>
<td>SOURCE 2 E(NO/yr)</td>
<td>-0.132E-02</td>
<td>-0.213E-04</td>
</tr>
<tr>
<td>(BACKGROUND) E(NO/yr)</td>
<td>0.469E+00</td>
<td>0.136E-02</td>
</tr>
<tr>
<td>ALL SOURCES E(NO/yr)</td>
<td>0.133E+01</td>
<td>0.102E-01</td>
</tr>
<tr>
<td>ALL SOURCES RISK</td>
<td>0.735E+00</td>
<td>0.101E-01</td>
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</table>

<table>
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<td>0.166E-02</td>
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<tr>
<td>SOURCE 1 E(NO/yr)</td>
<td>0.114E+00</td>
<td>0.230E-03</td>
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<td>SOURCE 1 E(NO/yr)</td>
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<td>0.115E-03</td>
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<td>SOURCE 1 E(NO/yr)</td>
<td>0.210E-02</td>
<td>0.127E-05</td>
</tr>
<tr>
<td>SOURCE 2 E(NO/yr)</td>
<td>0.528E+00</td>
<td>0.581E-01</td>
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<tr>
<td>SOURCE 2 E(NO/yr)</td>
<td>-0.192E-01</td>
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<tr>
<td>SOURCE 3 E(NO/yr)</td>
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<tr>
<td>SOURCE 1 E(NO/yr)</td>
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<tr>
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<tr>
<td>SOURCE 2 E(NO/yr)</td>
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<td>0.846E-02</td>
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<tr>
<td>SOURCE 3 E(NO/yr)</td>
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<td>-0.285E-03</td>
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<tr>
<td>(BACKGROUND) E(NO/yr)</td>
<td>0.469E+00</td>
<td>0.331E-01</td>
</tr>
<tr>
<td>ALL SOURCES E(NO/yr)</td>
<td>0.163E+01</td>
<td>0.391E-01</td>
</tr>
<tr>
<td>ALL SOURCES RISK</td>
<td>0.804E+00</td>
<td>0.384E-02</td>
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</tbody>
</table>

| RISKS | 0.100000 0.020000 0.010000 0.005000 |
| INTENSITY | 4.66 | 5.11 |
| ANTILOG(1200) | 0.735E+00 | 0.117E+00 |

### RESULTS FOR SITE LOCATION

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<tr>
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<td>SOURCE 1 E(NO/yr)</td>
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<td>-0.488E-02</td>
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| RISKS | 0.100000 0.020000 0.010000 0.005000 |
| INTENSITY | 4.66 | 5.11 |
| ANTILOG(1200) | 0.735E+00 | 0.117E+00 |
### RESULTS FOR SITE LOCATION

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RISKS:

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### RESULTS FOR SITE LOCATION

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RISKS:

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### RESULTS FOR SITE LOCATION

#### 70.00

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**CAUTION:** NUMERICAL INTEGRATION ERROR IN AREA IS 14.68% FOR (OUTSIDE) SOURCE 1

**SOURCE 2** E(NO/HR) | .424E-01 | .449E-02 | .116E-02 | .397E-03 | .164E-03 | .748E-04 | .183E-04 | .351E-05 |

**CAUTION:** NUMERICAL INTEGRATION ERROR IN AREA IS 7.20% FOR (OUTSIDE) SOURCE 2

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### RESULTS FOR SITE LOCATION

#### 95.00

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**CAUTION:** NUMERICAL INTEGRATION ERROR IN AREA IS 8.31% FOR (OUTSIDE) SOURCE 2

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### RESULTS FOR SITE LOCATION

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**END OF JOB**
APPENDIX C

PROGRAM LISTING
MAINROUTINE
R K MCGUIRE  U.S.G.S. JANUARY 1975
PLANAR VERSION (CARTESIAN COORDINATES)

INTERNAL SOURCE AREA SIDE AND CORNER NOTATION FOLLOWS......

SIDE 4
(X3,Y3)------------------(X4,Y4)

SIDE 3
(X1,Y1)------------------(X2,Y2)

SIDE 1

COMMON NRD,NWR,NLEI,TI(12),RSKTI(12)
COMMON C1,C2,C3,SIG,RZERO, RONE,AAA, BBB
COMMON NGS,NRS(10),AMO(11),AML(11),LORS(11)
COMMON BETA(11),RATE(11),COEF(11),FDEPTH(11)
COMMON NSTEPO,NSTEPI, JCALC,JPRNT
COMMON INDIC(4), AREA(10,11),X(10,11,2),Y(10,11,2)
DIMENSION TITLE(20)
DIMENSION RISKS(9),ATI(12),BRISK(12),TIF(8)

TO MODIFY LIMITS AS STATED IN PROGRAM DOCUMENTATION, CHANGE
COMMON DIMENSION STATEMENTS IN MAIN PROGRAM AND SUBROUTINES
FOLLOWS:

(1) TO CHANGE MAX. NO. OF GROSS SOURCES (PRESENTLY 10):
   (A) CHANGE ALL 10' S TO NEW MAX.
   (B) CHANGE ALL 11'S IN SINGLE DIMENSION ARRAYS TO
       NEW MAXIMUM + 1.

(2) TO CHANGE MAX. NO. OF SUBSOURCES IN EACH GROSS SOURCE
   (PRESENTLY 10):
   (A) CHANGE ALL 11'S IN DOUBLE- AND TRIPLE-DIENSION ARRAYS
       TO NEW MAXIMUM + 1.

(3) TO CHANGE MAX. NO. IN THE LIST OF EXAMINED INTENSITIES
   (PRESENTLY 12):
   (A) CHANGE ALL 12'S TO NEW MAXIMUM.

(4) TO CHANGE MAX. NO. OF INPUT RISK LEVELS (PRESENTLY 8):
   (A) CHANGE 9 TO NEW MAX. + 1
   (B) CHANGE STATEMENT BELOW: 'RISKS(9)=0.0'
       TO 'RISKS(NEW MAX. + 1) = 0.0'.

NRD = 5
NWR = 6

READ TITLE
READ (NRD,900) (TITLE(I),I=1,20)
FORMAT (20A4)
WRITE (NWR,910) (TITLE(I),I=1,20)
FORMAT (10X,20A4)
READ STEP SIZE AND SWITCH VALUES.
READ (NRD,921) NSTEP,JCALC,JPRNT
WRITE (NWR,922) NSTEP,JCALC,JPRNT
C
C NSTEPO IS STEP SIZE USED WHEN SITE IS OUTSIDE
(CUADRILATERAL) SOURCE BEING CONSIDERED.
C NSTEPI IS STEP SIZE USED WHEN SITE IS INSIDE
(CUADRILATERAL) SOURCE BEING CONSIDERED.
C
NSTEPO=NSTEP
NSTEPI=NSTEP
C
READ NUMBER AND LIST OF EXAMINED INTENSITIES.
READ (NRD,901) NLEI,(TI(I),I=1,NLEI)
WRITE (NWR,902) (TI(I),I=1,NLEI)
FORMAT (/, LIST OF EXAMINED INTENSITIES ',12F5.3)
901
902

READ LIFETIME AND RISKS DESIRED.
READ (NRD,903) (RISKS(I),I=1,8)
WRITE (NWR,919) (RISKS(I),I=1,8)
FORMAT (/ RISKS DESIRED ',8F8.4)
919
919
C
READ ATTENUATION DATA
READ (NRD,920) C1,C2,C3,SIG,RZERO, RONE,AAA,BBB
WRITE (NWR,905) C1,C2,C3,SIG,RZERO, RONE,AAA,BBB
FORMAT (/, ATTENUATION DATA: C1 C2 C3
1, 'SIGMA RZERO RONE AAA BBB',/16X,8F8.2)
905
905
IF (BBB+0.00001) 101,102,102
101
101
GO TO 890
102

IF (C2-BBB) 101,103,103
103
103
IF (BBB-0.00001) 104,105,105
104
104
BBB=0.0000000001
908
908

READ SOURCE DATA
READ (NRD,906) NGS,(NRS(I),I=1,NGS)
WRITE (NWR,907) NGS,(NRS(I),I=1,NGS)
FORMAT (/, NO. OF GROSS SOURCES ',16I5)
907
907

