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# Socioeconomic Consequences of Nuclear Reactor Accidents

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**Prepared for**
**U.S. Nuclear Regulatory Commission**

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**U.S. Nuclear Regulatory Commission**
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## ABSTRACT

This report identifies and characterizes the off-site socioeconomic consequences that would likely result from a severe radiological accident at a nuclear power plant. The types of impacts that are addressed include economic impacts, health impacts, social/psychological impacts and institutional impacts. These impacts are identified for each of several phases of a reactor accident--from the warning phase through the post-resettlement phase. The relative importance of the impact during each accident phase and the degree to which the impact can be predicted are indicated. The report also examines the methods that are currently used for assessing nuclear reactor accidents, including development of accident scenarios and the estimating of socioeconomic accident consequences with various models. Finally, a critical evaluation is made regarding the use of impact analyses in estimating the contribution of socioeconomic consequences to nuclear accident reactor accident risk.

## SUMMARY

Partly as a result of the reactor accident at Three Mile Island, recent policy of the U.S. Nuclear Regulatory Commission (NRC) has been to give increased consideration to the off-site consequences of major reactor accidents. The current study was commissioned by the Environmental Effects Branch of the Office of Nuclear Regulatory Research and is an outgrowth of this policy.

The NRC uses a classification scheme to characterize power reactor accidents. The most severe class of accidents is designated SST-1 (for Siting Source Term, Group 1) and includes accidents in which there is a loss of all installed safety features and a severe direct breach of the containment vessel. It is believed that radioactive releases from such an accident would be roughly one million times as great as those at Three Mile Island. However, the likelihood of an SST-1 accident is considered to be extremely remote.

The current study focuses on the off-site socioeconomic effects of SST-1 accidents. Many of the impacts addressed in this report are based on the results of a computer model developed for and used by the NRC. This model simulates a pre-designated accident through the radiological release, dispersion and contamination stages. Selected economic and health effects are then estimated. However, because of the large degree of uncertainty regarding the physical process of the accident itself, estimates of the socioeconomic effects must also be uncertain.

This report examines the contribution to risk from off-site socioeconomic consequences according to four impact categories: economic, health, social/psychological and institutional. The report then reviews methods currently being used by the NRC to assess severe nuclear reactor accidents. The final chapter is devoted to a theoretical treatment of the social costs of severe reactor accidents. One of the main purposes of this last chapter is to identify impact areas in which the customarily reported impacts fail to provide a reasonably good indication of the relevant social costs. Such divergences between impacts and social costs are important to note when making policy decisions based on the predicted impacts. The major findings of this report are summarized below.

### Economic Impacts

Estimating the economic effects of a nuclear power plant accident requires determining the impacts on businesses, individuals, governments and the environment for the extended time period following an accident. Both impacts on the local and nonlocal economy as well as those involving interrelationships between the economy and other impact categories (e.g., social/psychological) need to be addressed.

Major impacts on individuals within the directly impacted areas include evacuation expenses, loss of wages and salaries, risk of property loss through looting, and actual property losses because of radiological contamination. In the host areas, the influx of evacuees would mean greater traffic congestion, increased crowding of stores and other public places, increased competition for jobs, and higher prices for and perhaps shortages of goods and services. Higher taxes and/or a deterioration in public services are also possible in the host areas.

Businesses within the directly impacted area may have to take actions to curtail operations. Where this includes shutting down production lines, the procedures could be lengthy and costly. Trade between businesses within and outside the directly impacted area would likely be suspended. Outside establishments could be seriously impacted, at least in the near term until alternative supplies could be located. Property losses through contamination of plant, equipment, materials and inventories could be huge; looting, fire and other casualties could contribute to the business losses.

Retail establishments in the host areas would generally be favorably impacted by the radiological accident, since the evacuees would provide new business. Other types of businesses could be either helped or hurt, depending upon whether the accident had helped or hurt suppliers, buyers or competitors.

State and local governments would almost invariably be adversely impacted by the radiological accident. Responsibilities during the evacuation and clean-up would be increased above normal levels while the destruction of property and curtailment of business would cause tax revenues to decrease. In addition, there is also likely to be a loss of government infrastructure within the directly impacted area.

The most significant impacts on the physical environment are likely to be as the direct result of contamination. Indirect impacts, especially on recreational areas, might also occur.

