- Using the fragility curves for the different structural types to estimate the number of buildings expected to collapse;
- Applying casualty ratios (percentages of occupants) to the average occupancies of collapsed buildings to estimate the number of deaths and injuries incurred.

Ideally, the casualty ratios would have been determined from statistical data and records of previous earthquakes. However, such detailed data could not be obtained without an extensive investigation considerably beyond the scope of the present study. In the absence of such data, the casualty ratio for deaths (the number of deaths as a portion of total occupants of collapsed buildings) was set initially on the basis of a small number of known cases. The number of serious injuries (injuries requiring hospitalization) was estimated at about four times the number of deaths. Professional judgement was then used to calibrate and adjust the ratios by comparing the estimated casualties for the six cities with casualties experienced in past earthquakes and with estimates made in previous studies of other areas.

As a result of the process of calibration, the number of deaths was estimated at two percent of the occupants of collapsed buildings and the number of injuries at eight percent of the occupants. The injury category was assumed to include only those persons with injuries serious enough to require professional medical attention.

Deaths and injuries not directly caused by collasped buildings, such as those caused by falling objects, collapsed bridges, accidents, heart attacks, etc., were assumed to be minor in comparison. The casualties caused by such events were assumed to be included in those predicted by the casualty ratios applied to the collapsed buildings, as a small portion of the total casualties expected to occur.

Casualties were estimated by census tract to incorporate the detailed data which were available and to indicate where the casualties and associated problems would be most likely to occur in each city. A large amount of uncertainty is associated with the estimate for an individual tract, but when the tracts are aggregated into larger areas, the uncertainty is reduced and the combined estimates become more reliable.

To reflect differences caused by the geographical location of the population, casualties were estimated for two periods: nighttime or early morning (2:00 A.M.) and daytime or early afternoon (2:00 P.M.). In the early morning, when the fewest casualties would be expected, most of the population is at home, with a large portion in relatively safe wood frame structures. In the early afternoon of a winter weekday, when casualties would be greatest, people are found primarily in business, industrial and education settings, and in relatively unsafe structures with a high probability of damage or collapse. School children as well as office and factory workers would suffer death and injury to a much greater extent in their places of study and employment than they would at home.

Nighttime (Early Morning) Casualties

Most nighttime casualties will occur in residences. Four basic elements of data were used for determining residential casualties in each census tract: the population, the number of housing units, the number of single family residential structures, and the number of multi-family residential structures. The first two were obtained from 1980 census data; the latter two were provided in this study's structural inventory. Using these data, the average number of persons per single family structure and the average number of persons per multi-family structure were calculated for each census tract.

The numbers of single family and multi-family residential structures expected to suffer collapse in each census tract were determined from the estimated earthquake intensity, the fragility curves and the inventory of residential structures, taking into account the type of construction of the buildings in the tract. Almost all the single family dwellings in the six cities are of wood frame construction, but a significant number of the multi-family residences are non-wood frame structures (predominately masonry bearing wall and shear wall construction) with greater probabilities of collapse.

The probable number of residential casualties in each census tract was calculated by multiplying the average number of persons per structure by the expected number of collapsed structures and then multiplying this product by the death and injury ratios for the occupants of collapsed buildings (two percent and eight percent, respectively). This calculation was performed for both single family and multi-family structures, and the two results were summed to obtain the total number of estimated residential nighttime casualties in each tract. Separate calculations were performed for the Ms=7.6 and the Ms=8.6 earthquake scenarios.

A certain number of nighttime casualties can also be expected to occur in non-residential structures such as hospitals, hotels, and commercial and industrial buildings with night workers. Except for hospital casualties, the non-residential nighttime casualties were estimated at about five percent of the total expected daytime casualties in non-residental structures, assuming that the total occupancy of such structures would be about five percent of the total daytime occupancy. The procedure for estimating the non-residential daytime casualties is described below. Nighttime hospital casualties were estimated separately by determining the average nighttime occupancy of the hospitals, all of which are non-wood frame structures, and applying the same procedure used to estimate daytime hospital casualties, as described below.

Nighttime casualties in universities were also estimated separately. In the case of Carbondale, where dormitories were distinguishable from other buildings in the structural inventory, along with their occupancies, the number of deaths and injuries expected to occur in those structures was estimated by following the same procedure used to estimate daytime casualties in universities, as explained below. In other cities, the number of students living in university dormitories was estimated at about 10 percent of the total number of students (based on information from universities), and the probable nighttime casualties were estimated at that proportion of the expected daytime casualties.

Daytime (Early Afternoon) Casualties

Daytime casualties, most of which would occur in non-residential structures, were calculated for the following five categories of buildings: residential; commercial, industrial and public non-educational; hospitals; schools; and universities.