WRITE (NWR,918)
FORMAT (/, GROSS SOURCE L/S',5X,'COEF',7X,
1'MO',8X,'MI',6X,'BETA',5X,'RATE/YR',3X,'FDEPTH')
918
918
MGS1=NGS+1
104
104
DO 110 I=1,NGS1
110
110
READ (NRD,904) LORS(I),COEF(I),AMO(I),AM1(I),BETA(I),RATE(I),
FDEPTH(I)
105
105
FORMAT (I10,6F10.2)
110
110
IF (I-NGS1) 110,120,120
120
120
WRITE (NWR,908) I,LORS(I),COEF(I),AMO(I),AM1(I),BETA(I),RATE(I),
1 FDEPTH(I)
109
109

0111 908 FORMAT (1X,I7,3X,I7,3F10.2,3F10.4)
0112 C WRITE BACKGROUND SEISMICITY
0113 120 WRITE (NWR,925) LORS(I),COEF(I),AMO(I),AMI(I),BETA(I),RATE(I),
0114 1 FDEPTH(I)
0115 925 FORMAT(1X,9F10.4)
0116 DO 200 II=1,NGS
0117 NRSII=NRS(II)+1
0118 DO 150 JJ=1,NRSII
0119 READ (NRD,903) X(II,JJ,1),Y(II,JJ,1),X(II,JJ,2),Y(II,JJ,2)
0120 WRITE (NWR,909) II,X(II,JJ,1),Y(II,JJ,1),X(II,JJ,2),Y(II,JJ,2)
0121 909 FORMAT(13X,'GROSS SOURCE',13,' SUBSOURCE COORDINATE DATA ',4F10.2)
0122 150 CONTINUE
0123 200 WRITE (NWR,932)
0124 932 FORMAT(IX)
0125 C CALCULATE AREA OF EACH SUBSOURCE AND GROSS SOURCE.
0126 C IF ARRAYS X( ) AND Y( ) CONTAIN LONGITUDE
0127 C AND LATITUDE, CHANGE SUBROUTINE 'AREAS' TO
0128 C CALCULATE CORRECT AREAS USING THESE PARAMETERS.
0129 C SEE ALSO REQUIRED CHANGES BELOW.
0130 DO 400 II=1,NGS
0131 NTOT=NRS(II)+1
0132 AREA(II,NTOT)=0.0
0133 DO 300 JJ=1,NRS(II)
0134 CALL AREAS(X(II,JJ,1),Y(II,JJ,1),X(II,JJ,2),Y(II,JJ,2),
0135 1 X(II,JJ+1,1),Y(II,JJ+1,1),X(II,JJ+1,2),Y(II,JJ+1,2),AREA(II,JJ)
0136 WRITE (NWR,911) II,JJ, AREA(II,JJ)
0137 911 FORMAT(13X,'GROSS SOURCE',13,' SUBSOURCE',13,' EXACT AREA',F10.1)
0138 300 AREA(II,NTOT)=AREA(II,NTOT)+AREA(II,JJ)
0139 400 WRITE (NWR,913) II,AREA(II,NTOT)
0140 913 FORMAT(13X,'GROSS SOURCE',13,' TOTAL AREA',F10.1)
0141 C COMPUTE BACKGROUND SEISMICITY
0142 IF(RATE(NGS1)-0.0000000001) 420,420,405
0143 405 RBACK=150.
0144 C FOR BACKGROUND SEISMICITY, NSTEPI IS DOUBLED (AND
0145 C THEN HALVED AFTER CALCULATIONS).
0146 420 NSTEPI=2*NSTEPI
0147 CALL CIRCLE(RBACK,NGS1,1.,BRISK)
0148 NSTEPI=NSTEPI/2
0149 DO 410 I=1,NLEI
0150 410 BRISK(I)=COEF(NGS1)*BRISK(I)/10000.
0151 CALL CIRCLE(RBACK,1.,(ATI(I),I=1,NLEI)
0152 926 FORMAT(13X,'RESULTS FOR BACKGROUND SEISMICITY)',13X,'INTENSITY:
0153 1 F7.2,11(2X,F7.2))
0154 WRITE(NWR,923)(ATI(I),I=1,NLEI)
0155 WRITE(NWR,927)(BRISK(I),I=1,NLEI)
0156 927 FORMAT(13X,'BACKGROUND'),E(112E9.3)
0157 C LOOP ON SETS OF SITES FOR ANALYSIS
0158 420 READ (NRD,914) NX,NY,XZERO,YZERO,XDELTA,YDELTA
0159 914 FORMAT (2I5,4F10.2)
0160 430 IF (NX) 850,850,430
0161 850 DO 800 IY=1,NY
0162 YNOT=YZERO+(IY-1)*YDELTA
0163 800 WRITE(NWR,914) IX,YNOT
0164 DO 700 IX=1,NX
0165 700 WRITE(NWR,914) IX,YNOT
0166 440 WRITE(NWR,914) IX,YNOT
0167 450 DO 800 IY=1,NY
0168 YNOT=YZERO+(IY-1)*YDELTA
0169 800 WRITE(NWR,914) IX,YNOT
0170 460 WRITE(NWR,914) IX,YNOT
0171 470 DO 800 IY=1,NY
0172 YNOT=YZERO+(IY-1)*YDELTA
0173 800 WRITE(NWR,914) IX,YNOT
0174 480 WRITE(NWR,914) IX,YNOT
0175 490 DO 800 IY=1,NY
0176 YNOT=YZERO+(IY-1)*YDELTA
0177 800 WRITE(NWR,914) IX,YNOT
0178 500 WRITE(NWR,914) IX,YNOT
0179 510 DO 800 IY=1,NY
0180 YNOT=YZERO+(IY-1)*YDELTA
0181 800 WRITE(NWR,914) IX,YNOT
0182 520 WRITE(NWR,914) IX,YNOT
0183 530 DO 800 IY=1,NY
0184 YNOT=YZERO+(IY-1)*YDELTA
0185 800 WRITE(NWR,914) IX,YNOT
0186 540 WRITE(NWR,914) IX,YNOT
0187 550 DO 800 IY=1,NY
0188 YNOT=YZERO+(IY-1)*YDELTA
0189 800 WRITE(NWR,914) IX,YNOT
0190 560 WRITE(NWR,914) IX,YNOT
0191 570 DO 800 IY=1,NY
0192 YNOT=YZERO+(IY-1)*YDELTA
0193 800 WRITE(NWR,914) IX,YNOT
0194 580 WRITE(NWR,914) IX,YNOT
0195 590 DO 800 IY=1,NY
0196 YNOT=YZERO+(IY-1)*YDELTA
0197 800 WRITE(NWR,914) IX,YNOT
0198 600 WRITE(NWR,914) IX,YNOT
0199 610 DO 800 IY=1,NY
0200 YNOT=YZERO+(IY-1)*YDELTA
0201 800 WRITE(NWR,914) IX,YNOT
0202 620 WRITE(NWR,914) IX,YNOT
0203 630 DO 800 IY=1,NY
0204 YNOT=YZERO+(IY-1)*YDELTA
0205 800 WRITE(NWR,914) IX,YNOT
0206 640 WRITE(NWR,914) IX,YNOT
0207 650 DO 800 IY=1,NY
0208 YNOT=YZERO+(IY-1)*YDELTA
0209 800 WRITE(NWR,914) IX,YNOT
0210 660 WRITE(NWR,914) IX,YNOT
0211 670 DO 800 IY=1,NY
0212 YNOT=YZERO+(IY-1)*YDELTA
0213 800 WRITE(NWR,914) IX,YNOT
0214 680 WRITE(NWR,914) IX,YNOT
0215 690 DO 800 IY=1,NY
0216 YNOT=YZERO+(IY-1)*YDELTA
0217 800 WRITE(NWR,914) IX,YNOT
0218 700 WRITE(NWR,914) IX,YNOT
0219 710 DO 800 IY=1,NY
0220 YNOT=YZERO+(IY-1)*YDELTA
0221 800 WRITE(NWR,914) IX,YNOT
0222 720 WRITE(NWR,914) IX,YNOT
0223 730 DO 800 IY=1,NY
0224 YNOT=YZERO+(IY-1)*YDELTA
0225 800 WRITE(NWR,914) IX,YNOT
0226 740 WRITE(NWR,914) IX,YNOT
0227 750 DO 800 IY=1,NY
0228 YNOT=YZERO+(IY-1)*YDELTA
0229 800 WRITE(NWR,914) IX,YNOT
0230 760 WRITE(NWR,914) IX,YNOT
0231 770 DO 800 IY=1,NY
0232 YNOT=YZERO+(IY-1)*YDELTA
0233 800 WRITE(NWR,914) IX,YNOT
0234 780 WRITE(NWR,914) IX,YNOT
0235 790 DO 800 IY=1,NY
0236 YNOT=YZERO+(IY-1)*YDELTA
0237 800 WRITE(NWR,914) IX,YNOT
0238 800 CONTINUE
XNOT = XZERO + (IX - 1) * XDELTA