## Health Impacts

The health impacts of radiation exposure can be divided into three general categories. The first two categories include effects occurring only in individuals who have had direct exposure with radiation. These are called early and latent somatic effects. Early somatic effects occur shortly after exposure and can therefore be directly associated with the accident. Latent somatic effects include a variety of cancers. Because of the low incidence rate following most levels of radiation exposure, latent cancers are difficult to predict and associate with the radiation exposure. The third category of health effect, genetic effects, occur in the offspring of the irradiated individuals. These effects are manifest as an increase in the frequency of various traits, ranging from very severe (e.g., premature death), to fairly innocent (e.g., changes in eye color).

All three types of effects can be the result of external or internal doses. External doses may be from the plume, waterborne contamination, or ground contamination. Internal doses may result from inhalation or ingestion of irradiated food or water. Late somatic and genetic effects include disorders from early exposure plus radiation exposure over longer periods due to consumption of contaminated food crops, animal products, and drinking water, or exposure to contaminated ground.

In addition to the effects of radiation exposure, health impacts include any accidents or other health effects resulting from individuals attempting to respond to the accident, such as traffic accidents during an evacuation. Also included are the costs and expenses to monitor and treat the health effects. These begin soon after radiation exposure and may last several generations to include detection of genetic effects.

Social/Psychological Impacts

One can reasonably predict that some, but not all, of the social and psychological effects of a radiological accident will be similar to the effects observed at other types of disasters and during the accident at Three Mile Island. Certain characteristics of the population in the preaccident phase--such as knowledge of protective actions and attitudes about nuclear power--can affect behavior during an accident. After a warning is given, people tend to confirm the warning, try to obtain additional information, inform friends and family members and discuss proper actions. The experience of TMI indicates that some people will begin to evacuate during the warning phase. If the amount of radiation released is large enough to cause significant damage to peoples' health, then it will be important to estimate the extent to which people take proper protective reactions: In case sheltering is recommended, it will be important to predict the number of people that fail to shelter properly. In case an evacuation is called, it will be important to estimate the total evacuation time, and the number of people that fail to evacuate.

The family is important during disasters. People are willing to spend extra time in the danger zone in order to unite their family before evacuating. The decision to evacuate or not to evacuate is typically made as a family. If family members evacuate separately, they typically try to reunite as soon as they are out of the danger zone.

It is commonly believed that panic is a major problem during evacuation, but careful research on a very large number of disasters including TMI has yielded few cases in which panic is a major problem. From this evidence it is reasonable to predict that for relatively small radiological accidents under the most probable circumstances panic will not be a major problem. However, a large radiological accident occurring under special circumstances conceivably could cause panic or related serious evacuation problems.

Evacuees typically prefer to stay with relatives or friends, or in commercial accommodations such as hotels and motels. In most disasters only a minority of evacuees stay in public shelters, and even those people usually try to leave the shelter as soon as possible in order to stay with relatives or in other more comfortable quarters.

If an area is interdicted, one can expect that citizens will attempt to influence interdiction, decontamination and resettlement policy, and that these attempts will be stronger the longer the interdiction lasts. Authorities will be faced with a dilemma: if they set interdiction standards loosely, they will risk being accused of failing to safeguard the public--people will lose faith in government standards, and some people might avoid entering areas and avoid purchasing products that the government has certified as safe. On the other hand, if the authorities set interdiction standards strictly, some people will perceive correctly that they can violate government interdiction policy with little danger to their health.

Studies of natural disasters that caused few deaths reveal little evidence of long-term adverse psychological effects. There is some evidence, however, that disasters that cause a large number of deaths and widespread destruction can cause long-term mental health problems. In the case of even a relatively small radiological accident, a change in public opinion toward nuclear power could be an important impact.

## Institutional Impacts

Analysis shows that institutions can be affected by two classes of impacts as a result of a radiological accident: temporary effects (occurring only during the active phases of the accident), and long-term impacts (relatively permanent changes that take place during the aftermath of the accident). While the two are causally related, experience from other types of disasters (both from natural and technological causes) indicates that major long-term effects tend to be much less likely than might be expected.

Temporary effects of a radiological accident are largely in the form of adaptive responses on the part of various institutions to the extraordinary demands created by the need to warn, inform, protect, temporarily shelter and resettle large population groups located within the risk area. Special population groups (school children, patients at medical facilities, prison inmates, etc.) pose particularly difficult problems for institutions during a mass emergency such as a radiological accident. In order to deal with the demands of an emergency, institutions often find it necessary to expand or extend their organizational structures or responsibilities. In numerous situations, even this response is inadequate, and new structures (e.g., multi-institutional committees or citizen volunteer groups) emerge to provide adequate coordination of tasks, or to perform functions outside the normal operating modes of existing institutions.