The residential daytime casualties were derived from the estimates of the residential nighttime casualties. The nighttime casualties in each tract were reduced by the overall average percentage of the city's population either employed or attending school, as indicated in census data. In the case of Memphis, around 70 percent of the population was estimated to be away from home in the afternoon, whereas for Evansville and Paducah, that figure dropped to about 60 percent. The employed and student populations of the other cities fall between those two extremes. The residential daytime casualties were therefore estimated at between 30 and 40 percent of the residential nighttime casualties in each census tract, depending on the city.

The calculation of expected casualties in commercial, industrial and public non-educational buildings followed a procedure similar to that employed for the nighttime residential casualties, except that employment data were used to determine the population at risk. The number of jobs, or the number of people working, in each census tract was determined from whatever data were available. In some cases this information was obtained from transportation studies which provided origin and destination data by census tract or by smaller zone; in others the total employment of the city was distributed among the census tracts on the basis of the number of floors of commercial, industrial and public non-educational buildings in each tract. This latter procedure was used only if no other information was available. Since building size (volume) was not included in the inventory data, the total number of floors provided the best basis for distributing employment among tracts. In Memphis, for example, where the employment in each of 15 planning districts was available from the Memphis Transportation Study, the employment in each census tract in each planning district was estimated in proportion to the number of building floors in each tract within the district.

The average occupany of the commercial, industrial and public non-educational structures in each tract was obtained from the total employment and the total number of such buildings in the tract. Applying the fragility curves to the inventory of structures provided the number of buildings estimated to collapse and, consequently, the number of people in collapsed buildings, to which the casualty ratios (two percent deaths and eight percent injuries) were then applied to obtain the estimated total number of deaths and injuries in each tract. Separate calculations were performed for each of the two earthquake scenarios.

For hospitals, schools and universities, instead of calculating an average number of occupants per structure, the total number of persons in all buildings of each type of construction (primarily masonry shear wall and masonry bearing wall) was determined for each census tract, based on occupancy data obtained from available data bases or information resources. Deaths and injuries were then estimated by multiplying the total number of persons in each type of building by the probability of collapse obtained for that type of building from the appropriate fragility curve, and then multiplying that product by the casualty ratios for death and injury among occupants of collapsed buildings. The results for all structural types were summed to get the total deaths and injuries in each tract for hospitals, for schools and for universities. When data by tract were not available, casualties were estimated for the city as a whole.

Comments on the Methodology

As indicated above, the objective of developing the casualty estimation procedure was to produce a systematic approach that would be capable of explicitly taking into account differences in earthquake intensity, population factors and the expected extent of damages to structures, by type of construction. It was also desired to develop a technique that would provide a logical and rational explanation of the expected consequences of the earthquake scenarios. The use of the casualty ratios to estimate deaths and injuries in collapsed buildings, which were obtained by applying the fragility curves to the structural inventories, enabled those objectives to be met.

As was pointed out above, all the inputs to the casualty methodology -- the structural inventories, the fragility curves and the casualty ratios -- are subject to some level of uncertainty, and that uncertainty should not be ignored in an interpretation of the casualty estimates. However, the approach used in this study is a necessary first step in the development of a quantitative and systematic method for casualty estimation based on reliable data that would enable the level of uncertainty in the estimates to be reduced significantly.

Adequate historical data which would permit an empirical determination of casualty rates for occupants of different types of buildings in the central United States are not available. The casualty rates used in these analyses were estimated on the basis of professional judgement and were verified by comparing the results of the analysis (in terms of deaths per 100,000 population) with casualties produced by U.S. earthquakes in the past. In general, the results are reasonably consistent with historical events, taking into account the general lack of seismic factors in the building codes and construction practices in the six cities. Further research could be used to verify empirically the assumptions on which this study is based. Such research would focus not only in casualties in collapsed buildings but also on those which would occur in moderately or severely damaged buildings and around other structures, such as collapsed bridges, enabling such casualties to be estimated separately.

The casualty estimates in this study are based generally on 1980 population and employment data and on structural inventory data gathered in 1981 and 1982. To project the 1980 casualty estimates into future years, the expected growth rate of the population in each city should be used as a basis, assuming that no significant changes in building practices or population distribution take place.

### 2.5.2 Casualties from Flooding and Conflagration

In addition to the casualties resulting from structural failure and related causes, death and injury could also be produced by secondary events such as flash flooding and fire or conflagration.

Flash flooding, as a consequence of the failure of water impoundment structures, could occur in four of the six cities included in the study. Although such flooding would be unlikely to produce a significant number of casualties, a low risk of death and injury would exist. Persons already having suffered injury from structural failure would be especially susceptible to drowning if they were unable to care for themselves and had no one to help them. If flooding occurred, it would take place rapidly with little or no warning, and accidents could result from the confusion and haste to evacuate the endangered areas.