DO 450 I = 1, NLEI

RSKTI(I) = BRISK(I)

WRITE (NWR, 915) XNOT, YNOT, (TI(I), I = 1, NLEI)

FORMAT (' RESULTS FOR SITE LOCATION ', 2F10.2)

1 /13X, 'INTENSITY: ' , F7.2, 11(2X, F7.2))

WRITE (NWR, 923) (ATI(I), I = 1, NLEI)

FORMAT (' ANTILOG (INTENSITY): ', F7.2, 11(2X, F7.2))

DO 600 II = 1, NGS

DO 500 JJ = 1, NRS(II)

INGS = II

INSS = JJ

C IF THE USER WISHES THIS PROGRAM TO WORK ON LONGITUDE AND
C LATITUDE COORDINATES, SIMPLY INPUT THESE COORDINATES AS IN T
C CARTESIAN CASE; AT THIS POINT CALCULATE (IN UNITS
C CONSISTENT WITH THE ATTENUATION FUNCTION) THE CARTESIAN
C LOCATION OF X(II, JJ, 1), Y(II, JJ, 1) WITH RESPECT TO XNOT, YNOT,
C AND SIMILARLY WITH THE OTHER 3 POINTS DESCRIBING THE SOURCE
C AREA UNDER CONSIDERATION, AND PLACE THESE CALCULATED CARTESI
C COORDINATES IN THE ARGUMENT LIST OF THE FOLLOWING CALL STATE
C MENT (WITH XNOT AND YNOT AS THE ORIGIN, I.E. (0.0, 0.0)).
C SEE ALSO CHANGES REQUIRED ABOVE FOR SUBROUTINE 'AREAS'.

CALL RRISK(XNOT, YNOT, INGS, INSS, X(II, JJ, 1), Y(II, JJ, 1), X(II, JJ, 2), Y(II, JJ, 2), X(II, JJ + 1, 1), Y(II, JJ + 1, 1), X(II, JJ + 1, 2), Y(II, JJ + 1, 2)

CONTINUE

CONTINUE

IF (JPRNT) 615, 615, 610

WRITE (NWR, 927) (BRISK(I), I = 1, NLEI)

WRITE (NWR, 916) (RSKTI(I), I = 1, NLEI)

FORMAT (' ALL SOURCES E(NO/YR): ', 12E9.3)

DO 620 I = 1, NLEI

RSKTI(I) = 1. - EXP(-RSKTI(I))

WRITE (NWR, 931) (RSKTI(I), I = 1, NLEI)

FORMAT (' ALL SOURCES RISK: ', 12E9.3)

ESTIMATE INTENSITIES AT RISKS DESIRED.

RISKS(9) = 0.0

IA = 0

IF (RISKS(1) - 0.0000000001) 700, 700, 625

DO 630 IRK = 1, 8

IF (RISKS(IRA) = RSKTI(1)) 640, 640, 630

TIF(IRA) = 1000000.

GO TO 700

IF (IA = NLEI) 650, 645, 645

TIF(IRA) = 1000000.

IRK = IRA + 1

IF (RISKS(IRA) = 0.00000000001) 680, 680, 645

IF (RISKS(IRA) = RSKTI(IA + 1)) 640, 655, 655

TIF(IRA) = (ALOG(RSKTI(IA)/RISKS(IRA)))

1 /(ALOG(RSKTI(IA)/RISKTI(IA + 1)))

TIF(IRA) = TIF(IA) + TIF(IRA) * (TIF(IA + 1) - TIF(IA))

IRK = IRA + 1

IF (RISKS(IRA) = 0.00000000001) 680, 680, 660

IF (RISKS(IRA) = RSKTI(IA + 1)) 640, 655, 655

IRK = IRA - 1
SUBROUTINE RRISK(XNOT, YNOT, INGS, INSS,
1 XI, Y1, X2, Y2, X3, Y3, X4, Y4)
COMMON NRD, NWR, NLEI, TI(12), RSKTI(12)
COMMON C1, C2, C3, SIG, RZERO, RONE, AAA, BBB
COMMON NGS, NRS(10), AMO(11), AMI(11), LORS(11)
COMMON BETA(11), RATE(11), COEF(11), FDEPTH(11)
COMMON NSTEPO, NSTEPI, JCALC, JPRNT
COMMON INDIC(4), AREA(10, 11)
DIMENSION XL(4), YL(4), XR(4), YR(4), AA(4), BB(4)
PUBLIC NRD, NWR, NLEI, TI(12), RSKTI(12)
COMMON NRD, NWR, NLEI, TI(12), RSKTI(12)
COMMON C1, C2, C3, SIG, RZERO, RONE, AAA, BBB
COMMON NGS, NRS(10), AMO(11), AMI(11), LORS(11)
COMMON BETA(11), RATE(11), COEF(11), FDEPTH(11)
COMMON NSTEPO, NSTEPI, JCALC, JPRNT
COMMON INDIC(4), AREA(10, 11)
DIMENSION XL(4), YL(4), XR(4), YR(4), AA(4), BB(4)
EXTERNAL WHICH

XL(1) = X1
YL(1) = Y1
XR(1) = X2
YR(1) = Y2
XL(2) = X2
YL(2) = Y2
XR(2) = X4
YR(2) = Y4
XL(3) = X3
YL(3) = Y3
XR(3) = X1
YR(3) = Y1
XL(4) = X4
YL(4) = Y4
XR(4) = X3
YR(4) = Y3

C DETERMINE IF ANY SIDES ARE VERTICAL LINES
DO 200 II = 1, 4
DIF = XL(II) - XR(II)
IF (DIF) 140, 180, 160
IF (DIF + 0.01) 190, 190, 180
IF (DIF - 0.01) 180, 190, 190
INDIC(II) = 1 IMPLIES NOT A VERTICAL LINE
INDIC(II) = 2 IMPLIES A VERTICAL LINE (INFINITE SLOPE).
30037  180  INDIC(II)=2
30038  AA(II)=0.
30039  BB(II)=0.
30040  GO TO 200
30041  190  INDIC(II)=1
30042  AA(II)=(YR(II)-YL(II))/(XL(II)-XR(II))
30043  BB(II)=YL(II)-AA(II)*XL(II)
30044  C  AA(II) IS SLOPE OF II' TH SIDE
30045  C  BB(II) IS INTERCEPT OF II' TH SIDE
30046  200  CONTINUE
30047  C  DETERMINE IF SITE IS INSIDE SOURCE AREA.
30048  DO 220  II=1,4
30049       IJ=5-II
30050  GO TO (210,215),INDIC(II)
30051  210  DIFNOT=YNOT-AA(II)*XNOT-BB(II)
30052  DIF=YL(IJ)-AA(II)*XL(IJ)-BB(II)
30053  211  IF (DIF) 214,214,212
30054  212  IF (DIFNOT) 400,400,220
30055  214  IF (DIF) 220,400,400
30056  215  DIF=XL(IJ)-XL(II)
30057  DIFNOT=XNOT-XL(II)
30058  GO TO 211
30059  220  CONTINUE
30060  C  IF DO LOOP FINISHED, POINT LIES WITHIN AREA.
30061  CALL INSIDE(XNOT,YNOT,INGS,INSS,XL,YL,XR,YR,AA,BB)
30062  GO TO 900
30063  400  CALL OUTSID(XNOT,YNOT,INGS,INSS,XL,YL,XR,YR,AA,BB)
30064  900  RETURN
30065  END