In most instances, these temporary adaptive responses do not have significant permanent effects on organizations. However, organizational changes, particularly in the area of efforts to improve emergency planning and response capabilities generally do occur to varying degrees. In the event of a sizeable radiological accident, some changes are very likely to be made within all types of institutions. In addition, the political and legal ramifications of such an accident will serve as further impetus to organizational changes and other effects on institutions.

## Current Methods for Assessing Nuclear Reactor Accidents

The NRC's ability to assess socioeconomic accident consequences has been significantly enhanced with the recent development of some specialized computer models, the improvement of existing models and improved data gathering techniques. All of these enhancements emphasize site-specific information, the use of which should provide more reliable estimates.

The model most commonly used by the NRC to estimate off-site accident consequences is the CRAC2 code. Apart from meteorological data, CRAC2 was designed to be used with generic information; however, a considerable number of inputs to the program can make use of site-specific information. We have provided the sources of site-specific information being currently used by the NRC and its contractors in developing EIS's. Because data developed by the federal government would usually be available for all reactor sites, we have relied on it whenever it was available. In other instances, we have had to draw upon state- or locally-developed data sources.

Because CRAC2 is relatively crude in the way that it estimates off-site accident consequences--except those relating to health effects--other models available to the NRC or currently under development serve to complement the information provided by CRAC2. The BEA RIMS II model is useful for providing estimates of the indirect effects of an accident. It does this through an impact analysis of an "affected" and an "unaffected" region. The MASTER model developed at Pacific Northwest Laboratories can also be used to provide estimates of direct and indirect regional impacts. HECOM is a health effects cost model that takes CRAC2's estimates of the health effects of an accident and uses these to provide estimates of the direct costs of health care and the societal losses due to impaired productivity and premature death caused by the accident.

DECON is a computer model currently under development that takes the CRAC2-produced ground concentrations of contaminants and identifies cost-effective decontamination procedures. DECON selects the method, computes the decontamination cost and develops a decontamination schedule so as to minimize the accident consequences, given a user-supplied level or standard of clean-up.

Finally, a model that is being developed for FEMA is examined. Named the Economic Recovery Dynamics Model (ERDM), it has the potential to investigate the consequences from various policy decisions that might be made following a severe reactor accident. The model is currently being designed to simulate recovery of the U.S. economy following a nuclear attack.

## Evaluation of Accident Risk

Socioeconomic impact analysis is useful in providing a description of what happens as the result of some event or project. It also can provide a good picture of the distribution of the impacts; that is, which groups benefit and which groups lose because of the event or project. A common use of impact analysis is to show regional distributions of impacts, especially when one region loses substantially while other regions benefit.

While the distributional effects are an important dimension in policy evaluation, another aspect concerns the efficient use of society's resources. Issues such as whether society's resources are best spent on improving reactor plant safety, or alternatively on improving evacuation response, health care, or even the quality of education need to be examined with respect to net benefits to society as well as their distributional aspects. Because these efficiency issues tend to be ignored or even misrepresented by impact analyses, it was felt important to address them in this report, especially if policy decisions are to be based on the analyses.

Among the impacts that fail to provide a reliable indication of social costs are sales and production impacts; in general, the loss of sales and production resulting from, say, major disasters seriously overstate the costs to society. An accurate measure of losses within the business sector is provided by the loss of wealth, or equivalently, the present discounted value of the earnings stream. Wealth losses, however, are usually much more difficult to measure than sales or production losses.

The reporting of both job losses and loss of wage and salary income overstates the social loss. The loss of factor payments, by themselves, is usually a fairly reliable measure of the social loss due to deferred or reduced production. Factor payments include wages, salaries, rents, interest, dividends and retained business earnings.

In situations where property loss is widespread, assessing the social loss at pre-accident market value can seriously understate the true social cost. First, if a significant proportion of the housing within a town or city is removed from the usable housing stock, losses may greatly exceed the pre-accident market value estimate. The reason for this is that some people place a greater value on their property than that indicated by the current market price. Furthermore, because substitute housing opportunities within the town have been significantly reduced by the disaster, the social loss from a particular housing unit is even greater.