The number of deaths and injuries which would be caused by flooding in each area would depend on several factors difficult to quantify such as depth of floodwater and time taken to reach maximum depth, which would depend on the extent of damage to the dams or levees. Such a detailed analysis would be beyond the scope of the present analysis. However, as a rough indication of the casualties which could be caused by flooding, a casualty rate of 0.1% per 100,000 affected persons was applied (50 deaths and 50 injuries), the number of affected persons being defined as the population of the 100 year flood plain which would be exposed by failure of a city's levees. The population estimates were derived from 1980 census records, in proportion to the approximate area of each tract that would be affected by the flooding. For such inundation to occur, of course, the water level in the area would have to be sustantially above normal at the time of the earthquake. (The casualties which would be caused by abnormally high water in areas unprotected by levees were not estimated since the seismic event is not the cause of such flooding.

No distinction was made between daytime and nighttime events nor between the Ms=7.6 and the Ms=8.6 earthquakes scenarios since both earthquakes were assumed to produce damage sufficient to allow the 100 year flood plains protected by the levees to be inundated. In comparison to the casualties caused by structural failure, those caused by flooding would not be significant.

Casualties could also be caused by fire. However, extensive fires or conflagrations are considered unlikely to occur, and since smaller or limited fires would not be likely to cause a significant number of casualties (with the possible exception of further injury to persons already injured as a consequence of structural failure), no additional casualties were estimated for this type of secondary event.

### 2.5.3 Casualties Among Medical Personnel

The expected casualties among doctors and nurses were estimated to provide an indication of the probable availability of medical personnel in the six cities after the scenario earthquakes. The number of doctors and nurses (including both registered nurses and licensed practitioners) in each city was derived from surveys of local medical facilities, local telephone directories and health manpower publications.

Casualties were estimated for both daytime (early afternoon) and nighttime (early morning) occurrences of the two earthquake scenarios. Both a daytime distribution and a nighttime distribution of the medical personnel among hospitals, non-residential structures (private offices, etc.) and residences were assumed, and casualties were assumed to occur among the medical personnel in each of the three types of structures at the same rate as would be experienced by the total population in each type of structure.

According to medical data centers, half the doctors in each city were assumed to work in hospitals. It was estimated that ninety percent of these physicians would be present in a hospital during a daytime occurrence; ten percent would be at home during the daytime but in a hospital during a nighttime occurrence of an earthquake. The other half were assumed to be found in non-residential structures during the daytime. Except for the small number working in hospitals, all doctors would be at home during a nighttime occurrence.

Among the nurses, it was estimated that ninety percent work in hospitals and ten percent in other non-residential structures (convalescent homes, doctors' offices, etc.) Taking into account three shifts, fifty percent of the total nurses working in each type of structure were assumed to be present at their workplace in the daytime, with the other fifty percent assumed to be in their residences. During a nighttime occurrence, twenty percent would be at their place of work and eighty percent at home.

## 2.6 Estimation of Shelter Requirements

### 2.6.1 Displaced Persons Due to Structural Damage and Flooding

Estimates of the numbers of persons likely to require shelter in the six cities as a result of the effects of an occurrence of the earthquake scenarios were derived from two sources. Persons displaced due to flooding of residential areas comprised the first group. As stated in the previous section, persons living in innundated areas were presumed to require relocation and shelter.

The second source of persons needing shelter was damage to residential structures. Single and multi-family residences which were likely to sustain moderate or greater damage were considered to be uninhabitable, at least in the short term. Inspection for safety and expedient repair could render some of these residential structures useable after a period of time. Therefore, persons residing in structures estimated to sustain moderate or greater damage were assumed to require relocations and shelter.

This analysis is based on forced displacement solely, due to a residence being uninhabitable due to structural damage or flooding (the presumed primary causes). No estimates were attempted for situations which could mandate sheltering in areas away from a person's normal place of residence due to prolonged unavailability of one or more utility or lifeline systems. The factors governing such estimates were too variable and complex to be within the scope of this study.

2.6.2 Available Shelter

Many structures with large capacities to house displaced persons will be available following either the Ms=7.6 or the Ms=8.6 earthquake scenarios. A large percentage of those will require safety inspections by competent individuals prior to such use. Available floor space in a safe building, however, is not the only criterion for sheltering persons for even a short time. Sanitary and eating facilities, among others, should be available. From the information collected during this study, school structures were the only structure data subset which were likely to have the appropriate facilities available in most of the cities. The use of schools has an additional advantage in that many or most are controlled by govenmental agencies and thus may be made available promptly for general disaster relief usage. School structures are generally the first category of buildings to be selected in relief efforts for immediate shelter of large numbers of persons. School structures which were estimated to sustain less than moderate damage were assumed to be potentially available for shelters. Although, in many cases, a significant percent of schools sustained damage greater than moderate (with corresponding casualties), those with less than moderate damage (and thus suitable for shelter) were tabulated for that purpose.