SUBROUTINE OUTSID(XNOT,YNOT,INGS,INSS,XL,YL,XR,YR,AA,BB)
COMMON NRD,NWR,NLEI,TI(12),RSKTI(12)
COMMON C1,C2,C3,SIG,RZERO,RONE,AAA,BBB
COMMON NGS,NRS(10),AMO(11),AM1(11),LORS(11)
COMMON BETA(11),RATE(11),COEF(11),FDEPTH(11)
COMMON NSTEPO,NSTEPI,JCALC,JPRNT
COMMON INDIC(4),AREA(10,11)
DIMENSION XL(4),YL(4),XR(4),YR(4),AA(4),BB(4),XC(4),YC(4)
DIMENSION RSK(12)

C  SUBROUTINE FOR CALCULATING RISK WHEN SITE IS OUTSIDE
C  (QUADRILATERAL) SOURCE AREA.
C  DEFINE DISTANCE VALUES TO SELECT STEP SIZE.
C  (RC IS CLOSEST DISTANCE BETWEEN SITE AND SOURCE.)
C  RC BETWEEN 0.0 AND RZ1 IMPLIES STEP SIZE = NSTEPO.
C  RC BETWEEN RZ2 AND RZ3 IMPLIES LUMP RISK
C  RC BETWEEN RZ2 AND RZ3 IMPLIES LUMP RISK
C  AT CENTER OF SOURCE (DEFINED BY AVERAGING LOCATIONS
C  OF CORNER POINTS).
C  RC GREATER THAN RZ3 IMPLIES IGNORE SOURCE.

RZ1=100.
RZ2=300.
RZ3=500.
C  TO BY-PASS THIS ALGORITHM, SET RZ1 TO A LARGE NUMBER.
C  TO PRODUCE 0-1 ALGORITHM (DISREGARD, OR CALCULATE USING
C NSTEPO), SET RZ1=RZ2=RZ3=DISTANCE WITHIN WHICH YOU
WISH TO CONSIDER RISK.

C FIND CLOSEST (IC,RC) AND FARTHEST (IF,RF) POINTS AND DISTANC
RC2=10000000000.
RZ2=0.
DO 108 II=1,4
DIST=(XNOT-XL(II))*(XNOT-XL(II))+(YNOT-YL(II))*(YNOT-YL(II))
IF (RC2-DIST) 104,104,102
102 RC=SQR(DIST)
RC2=DIST
IC=II
104 IF (DIST-RF2) 108,108,106
RF=SQR(DIST)
RF2=DIST
IF=II
108 CONTINUE
ICS=0
C SEE IF ANY SIDE LIES CLOSER THAN CLOSEST POINT
DO 150 II=1,4
C IS SLOPE INFINITE?
GO TO (130,121),INDIC(II)
121 XS=XL(II)
YS=YNOT
GO TO 145
C IS SLOPE ZERO?
130 IF (AA(II)-0.001) 131,140,140
131 IF (AA(II)+0.001) 140,140,132
132 XS=XNOT
YS=YL(II)
GO TO 145
C SLOPE IS NOT ZERO, SO CALCULATE NEAREST POINT.
140 XS=(YNOT+(XNOT/AA(II))-BB(II))/(AA(II)+(1./AA(II)))
YS=((XNOT-XS)/AA(II))+YNOT
C CALL BETWEEN(XL(II),YL(II),XR(II),YR(II),XS,YS,INDIC(II),IANS)
145 IF (IANS) 150,146,148
146 NERROR=1
GO TO 800
148 DIST=(XNOT-XS)*(XNOT-XS)+(YNOT-YS)*(YNOT-YS)
149 RC2=DIST
RC=SQR(DIST)
ICS=II
150 CONTINUE
APPROX=0.0
150 DO 290 II=1,NLEI
RZK(II)=0.
290 RSK(II)=0.
C DETERMINE STEP SIZE FROM RZ1,RZ2, AND RZ3.
IF (RC-RZ1) 308,308,292
292 IF (RC-RZ2) 294,294,296
294 NSTEPX=NSTEPO/2
GO TO 310
IF (RC-RZ3) 298,298,850
C IF RC IS BETWEEN RZ2 AND RZ3, CALCULATE RISK
C ASSUMING SEISMICITY IS LUMPED AT CENTER (AVERAGE
C OF CORNER POINTS).
XAVE = (XL(1) + XL(2) + XL(3) + XL(4)) / 4.
YAVE = (YL(1) + YL(2) + YL(3) + YL(4)) / 4.
R = SQRT((XAVE - XNOT) * (XAVE - XNOT) + (YAVE - YNOT) * (YAVE - YNOT)).
NTOT = NRS(INGS) + 1.
RATEI = RATE(INGS) * AREA(INGS, INSS) / AREA(INGS, NTOT).
DO 306 JJ = 1, NLEI
   IF (JCALC) 300, 302, 302
   CALL RISK1 (TI(JJ), R, INGS, RISK).
   GO TO 304
300 CALL RISK2(TI(JJ), R, INGS, RISK)
302 GO TO 304
304 IF (RISK - 0.0000000001) 600, 600, 305
305 RSK(JJ) = COEF(INGS) * RISK * RATEI
306 RSKTI(JJ) = RSKTI(JJ) + RSK(JJ)
GO TO 600
600 NSTEPX = NSTEPO
   AN = NSTEPX
   STSIZE = (RF - RC) / AN
   STEP THRU SOURCE AREA.
   DO 500 ISTEP = 1, NSTEPX
      AI = ISTEP
      R = RC + (AI - 0.5) * STSIZE
      NPT = 0
      ANGLE = 0.
      SIGNAL = 1.
   DO 400 11 = 1, 4
      GO TO (330, 320)
   IF (SIDE II IS A VERTICAL LINE) 340, 340, 330
      A = XL(II) - XNOT
      IF (A) 322, 322, 323
      IF (R + A) 400, 400, 324
      IF (R - A) 400, 400, 324
   C COMPUTE TWO INTERSECTION POINTS
      X1 = XL(II)
      B = SQRT(R * R - (X1 - XNOT) * (X1 - XNOT))
      Y1 = YNOT + B
      X2 = XL(II)
      Y2 = YNOT - B
      GO TO 341
   A = 1. + AA(II) * AA(II)
   B = 2. * (-XNOT + AA(II) * (BB(II) - YNOT))
   C = XNOT * XNOT + YNOT * YNOT + BB(II) * (BB(II) - 2. * YNOT) - R * R
   D = B * B - 4. * A * C
   IF (D) 400, 400, 340
   D = SQRT(D)
   X1 = (-B + D) / (2. * A)
   Y1 = AA(II) * X1 + BB(II)
   X2 = (-B - D) / (2. * A)
   Y2 = AA(II) * X2 + BB(II)
   C TWO INTERSECTIONS, CALCULATE FIRST INTERSECTION POINT.
   D = SQRT(D)
   X1 = (-B + D) / (2. * A)
   Y1 = AA(II) * X1 + BB(II)
   X2 = (-B - D) / (2. * A)
   Y2 = AA(II) * X2 + BB(II)
   C SEE IF (X1, Y1) IS ON BOUNDARY
   CALL BETWEEN(XL(II), YL(II), XR(II), YR(II), X1, Y1, INDIC(II), IANS)
   IF (IANS) 360, 342, 345
   NERROR = 4
GO TO 800

CALCULATE OTHER POINT, SEE IF IS ON BOUNDARY.
"CALL BETWEN(XL(II),YL(II),XR(II),YR(II),X2,Y2,INDIC(II),IANS)"
IF (IANS) 348,346,350
NERROR=5
GO TO 800

STORE FIRST POINT
NPT=NPT+1
XC(NPT)=X1
YC(NPT)=Y1
GO TO 400

SEE IF THIS SIDE IS CLOSEST TO POINT, IF SO, TREAT SPECIALLY.
IF (II-ICS) 352,355,352
SIGN 1.
GO TO 357
SIGN=1.
SIGN 1.
AD=SQRT((X1-X2)*(X1-X2)+(Y1-Y2)*(Y1-Y2))
IF (AD-2.*R) 358,359,359
ANGLE=SIGN*2.*ASIN(AD/(2.*R)) + ANGLE
GO TO 400
ANGLE=3.1415926536 + ANGLE
GO TO 400