Losses within the public sector include resources used directly in coping with the emergency and recovering from it. A loss of tax revenues, however, does not constitute a social cost, since tax payments and other purely monetary transactions--such as payments for welfare and unemployment--are transfers rather than costs; no scarce resources are used up.

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# 1.0 INTRODUCTION

This study was conducted by the Pacific Northwest Laboratory (PNL) for the Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES). It was undertaken primarily to assist the NRC in assessing potential social and economic impacts of severe radiological accidents at nuclear power plants. Although the likelihood of such accidents is extremely remote, the NRC must assess the accident consequences when making siting decisions, when preparing environmental impact statements, and when developing and implementing safety goals.

## 1.1 ORGANIZATION

This report is organized as follows. In the next section we present briefly, as background information, the evolution and nature of the NRC's concern with severe accident issues. This is followed by a statement of the objectives of this report. A short description of the approach that has been taken concludes this chapter.

The next four chapters address the expected accident impacts in each of four broad areas. The economic impacts are addressed in Chapter 2; Chapter 3 encompasses the health impacts; the social and psychological impacts are covered in Chapter 4; and the institutional impacts are examined in Chapter 5.

Chapter 6 raises and addresses the issue of the social impacts versus the social costs of a severe reactor accident. This distinction is an important one because, as argued in this chapter, impact analysis provides a relatively weak basis for making policy evaluations, as compared with social cost-benefit analysis. The chapter then considers the major impacts of a reactor accident and compares these with the social costs of the accident. The purpose of this analysis is to determine whether these commonly reported impacts underestimate, overestimate or equal the true social cost of the effect in question.

In Chapter 7 several models are considered that can be used for estimating accident consequences. First and foremost is the CRAC2 (Calculation of Reactor Accident Consequences, Version 2) model developed for and used by the NRC to simulate a reactor accident and to estimate the health and major economic impacts from the accident. Also considered are some models that are not currently used for accident impact analysis but have the potential to be adapted to this use. Finally, four specialized models are described. Two of these--MASTER, developed by PNL, and RIMS II, developed by the Bureau of Economic Analysis (BEA)--provide estimates of the regional employment and output effects of a reactor accident; the other two models, also developed at PNL, provide estimates of the health costs and the interdiction/decontamination costs of a reactor accident.

## 1.2 BACKGROUND

Regulations promulgated under the National Environmental Policy Act (NEPA) of 1969 require the NRC to prepare Environmental Impact Statements (EISs) prior to issuing a construction permit or operating license for each new nuclear power reactor. The EIS addresses the health, environmental and socioeconomic impacts of nuclear power reactor construction and operation.

The NRC has included accident scenarios in EISs since 1971. However, the March 28, 1979, accident at Three Mile Island suggested a need for changes in NRC policies relating to the potential impacts of serious accidents (Fed. Register Vol. 45, No. 116, p. 40101). Previous policy was therefore revised to require an analyses of health and safety risks associated with public exposure to radiological releases; these analyses are to reflect the current state of knowledge regarding such risks. In addition, consideration is required of potential socioeconomic impacts associated with emergency measures during and following an accident (Fed. Register, p. 40103).

The accident at the Three Mile Island nuclear power plant is suggestive of the nature and magnitude of potential impacts from a nuclear power plant accident. The President's Commission on The Accident at Three Mile Island estimated the total cost of the accident at somewhere between $1 billion and $1.86 billion (Report of the President's Commission on The Accident at Three Mile Island 1979, p. 32). Considering that officially recommended evacuations were minimal, that there were no significant health effects, no off-site cleanup and no areas interdicted, the impacts of Three Mile Island were both major and widespread. For example, the direct economic cost--including lost wages and evacuation costs--for those living within 15 miles of Three Mile Island was estimated at over $18 million (Flynn 1979). Although physical health effects were insignificant, The President's Commission concluded, "There was immediate, short-lived mental distress produced by the accident" (Report of the President's Commission on the Accident at Three Mile Island 1979, p. 34-35). A complete review of the process of federal regulation of nuclear power and a reexamination of NRC procedures were prompted by the accident, and numerous institutional changes were made as a result. Although a really severe reactor accident is extremely unlikely, the impacts could be magnitudes greater than those from Three Mile Island.