SEE IF SECOND POINT ONLY IS ON BOUNDARY
CALL BETWEN(XL(II),YL(II),XR(II),YR(II),X2,Y2,INDIC(II),IANS)
IF (IANS) 400,362,370
NERROR=6
GO TO 800
NPT=NPT+1
XC(NPT)=X2
YC(NPT)=Y2
CONTINUE
GO TO (410,420,410,440),NPT
IF (SIGNAL)460,405,405
NERROR=7
GO TO 800
NERROR=8
GO TO 800
AD=SQRT((XC(1)-XC(2))*(XC(1)-XC(2))+(YC(1)-YC(2))*(YC(1)-YC(2)))
ANGLE=ANGLE + SIGNAL*2.*ASIN(AD/(2.*R))
GO TO 460
FOUR INTERSECTION POINTS (EACH ON A DIFFERENT SIDE).
DETERMINE ANGLE BY FINDING CLOSEST 2 INTERSECTIONS TO
FARTHEST CORNER, CALCULATE ANGLE BETWEEN, AND ADD ANGLE
BETWEEN OTHER TWO INTERSECTIONS.
DIST1=10000000000.
I1=0
I2=0
I3=0
I4=0
DO 450 JJ=1,4
DIST=(XL(IFAR)-XC(JJ))*(XL(IFAR)-XC(JJ))
I +(YL(IFAR)-YC(JJ))*(YL(IFAR)-YC(JJ))
IF (DIST-DIST1) 442,444,444
DIST2 = DIST1
DIST1 = DIST
I4 = I3
I3 = I2
I2 = I1
I1 = JJ
GO TO 450
444 IF (DIST - DIST2) 445, 446, 446
DIST2 = DIST
I4 = I3
I3 = I2
I2 = JJ
GO TO 450
446 I4 = I3
I3 = JJ
450 CONTINUE
C CALCULATE ANGLE BETWEEN 2 CLOSEST POINTS TO FARTHEST CORNER
AD = SQRT((XC(I1) - XC(I2)) * (XC(I1) - XC(I2))
1 + (YC(I1) - YC(I2)) * (YC(I1) - YC(I2)))
ANGLE = 2. * ASIN(AD / (2. * R))
C CALCULATE ANGLE BETWEEN 2 POINTS FARTHEST FROM
FARTHEST CORNER AND ADD TO PREVIOUS ANGLE.
AD = SQRT((XC(I3) - XC(I4)) * (XC(I3) - XC(I4))
1 + (YC(I3) - YC(I4)) * (YC(I3) - YC(I4)))
ANGLE = 2. * ASIN(AD / (2. * R)) + ANGLE
C ANGLE FOR THIS RADIUS NOW KNOWN, CALCULATE RISK.
C COMPUTE RATE OF EARTHQUAKES IN THIS ANNULAR SOURCE
ANAREA = ANGLE * R * STSIZE
APPROX = APPROX + ANAREA
NTOT = NRS(INGS) + 1
RATEI = RATE(INGS) * ANAREA * AREA(INGS, INSS) / AREA(INGS, NTOT)
C CALCULATE CONTRIBUTION TO RISK
DO 480 JJ = 1, NLEI
470 CALL RISK1(TI(JJ), R, INGS, RISK)
GO TO 478
475 CALL RISK2(TI(JJ), R, INGS, RISK)
478 IF (RISK - 0.0000000001) 500, 490, 490
490 RSK(JJ) = RSK(JJ) + RISK * RATEI
480 CONTINUE
C NORMALIZE BY COMPUTED (APPROXIMATE) AREA
DO 550 JJ = 1, NLEI
RSK(JJ) = COEF(INGS) * RSK(JJ) / APPROX
550 CONTINUE
C PRINT RISKS FOR THIS SOURCE
WRITE(NWR, 902) INGS, INSS, (RSK(I), I = 1, NLEI)
SUBROUTINE RISK1 (TIC, REPIS, INGS, RISK)

COMMON NRD, NWR, NLEI, TI(12), RSKTI(12)
COMMON C1, C2, C3, SIG, RZERO, RONE, AAA, BBB
COMMON NGS, NRS(10), AMO(11), AM1(11), LORS(11)
COMMON BETA(11), RATE(11), COEF(11), FDEPTH(11)
COMMON NSTEPO, NSTEPI, JCALC, JPRNT
COMMON INDIC(4), AREA(10, 11)

SUBROUTINE TO CALCULATE RISK WHEN THE FOLLOWING SPECIAL
FORM OF ATTENUATION FUNCTION IS USED:
\[ I = C1 + C2 \times M + C3 \times \log(R + RZERO) \]

SIGG = SIG
RFOC = sqrt((REPIS*REPIS + FDEPTH(INGS)*FDEPTH(INGS)))

IF (RFOC < RONE) GO TO 10, 10, 20

R = RONE

IF DIFFERENT STANDARD DEVIATION INSIDE RADIUS RONE IS
DESIRED, SET SIGG TO THIS STANDARD DEVIATION HERE.

GO TO 30

R = RFOC
RLN = \log(R + RZERO)

IS THIS LOOSE OR STRICT SOURCE?

IF STRICT, RISK COMPUTED IS THAT FOR A SINGLE EARTHQUAKE
WITH (EXPONENTIALLY-DISTRIBUTED) RANDOM MAGNITUDE
(OR INTENSITY) BETWEEN AMO AND AM1. IF A LOOSE
SOURCE, RISK COMPUTED IS THAT FOR 'ANEQ' EARTHQUAKES
WITH (EXPONENTIALLY-DISTRIBUTED) RANDOM MAGNITUDE
(OR INTENSITY) BETWEEN 0.0 AND AM1, WITH 'ANEQ' CALCULATED
SO THAT THE EXPECTED NUMBER OF EVENTS BETWEEN AMO AND AM1
IS UNITY.

IF (LORS(INGS)) GO TO 40, 40, 50

AK = 1. / (1. - exp(-BETA(INGS) * AM1(INGS)))
ANEQ = 1. / (1. - AK + AK * exp(-BETA(INGS) * AMO(INGS)))
AMZ = 0.0
GO TO 60

AK = 1. / (1. - exp(-BETA(INGS) * (AM1(INGS) - AMO(INGS))))
ANEQ = 1.
AMZ = AMO(INGS)

CALCULATE MAGNITUDE 'AMSTAR' ASSOCIATED WITH MAX. INTENSITY
AT THIS DISTANCE (R); IF LESS THAN AM1, EVALUATE RISK
FOR MAGNITUDES BETWEEN AMSTAR AND AM1 SEPARATELY.

AMSTAR = (AAA - C1 - C3*RLN) / (C2 - BBB)
IF (AM1(INGS)-AMSTAR) 65,65,70
NONE OF MAGNITUDE INTEGRATION LIES ABOVE AMSTAR.
CALL ERISK(AMZ,AM1(INGS),C1,C2,C3,RLN,SIGG,BETA(INGS),TIC,
1 G1,G2,G3,G4,CON1,CON2,CON3)
GO TO 77
IF (AMZ-AMSTAR) 80,75,75
ALL OF MAGNITUDE INTEGRATION LIES ABOVE AMSTAR.
CALL ERISK(AMZ,AM1(INGS),AAA,BBB,0.,RLN,SIGG,BETA(INGS),TIC,
1 G1,G2,G3,G4,CON1,CON2,CON3)
77 RISK=((-1.-AK)*G1 + AK*G2 + AK*(G3-G4)*CON1*CON2)*ANEQ
GO TO 100
SOME OF MAGNITUDE INTEGRATION LIES ABOVE MSTAR, SOME BELOW.
CALL ERISK(AMZ,AMSTAR,C1,C2,C3,RLN,SIGG,BETA(INGS),TIC,
1 GG1,GG2,GG3,GG4,CCON1,CCON2,CCON3)
CALL BRISK(AMSTAR,AM1(INGS),AAA,BBB,0.,RLN,SIGG,BETA(INGS),TIC,
1 GG1,GG2,GG3,GG4,CCON1,CCON2,CCON3)
RISK=((1.-AK)*G1 +AK*G2 +AK*(G3-G4)*CON1*CON2)*ANEQ
100 RETURN