As the accident at Three Mile Island demonstrates, events that occur during and following a reactor accident are a complex interaction between physical phenomena and human responses. In particular, the socioeconomic impacts depend on the nature and severity of the accident, its location, the characteristics of the population, and what people do during the accident. For example, differences in the type and severity of the accident would cause the economic and health effects to vary. Similarly, identical accidents at two locations, one rural and the other near a metropolitan area, would produce very different effects. Lastly, differing human responses--such as the effectiveness of public officials, how rapidly individuals evacuate, whether they panic, and how they perceive the risks of radiation exposure--would also cause otherwise identical accidents to have different effects.

## 1.3 OBJECTIVES

It is within this context that the NRC commissioned PNL to perform the present study. The primary objectives of this study are: 1) to synthesize the current knowledge regarding potential socioeconomic effects of severe nuclear power plant accidents; 2) to evaluate current methods for assessing these socioeconomic effects; and 3) to provide improved methods for assessing these effects. The first objective is addressed primarily in the first four chapters, where the likely economic, health, social/psychological and institutional effects are discussed. Current methods are evaluated in Chapters 6 and 7--whether impact analysis itself is an appropriate technique is evaluated in Chapter 7, and specific models are evaluated in Chapter 6. These chapters also suggest improved methods for assessing the accident consequences. Chapter 7 indicates how social cost-benefit analysis could lead to improved estimates of the accident consequences, and Chapter 6 considers some improvements to CRAC2. The recently developed PNL computer models for estimating the health and interdiction/decontamination costs of an accident also are improved methods for assessing accident consequences. Finally, Appendix D provides current estimates of various costs that are required as inputs to CRAC2; users of CRAC2 should find these estimates useful.

## 1.4 APPROACH

The approach followed in this report is relatively straightforward and has already been suggested above. However, in presenting the current knowledge regarding accident consequences (Chapters 2 through 5), we have found it convenient to present the accident consequences according to their chronology. To do this we have divided a severe reactor accident into various phases, as described below.

### 1.4.1 Seven Phases of a Reactor Accident

Some impacts from a severe reactor accident would occur immediately, while others would occur years after the accident itself is over. The accident also would likely cause secondary impacts on parts of the economy far removed from the accident site. For example, an accident might severely impact a distant manufacturer if a supplier was forced to close. For these and other reasons, tracing the process of a power plant accident and estimating its effects are difficult.

For expository purposes, it is convenient to consider a reactor accident over seven phases. The phases are presented below, along with a short description of each.

- Warning Phase: The warning phase begins at the onset of an emergency and includes a number of actions taken to minimize the effects of the accident to on-site workers and to notify the appropriate federal, state and local officials.

- Sheltering/Evacuation Phase: This phase includes actions or decisions to mitigate the effects of the accident, given actual or imminent releases of radiation to the environment.

- Release Phase: The release phase is defined as beginning with actual releases of radiation to the environment. Actions taken by authorities during this phase include monitoring the release and estimating its likely path and dispersion.

- <u>Interdiction Phase</u>: The interdiction phase includes 1) a determination that contamination levels over potential pathways to human exposure exceed safe levels; 2) decision making about the safety of drinking water, aquatic foods, crops, animal products, shorelines, and populated areas; and 3) possible long-term monitoring to determine contamination levels.

- <u>Decontamination Phase</u>: Once contamination levels of interdicted areas have been determined, decisions and actions regarding possible decontamination activities can occur. This phase includes the process of decontaminating affected areas.

- <u>Resettlement Phase</u>: This phase begins when decontamination efforts are considered sufficient to allow reinhabitation of evacuated areas.

- <u>Post-Resettlement Phase</u>: The post-resettlement phase includes periodic monitoring and dose evaluation to determine whether the affected pathways remain safe.

The order in which the phases are presented above would not necessarily be the order in which they would occur during a specific accident. For example, sheltering/evacuation could occur before, concurrently with, or after a radiological release; and certain areas are likely to be decontaminated while others remain interdicted.

In the chapters that follow, we describe the major socioeconomic consequences of a severe reactor accident for each of the following four categories: economic, health, social/psychological and institutional impacts.

## 2.0 EXPECTED ECONOMIC IMPACTS FROM SEVERE REACTOR ACCIDENTS

In this chapter we focus on the major economic consequences of a severe nuclear power plant accident. They are discussed in terms of four broad sectors: individuals and households; the business sector, comprised of industrial, commercial and agricultural enterprises; the government sector, consisting of federal, state and local governments; and, finally, the physical environment. In addition to this sectoral breakdown, we also distinguish between impacts occurring within and outside the directly impacted area. (We define the directly impacted area to include any area that must be decontaminated in order to permit safe inhabitation, and/or any area that was officially evacuated at the time of the accident.)

### 2.1 IMPACTS ON INDIVIDUALS AND HOUSEHOLDS

There are two groups of individuals and households that are considered; the first group consists of those within the directly impacted area, while the second group is made up of those in the host areas.

#### 2.1.1 Individuals and Households within the Directly Impacted Area

Individuals and households within the directly impacted area could experience severe, adverse economic impacts as a result of the accident. In the initial accident phases (warning and sheltering/evacuation), those relatively close to the accident site would be required to evacuate. Many would face the prospect of lost wages and salaries during the evacuation period and would bear, at least temporarily, the burden of evacuation expenses. Evacuation expense items include transportation out of the evacuation zone and shelter and meals during the evacuation period. Additional costs to be considered are the increased risk of property loss through looting, fire or other casualty. In addition, there are the inconvenience costs associated with the evacuation itself. These include waiting in lines to withdraw cash from the bank and to fuel up the evacuation vehicle and the severe disruption of one's daily routine.

Some evacuation costs are likely to be higher the longer one waits to evacuate; for example, the least costly means of public transportation and the most reasonably priced lodging facilities would tend to be taken first. On the other hand, those evacuating from their property earliest would face a higher risk from looting or other casualty to property. In this connection, we observe that some individuals would evacuate the area even before an official evacuation is ordered, while others would refuse to evacuate even after the order is given.

Some people will perceive health risks from property lying outside the evacuation and decontamination zones. Because of these perceptions, owners of such property could conceivably suffer some decline in its value. (However, the evidence from Three Mile Island suggests that uncontaminated property near an accident site will not lose value (Flynn and Chalmers 1979). In addition, all property within the decontamination zone could be expected to decline in value. First of all, the property would have to be decontaminated before it could be restored to productive use; loss of use of the property pending decontamination would detract from its pre-accident value. Second, the decontamination necessary to restore the property would usually be relatively costly. Third, even after the property has been decontaminated, some residual contamination would remain. Concern about health risks from the residual contamination would cause the property value to be further discounted. Finally, property values are determined largely by the location of the property and its proximity to desirable and/or undesirable activity areas such as schools, parks, smoke stacks, etc. Since a severe accident could be highly disruptive of these spatial relationships, property values which are dependent upon them could also be significantly affected. On balance, property values could be expected to fall as a result of the accident.

In addition to bearing direct property losses, individuals would also suffer from the uncertainty associated with the safety of their home and personal property and the security of their pre-accident employment. Some workers may find that, while they have not had to evacuate from their homes, their place of employment has become contaminated. Meanwhile, those previously employed in the evacuated area who are unable or unwilling to obtain employment in the host areas would continue to suffer a loss of income. For some households there may be serious financial problems if cash or credit sources become depleted.

During the interdiction phase of the accident, serious, adverse impacts on individuals and households would continue. Those with residences near the accident site would have to relocate, since a large area around the plant would be interdicted. Those residing further away may search for semi-permanent living quarters until their pre-accident residences could be decontaminated. It also seems likely that personal property not taken out of these areas during evacuation would remain inaccessible. A schedule for decontaminating property would be developed, and while lightly contaminated property could receive immediate attention, other property could remain unusable for periods up to several decades or more.

During the decontamination and resettlement phases, individuals and households would be permitted to return to the noninterdicted portions of the accident area. The extent of the resettlement would be affected by the desire (social/psychological willingness) to return and the availability of employment opportunities. The social/psychological status of the population would also be conditioned by the extent of decontamination and the resolution of liability for lost property--the former factor affecting perceptions of health risks, and the latter impacting directly on household wealth.

The consequences to individuals and households discussed above would be mitigated to the extent that disaster aid from federal, state and local government agencies and from private sources was made available to the victims.

### 2.1.2 Individuals and Households Outside the Directly Impacted Area

Those residing in the host areas outside of the directly impacted area would also be affected by the evacuation. The influx of evacuees would mean greater traffic congestion, increased crowding of stores and other public places, increased competition for jobs, and higher prices for and perhaps shortages of goods and services--at least in the short run. Impacts attributable to this phase but occurring much later could include 1) an increase in retail electricity prices, since the lost power must be replaced from alternative sources, and 2) higher taxes--or a deterioration in some public services--to enable the local government to meet its increased responsibilities.