SUBROUTINE BRISK(AMZ,AMM,C1,C2,C3,RLN,SIG,BETA,TIC,
1 G1,G2,G3,G4,CON1,CON2,CON3)
EVALUATE RISK ASSOCIATED WITH EXPONENTIAL MAGNITUDE LAW
FOR MAGNITUDES BETWEEN AMZ AND AMM.
Z=(TIC-C1-C2*AMM-C3*RLN)/SIG
CALL NDTR(Z,G1,D)
Z=Z-BETA*SIG/C2
CALL NDTR(Z,G3,D)
Z=(TIC-C1-C2*AMZ-C3*RLN)/SIG
CALL NDTR(Z,G2,D)
Z=Z-BETA*SIG/C2
CALL NDTR(Z,G4,D)
IF (C2-0.001) 10,10,20
10 CON1=100000000.
CON3=CON1
GO TO 30
20 CON1=((-BETA*BETA*SIG*SIG)/(2.*C2*C2))+(BETA*AMZ)
1 +((C1-TIC)*BETA*C2)
CON3=CON1+BETA*(AMM-AMZ)
CON1=EXP(CON1)
CON3=EXP(CON3)
CON2=BETA*C3/C2
R=EXP(RLN)
CON2=R**CON2
RETURN
END

SUBROUTINE ERISK(AMZ,AMM,C1,C2,C3,RLN,SIG,BETA,TIC,
1 G1,G2,G3,G4,CON1,CON2,CON3)
EVALUATE RISK ASSOCIATED WITH EXPONENTIAL MAGNITUDE LAW
FOR MAGNITUDES BETWEEN AMZ AND AMM.
Z=(TIC-C1-C2*AMM-C3*RLN)/SIG
CALL NDTR(Z,G1,D)
Z=Z-BETA*SIG/C2
CALL NDTR(Z,G3,D)
Z=(TIC-C1-C2*AMZ-C3*RLN)/SIG
CALL NDTR(Z,G2,D)
Z=Z-BETA*SIG/C2
CALL NDTR(Z,G4,D)
IF (C2-0.001) 10,10,20
10 CON1=100000000.
CON3=CON1
GO TO 30
20 CON1=((-BETA*BETA*SIG*SIG)/(2.*C2*C2))+(BETA*AMZ)
1 +((C1-TIC)*BETA*C2)
CON3=CON1+BETA*(AMM-AMZ)
CON1=EXP(CON1)
CON3=EXP(CON3)
CON2=BETA*C3/C2
R=EXP(RLN)
CON2=R**CON2
RETURN
END

SUBROUTINE RISK2(TIC,REPIS,INGS,RISK)
COMMON NRD,NWR,NLEI,TI(12),RSKTI(12)
COMMON C1,C2,C3,SIG,RZERO,RONE,AAA,BBB
COMMON NGS,NRS(10),AMO(11),AM1(11),LORS(11)
COMMON Beta(11), Rate(11), Coef(11), FDepth(11)
COMMON NSTEPO, NSTEP1, JCALC, JPRNT
COMMON INDIC(4), AREA(10, 11)

C SUBROUTINE TO CALCULATE RISK WHEN AN ATTENUATION FUNCTION
C NON-SEPARABLE IN M AND R IS USED, OR WHEN NON-EXPOENTIAL
C DENSITY FUNCTION ON EARTHQUAKE SIZE IS USED, REQUIRING
C NUMERICAL INTEGRATION ON MAGNITUDE.

C THE EXAMPLE GIVEN HERE IS A SEPARABLE FUNCTION OF M AND R,
C FOR WHICH SUBROUTINE RISK1 WOULD ACTUALLY BE USED IN
C CALCULATIONS. IT IS USED HERE FOR DEMONSTRATION PURPOSES
C ONLY.

C AMINT IS MAGNITUDE INTERVAL USED FOR NUMERICAL INTEGRATION.
C NO. OF MAGNITUDE STEPS (E.G. (AM1-AM0)/AMINT) MUST BE
C A WHOLE NUMBER.

AMINT = 0.05
RISK = 0.0
SIGG = SIG
RFOC = SQRT(REPIS*REPIS + FDEPTH(INGS)*FDEPTH(INGS))
IF (RFOC-RONE) 80, 80, 90
R = RONE
IF (LORS(INGS)) 110, 110, 150
GO TO 100
90 R = RFOC

100 AK = 1./(1.-EXP(-BETA(INGS)*(AM1(INGS)-4.0)))
ANEQ = 1. / (1. - AK + AK*EXP(-BETA(INGS)*(AM1(INGS)-4.0)))
AMZ = 4.0
GO TO 200

150 AMZ = AM0(INGS)
ANEQ = 1.
AK = 1./(1.-EXP(-BETA(INGS)*(AM1(INGS)-AM0(INGS))))

C COMPUTE NUMBER OF INTEGRATION STEPS
NMAGS = (AM1(INGS)-AMZ)/AMINT + 0.1
LOOP ON MAGNITUDE, IN STEPS OF AMINT MAGNITUDE UNITS
DO 500 IMAG = 1, NMAGS
AM = IMAG
AMAG = AMZ + AM*AMINT -(AMINT/2.)
CALCULATE PROBABILITY OF EARTHQUAKE IN THIS MAGNITUDE STEP
PROB = AK*(EXP(-BETA(INGS)*(AMAGP-AMZ))

4 -EXP(-BETA(INGS)*(AMAGP-AMZ))
C CALCULATE MEAN INTENSITY FOR THIS MAGNITUDE (AND DISTANCE
C
C USER: INSERT YOUR MEAN FUNCTION HERE -------

A1 = C1 + C2*AMAG + C3*ALOG(R+RZERO)
IF (A1 < AAA-BBB*AMAG) 220, 220, 210
0060  210  ANEAN=AAA+BBB*AMAG
0061  220  CONTINUE
0062  C    CALCULATE STANDARDIZED VARIABLE
0063       Z = (TIC-AMEAN)/SIGG
0064  C    CALCULATE PROBABILITY OF EXCEEDING INTENSITY OF INTEREST
0065  C ------ USER : INSERT YOUR (COMPLEMENTARY CUMULATIVE)
0066  C    PROBABILITY FUNCTION HERE ------
0067       CALL NDTR (Z,G,D).
0068  C    ACCUMULATE RISK
0069       500  RISK = RISK + G*PROB
0070       RETURN
0071       END

0001  SUBROUTINE BETWEN(X1,Y1,X2,Y2,XP,YP,INDIC,IANS)
0002  C    SUBROUTINE TO DETERMINE IF (XP,YP) LIES BETWEEN
0003        (X1,Y1) AND (X2,Y2).
0004       GO TO (100,200),INDIC
0005       GO TO 300
0006       100  IF (X1-XP) 110,410,120
0007       110  IF (X2-XP) 420,420,410
0008       120  IF (X2-XP) 410,420,420
0009       200  IF (Y1-YP) 210,410,220
0010       210  IF (Y2-YP) 420,420,410
0011       220  IF (Y2-YP) 410,420,420
0012       C    ERROR RETURN
0013       300  IANS=0
0014       GO TO 500
0015       C    (XP,YP) LIES BETWEEN END POINTS, I.E. ON SOURCE BOUNDARY
0016       410  IANS=1
0017       GO TO 500
0018       C    (XP,YP) DOESN'T LIE BETWEEN END POINTS, I.E. IT'S OUTSIDE SOI
0019       420  IANS=-1
0020       500  RETURN
0021       END

0001  SUBROUTINE NDTR(X,P,D)
0002  C    X IS NO. OF STANDARDIZED NORMAL DEVIATES.
0003  C    P IS COMP. CUMULATIVE VALUE (OUTPUT).
0004  C    D IS DENSITY VALUE (OUTPUT)
0005       IF (X) 1,2,2
0006       1   AX=-X
0007       GO TO 3
0008       2   AX=X
0009       3   IF (AX-6.0) 5,4,4
0010       4   P=1.
0011       D=0.
0012       GO TO 6
0013       5   T=1./(1.0+.2316419*AX)
0014       D=0.3989423*EXP(-X*X/2.0)
0015       P = 1.0 - D*T*(((1.330274*T - 1.821256)*T + 1.781478)*T -
0016       1 - 0.3565638)*T + 0.3193815)
0017       6   IF (X) 8,7,7
SUBROUTINE AREAS(X1,Y1,X2,Y2,X3,Y3,X4,Y4,AREA)

SUBROUTINE TO CALCULATE AREA OF ARBITRARY QUADRILATERAL, WHERE (X1,Y1) AND X4,Y4 ARE OPPOSITE CORNERS.