Because of the influx of evacuees, there would be an increased demand for goods and services. Although this situation would not likely persist over the longer run, some employees might benefit from opportunities to work overtime, and there might be some new job opportunities as well. Finally, to the extent that some of the evacuees would seek to establish a permanent residence in the host area, real property values would tend to increase. On the other hand, residents of the host areas might also experience higher prices, such as for substitute power, and pay higher taxes in support of transfer payments to individuals from the directly impacted area.

## 2.2 ECONOMIC IMPACTS ON BUSINESSES

As with individuals and households, we distinguish the business sector lying within the directly impacted area from the business sector outside of this area, for the impacts are likely to differ not only in degree, but also in direction.

### 2.2.1 Impacts on Businesses within the Directly Impacted Area

During the warning and evacuation phases, businesses in the directly impacted area must make preparations to curtail operations. This may include the closing down of production lines, loading of valuable papers for evacuation, and securing of the premises. In some instances closing down a production line can be a lengthy and costly process; further, failure to properly close down the line could produce a hazardous situation. It is not difficult to imagine circumstances in which the employees' desires to reunite with their families prior to evacuation could sharply conflict with employers' desires to curtail operations in an orderly fashion.

Certain types of businesses within the directly impacted area would be heavily impacted by the evacuation itself. These businesses include gasoline service stations, supermarkets and other retail food outlets, and financial institutions. If the warning period is short, long queues can be expected at such establishments as people provision themselves for an extended absence from their homes. These businesses may also have a difficult time keeping their employees on the job to service the evacuees, and they may also have insufficient inventories on hand to satisfy the demand. Heavy withdrawals from financial institutions may require intervention by the Federal Reserve Board, such as designating local banks reserve depositories and thereby providing a means of quickly increasing their liquidity.

Trade between businesses within the directly impacted area and those outside would be suspended. Those outside establishments could be seriously impacted, at least in the near term until they can locate alternative sources of supply. Similarly, outside establishments shipping to within the directly impacted area would suffer the consequences of lost sales.

During the release phase businesses would suffer property losses due primarily to contamination of plant, equipment, inventories and supplies. Additional losses could occur through looting, fire or other casualty. Businesses dealing in perishable commodities could experience large losses in very short periods of time. In addition, if businesses are forced to remain closed over an extended period, depreciation losses could also become significant.

Certain types of businesses--especially those dealing in food stuffs--are particularly likely to suffer permanent damage. Even after an area has been successfully decontaminated, people may still perceive a health hazard from, say, food produced on decontaminated agricultural lands. Also, tourists may avoid eating in restaurants within the decontamination zone; indeed, tourists may avoid the affected area entirely.

Finally, for businesses located in an area that has been seriously and permanently disrupted by the radiological accident, reopening may not be a viable economic alternative. For example, a retail store may be located in an area that has permanently lost a large proportion of its population as a result of the accident. The remaining population may provide an insufficient volume of business to warrant continued operations.

The resettlement phase is a period of transition. Pre-accident business conditions are not likely to prevail until this phase is completed. This means that businesses that reopen may have to operate at a loss until they can reestablish their pre-accident trade patterns. An additional consideration concerns post-accident consumer expenditure patterns. Unless there is total restitution for property losses incurred by individuals and households, the decline in consumer wealth may cause expenditures out of current income to fall below the pre-accident level. This reduction in demand would adversely affect a significant proportion of businesses within the directly impacted area. On the other hand, the increased level of government activity and influx of personnel may temporarily offset at least some of the reduction in demand.

### 2.2.2 Impacts on Businesses outside the Directly Impacted Area

Before dealing with the economic impacts on businesses in the host areas, we take note of two issues that are national in scope. There may exist within the directly impacted area key facilities, the closing of which would have important implications for either the national economy or national security. For example, a large, financially troubled corporation might operate a key production line or acquire key inputs within the directly impacted area. If the loss of such facilities significantly reduced the corporation's wealth or its ability to maintain production, the company could be forced into bankruptcy. Countervailing actions might be taken by either private or public institutions; for example, the Congress might appropriate funds to be used as a loan to the corporation.