LOCATE INTERSECTIONS OF DIAGONALS:

IF (X4-X1-0.001) 20,30,30

IF (X4-X1+0.001) 30,30,25

XX=X1

A2=(Y3-Y2)/(X3-X2)

YY=(XX-X3)*A2 +Y3

DIST1=Y4-Y1

IF (DIST1) 26,27,27

DIST2=SQRT((X3-X2)*(X3-X2) + (Y3-Y2)*(Y3-Y2))

GO TO 100

30 IF (X3-X2-0.001) 50,70,70

50 IF (X3-X2+0.001) 70,70,65

XX=X3

A1=(Y4-Y1)/(X4-X1)

YY=(XX-X4)*A1+Y4

DIST2=Y3-Y2

IF (DIST2) 66,67,67

66 DIST2=-DIST2

67 DIST1=SQRT((X4-X1)*(X4-X1) + (Y4-Y1)*(Y4-Y1))

GO TO 100

70 A1=(Y4-Y1)/(X4-X1)

A2=(Y3-Y2)/(X3-X2)

XX=(Y2-Y1+A1*X1-A2*X2)/(A1-A2)

YY=A1*(XX-X1) + Y1

DIST1=SQRT((X4-X1)*(X4-X1) + (Y4-Y1)*(Y4-Y1))

DIST2=SQRT((X3-X2)*(X3-X2) + (Y3-Y2)*(Y3-Y2))

CALCULATE LENGTH OF SIDES OF SUB-TRIANGLE

SIDE1=SQRT((XX-X1)*(XX-X1) + (YY-Y1)*(YY-Y1))

SIDE2=SQRT((XX-X2)*(XX-X2) + (YY-Y2)*(YY-Y2))

SIDE3=SQRT((X1-X2)*(X1-X2) + (Y1-Y2)*(Y1-Y2))

SOLUTION ACCORDING TO C.R.C. HANDBOOK UNDER 'MENSURATION FORMULAE' AND 'TRIGONOMETRIC FORMULAE'

SS=(SIDE1+SIDE2+SIDE3)/2.

SINANG=2.*SQRT(SS*(SS-SIDE1)*(SS-SIDE2)*(SS-SIDE3))/(SIDE1*SID:

AREA=0.5*DIST1*DIST2*SINANG

RETURN

END

SUBROUTINE CIRCLE(RC,INGS,FRAREA,RSK)

COMMON NRD,NWR,NLEI,FI(12),RSKTI(12)

COMMON Cl,C2,C3,SIG,RZERO,ROKE,AAA,BBB

COMMON NGS,NRS(I0) ,AMO(I1) ,AML(I1) ,LORS(I1)

COMMON BETA(I1),RATE(I1),COEF(I1),FDEPTH(I1)

COMMON NSTEPO,NSTEPI,JCALC,JPRNT

COMMON INDIC(4),AREA(I0,11)

DIMENSION RSK(I2)
SUBROUTINE TO CALCULATE RISK FROM A CIRCULAR SOURCE WITH CENTER AT SITE, RADIUS RC.

NRC = RC

CHOOSE STEP SIZE:
STEP SIZE = NSTEPI UNLESS RESULTING STEP SIZE IS LESS THAN ONE KILOMETRE, IN WHICH CASE RC+1 STEPS ARE USED.

IF (NRC - NSTEPI) 10, 12, 12
10 NSTEPX = NRC + 1
GO TO 14
12 NSTEPX = NSTEPI
14 ANSTEP = NSTEPX
DO 90 II = 1, NSTEPX
AI = II
R = ((AI - 0.5) * RC) / ANSTEP
ANAREA = 6.2831853072 * R * RC / ANSTEP
RATEI = RATE(INGS) * ANAREA * FAREA
DO 80 JJ = 1, NLEI
IF (JCALC) 50, 50, 60
CALL RISK1(TI(JJ), R, INGS, RISK)
GO TO 70
CALL RISK2(TI(JJ), R, INGS, RISK)
RSK(JJ) = RSK(JJ) + RISK * RATEI
CONTINUE
CONTINUE
RETURN
END

SUBROUTINE INSIDE(XNOT, YNOT, INGS, INSS, Xl, YL, XR, YR, AA, BB)
COMMON NRD, NWR, NLEI, TI(12), RSKTI(12)
COMMON C1, C2, C3, SIG, RZERO, RONE, AAA, BBB
COMMON NGS, NRS(10), AMO(11), AM1(11), LORS(11)
COMMON BETA(11), RATE(11), COEF(11), FDEPTH(11)
COMMON NSTEPO, NSTEPI, JCALC, JPRNT
COMMON INDIC(4), AREA(10, 11)
DIMENSION XL(4), YL(4), XR(4), YR(4), AA(4), BB(4), XC(4), YC(4)
DIMENSION RSK(IO)

SUBROUTINE FOR CALCULATING RISK WHEN SITE IS INSIDE SOURCE AREA.
REFER TO DOCUMENTATION FOR ALGORITHM USED TO CHOOSE NUMBER OF INTEGRATION STEPS.

DO 50 II = 1, NLEI
RSK(II) = 0.
APPROX = 0.
RC2 = 10000000000.
RF2 = 0.
FIND CLOSEST SIDE AND FARTHEST POINT
DO 160 II = 1, 4
GO TO (120, 110), INDIC(II)
110 XS = XL(II)
120 IF (AA(II) - 0.001) 121, 125, 125
121 IF (AA(II) + 0.001) 125, 125, 122
XS=XNOT
YS=YL(II)
GO TO 140
SLOPE NOT ZERO
XS=(YNOT+(XNOT/AA(II))-BB(II))/(AA(II)+1./AA(II))
YS=((XNOT-XS)/AA(II))+YNOT
CALCULATE SQUARE OF DISTANCE BETWEEN SITE AND CLOSEST POINT.
DIST=(XNOT-XS)*(XNOT-XS)+(YNOT-YS)*(YNOT-YS)
IF (DIST-RC2) 151,152,152
RC=SQRT(DIST)
RC2=DIST
ICLO=II
CALCULATE DISTANCE BETWEEN SITE AND LEFT HAND POINT ON SIDE
DIST=(XNOT-XL(II))*(XNOT-XL(II))+(YNOT-YL(II))*(YNOT-YL(II))
IF (RF2-DIST) 154,160,160
RF=SQRT(DIST)
RF2=DIST
IFAR=II
CONTINUE
DETERMINE AZIMUTH OF FARTHEST POINT WITH RESPECT TO SITE
AZIMF=ACOS((XL(IFAR)-XNOT)/RF)
IF (YL(IFAR)-YNOT) 162,164,164
AZIMF=6.2831853072 - AZIMF
CONTINUE
RC IS NOW DISTANCE FROM SITE TO CLOSEST SIDE.
RF IS NOW DISTANCE FROM SITE TO FARTHEST CORNER.
IF (RC-0.01) 200,200,170
CALL SUBROUTINE CIRCLE TO CALCULATE RISK FROM CIRCULAR SOURCE WITH RADIUS RC
NTOT=NRS(INGS)+1
FRAREA=AREA(INGS,INSS)/AREA(INGS,NTOT)
call circle(RC,INGS,FRAREA,RSK)
APPROX=3.1415926536*RC*RC
LOOP ON R TO CALCULATE RISK FROM RC TO RF
AN=NSTEPI
PICK STEP SIZE BASED ON FRACTION OF AREA LEFT
FRLEFT=(AREA(INGS,INSS)-APPROX)/AREA(INGS,INSS)
NSTEPX=FRLEFT*AN + 1.
AN=NSTEPX
STSIZE=(RF-RC)/AN
DO 500 ISTEP=1,NSTEPX
AI=ISTEP
R=RC+(AI-0.5)*STSIZE
NPT=0
ANGLE=0.
LOOP ON EACH SIDE
DO 400 II=1,4
GO TO (330,320),INDIC(II)
SIDE II IS VERTICAL, DOES CIRCLE (RADIUS R) INTERSECT IT?
A=XL(II)-XNOT
IF (A) 322,322,323
IF (R+A) 400,400,324
IF (R-A) 400,400,324
COMPUTE 2 INTERSECTION POINTS
X1=XL(II)
B = SQRT(R*R - (X1 - XNOT)*(X1 - XNOT))
Y1 = YNOT + B
X2 = XL(II)
Y2 = YNOT - B
GO TO 341

A = 1. + AA(II)*AA(II)
B = 2.*(-XNOT+AA(II)*(BB(II)-YNOT))
C = XNOT*XNOT+YNOT*YNOT+BB(II)*(BB(II)-2.*YNOT)-R*R
D = B*B-4.*A*C

IF (D) 400, 400, 340

THERE ARE 2 INTERSECTION, CALCULATE THEIR COORDINATES.

D = SQRT(D)
X1 = (-B+D)/(2.*A)
Y1 = AA(II)*X1+BB(II)
X2 = (-B-D)/(2.*A)
Y2 = AA(II)*X2+BB(II)

SEE IF (X1, Y1) IS ON BOUNDARY
CALL BETWEN(XL(II),YL(II),XR(II),YR(II),X1,Y1,INDIC(II),IANS)
IF (IANS) 350, 342, 345
NERROR = 4
GO TO 800

IS SECOND POINT ALSO ON BOUNDARY?
CALL BETWEN(XL(II),YL(II),XR(II),YR(II),X2,Y2,INDIC(II),IANS)
IF (IANS) 348, 346, 360
NERROR = 5
GO TO 800

STORE FIRST POINT ONLY
NPT = NPT + 1
XC(NPT) = X1
YC(NPT) = Y1
GO TO 400

SEE IF SECOND POINT ONLY IS ON BOUNDARY
CALL BETWEN(XL(II),YL(II),XR(II),YR(II),X2,Y2,INDIC(II),IANS)
IF (IANS) 400, 352, 354
NERROR = 6
GO TO 800

NPT = NPT + 1
XC(NPT) = X2
YC(NPT) = Y2
GO TO 400

TWO INTERSECTION POINTS ON ONE SIDE BOTH LIE ON BOUNDARY,
CALCULATE ANGLE BETWEEN THEM.
CONTINUE

AD = SQRT((X1-X2)*(X1-X2)+(Y1-Y2)*(Y1-Y2))
ANGLE = 2.*ASIN(AD/(2.*R))+ANGLE
CONTINUE
IF (NPT) 402, 404, 408
NERROR = 7
GO TO 800

IF (ANGLE-0.001) 402, 406, 406
FOLLOWING IS FOR CASE OF NO SINGLE INTERSECTION POINTS;
ANGLE IS 2 * PI - ANGLE CALCULATED SO FAR.
PANGLE = 6.2831853072-ANGLE
GO TO 460
GO TO (402,410,402,440), NPT
NERROR=8
GO TO 800

C 2 INTERSECTION POINTS; DETERMINE AZIMUTHS.

IF (XC(1)-XNOT-R) 414, 413, 411
IF (XC(1)-XNOT-R-0.001) 413, 413, 412
NERROR=18
GO TO 800
AZIM1=0.0
GO TO 418
AZIM1=3.1415926536
GO TO 420
AZIM1=ACOS((XC(1)-XNOT)/R)
AZIM1=6.2831853072 - AZIM1
AZIM1=3.1415926536
GO TO 428
AZIM1=ACOS((XC(1)-XNOT)/R)
AZIM1=6.2831853072 - AZIM1
AZIM1=3.1415926536
GO TO 430
AZIM2=ACOS((XC(2)-XNOT)/R)
AZIM2=6.2831853072 - AZIM2
AZIM2=3.1415926536
GO TO 430
AZIM2=ACOS((XC(2)-XNOT)/R)
AZIM2=6.2831853072 - AZIM2
AZIM2=3.1415926536
GO TO 430

IF (PANGLE) 431, 439, 435
IF (AZIM1-AZIMF) 432, 439, 433
IF (AZIMF-AZIM2) 432, 439, 434
IF (AZIM2-AZIMF) 432, 439, 434
PANGLE=-PANGLE-ANGLE
GO TO 460
PANGLE=PANGLE-ANGLE
GO TO 460

DIST1=10000000000.
I1=0
I2=0
I3=0
I4=0
DO 450 JJ=1, 4
DIST = (XL(IFAR) - XC(JJ)) * (XL(IFAR) - XC(JJ))
1 + (YL(IFAR) - YC(JJ)) * (YL(IFAR) - YC(JJ))
IF (DIST - DIST1) 442,444,444
DIST2 = DIST1
DIST1 = DIST
I4 = I3
I3 = I2
I2 = I1
I1 = JJ
GO TO 450
IF (DIST - DIST2) 445,446,446
DIST2 = DIST
I4 = I3
I3 = I2
I2 = JJ
GO TO 450
I4 = I3
I3 = JJ
CONTINUE
CALCULATE ANGLE BETWEEN 2 CLOSEST POINTS TO FARTHEST CORNER
AD = SQRT((XC(I1) - XC(I2)) * (XC(I1) - XC(I2)) + (YC(I1) - YC(I2)) * (YC(I1) - YC(I2)))
PANGLE = 2 * ASIN(AD / (2 * R))
CALCULATE ANGLE BETWEEN 2 FARTHEST POINTS FROM FARTHEST CORNER AND ADD TO PREVIOUS ANGLE.
AD = SQRT((XC(I3) - XC(I4)) * (XC(I3) - XC(I4)) + (YC(I3) - YC(I4)) * (YC(I3) - YC(I4)))
PANGLE = 2 * ASIN(AD / (2 * R)) + PANGLE
ANGLE FOR THIS RADIUS IS NOW KNOWN, CALCULATE RISK
CONTINUE
ANAREA = PANGLE * R * STSIZE
APPROX = APPROX + ANAREA
NTOT = NRS(INGS) + 1
RANDLE = RATE(INGS) * ANAREA * AREA(INGS, INSS) / AREA(INGS, NTOT)
CONTINUE
DO 480 JJ = 1, NLEI
IF (JCALC) 470, 470, 475
CALL RISK1(TI(JJ), R, INGS, RISK)
GO TO 478
CALL RISK2(TI(JJ), R, INGS, RISK)
IF (RISK - 0.00000000001) 500, 490, 490
RSK(JJ) == RSK(JJ) + RISK * RANL
CONTINUE
DO 550 JJ = 1, NLEI
ARERR = ((APPROX - AREA(INGS, INSS)) / AREA(INGS, INSS)) * 100.
IF (ARERR - 5) 510, 520, 520
IF (ARERR + 5) 530, 540, 540
WRITE (NWR, 903) ARERR, INGS, INSS
FORMAT(10X, 'CAUTION: NUMERICAL INTEGRATION ERROR IN AREA IS ', F6.2, ' % FOR (INSIDE) SOURCE ', 2X, I3)
DO 540 JJ = 1, NLEI
RSK(JJ) = COEF(INGS) * RSK(JJ) / APPROX
RSKTI(JJ) = RSKTI(JJ) + RSK(JJ)
IF (JPRNT) 850, 850, 610
PRINT RISKS FOR THIS SOURCE.
90

)248 610 WRITE(NWR,902) INGS,INSS,(RSK(I),I=1,NLEI)
)249 902 FORMAT(' SOURCE',2I3,' E(NO/YR): ',12E9.3)
)250       GO TO 850
)251 C ERROR PRINTOUT
)252 800 WRITE (NWR,901) NERROR,INGS,INSS,IF,NPT,XNOT,YNOT,(XL(I),YL(I),
)253     1 I=1,4),RC,RF,R,PANGLE,(XC(I),YC(I),I=1,4)
)254 901 FORMAT (' ***** ERROR',I4,' IN SUBROUTINE INSIDE. SOURCE NO.',
)255     1 2I3,' DEBUG VALUES FOLLOW......',/10X,2I10,10(/10X,2F12.6))
)256 850 RETURN
)257 END