Similarly, key defense facilities might be endangered by a nuclear power plant accident. These might include military bases, ordnance production facilities, or transportation and communications facilities. While perhaps little could be done on short notice to eliminate the adverse impacts, the government and businesses might at least concentrate on: 1) removing key plans, tools or materials for production lines; 2) using alternative communications or transportation routes and facilities where possible; and 3) minimizing the adverse impacts of any potential contamination through advanced planning. Of course, in the long run, such considerations should be explicit in the decision where to site such defense facilities.

Apart from the key facilities effects just described, there are two other relationships that could cause businesses outside of the directly impacted area to be affected by the accident. One of these was noted earlier--the reduction in trade with businesses within the directly impacted area. Businesses receiving goods from the impacted area would find their supplies disrupted. Until new sources of supplies could be identified, such businesses might increase prices to ration the existing supply.

The second relationship concerns the in-migration of evacuees into the host areas. This in-migration would increase aggregate demand within the host areas and would tend to reinforce the upward pressure on the prices of affected goods and services. To handle the larger volume of business, firms would attempt to hire more workers, and this could put upward pressure on factor costs; however, the affected firms should be able to hire additional workers from among the evacuees.

If businesses were operating at or near full capacity prior to the accident, then the increase in aggregate demand could result in production bottlenecks. Such bottlenecks, however, would be a short-run phenomenon, unless government officials succeeded in freezing prices and/or wages.

These impacts in the initial phases would generally continue during the intermediate phases, although in different degrees. The release of radiological material and the subsequent contamination of the evacuated area would mean that owners of affected businesses in the host areas would experience increases in wealth. If they expected the increased demand to persist, they might decide to invest in new plant and equipment, especially if they were already operating at or near full capacity. On the other hand, businesses dependent on natural resources and/or intermediate goods and services from the directly impacted area must search for new sources of supply if they are to maintain or increase production.

In the later phases of the accident, conditions in the host areas would tend toward their pre-accident status. To the extent that evacuees decided to permanently relocate in the host areas, new firms might establish themselves there to exploit the increased demand, especially if existing firms were earning abnormally high profits.

## 2.3 IMPACTS ON THE GOVERNMENT SECTOR

A severe radiological accident could be expected to cause major impacts on the affected local governments and mild to moderate impacts on the federal and affected state governments. The impacts would include a change in revenues --due to tax collections on sales, income and property values--and expenditures --due to emergency response costs, including transfer payments. For local governments, however, there is a difference, depending upon whether they serve the directly impacted area or the host areas. In the former, revenues would fall as economic activity declines; in the latter, revenues would rise as economic activity increases.

The federal government has two concerns not shared by the other levels of government. First, as we have already noted, the federal sector may be concerned about the implications of the potential loss of key national economic or national security facilities. Second, the Federal Reserve System might have to take measures to mitigate the potential for runs on banks.

Both the federal and state governments could be involved in providing financial and other assistance to individuals, businesses and local governments. Several agencies of the federal government that might be affected include the Department of Housing and Urban Development, the Small Business Administration, the Federal Emergency Management Agency, the U.S Corps of Engineers and the U.S. Army.

Impacts on municipal and county governments in the directly impacted area would likely be severe. First of all, many local government agencies would be included in the various emergency operations from evacuation to monitoring and cleanup. Other local government agencies might have to reorganize in temporary quarters outside of the contaminated areas, while still other agencies might remain disbanded pending decontamination of former facilities.

Local governments--and to a lesser extent the state and federal government --may suffer a loss in infrastructure, plant or equipment due to contamination. Decontaminating streets, sewer systems, water treatment plants and other public facilities is costly, and such a financial burden on a local government could prove excessive. More than likely, state and federal government assistance would be forthcoming.

During the resettlement phase, the various levels of government would be concerned largely with providing emergency assistance and resolving questions of liability. These functions would be phased out during the post-resettlement phase. However, the level of government expenditures for monitoring and testing as well as for transfer payments could remain substantially above the pre-emergency levels.

In the long run, the local tax base distribution could be altered as the population, economic activity and wealth of the community becomes redistributed from the directly impacted to the outlying areas. Since many of the services provided by local government require heavy initial investments which must be amortized regardless of any subsequent changes in demand, the per capita cost of such services in the resettled area may rise above pre-accident levels. As already noted, it also seems likely that long-term transfer payments from the federal and state governments would be necessary to keep the local government financially afloat.

If the accident causes property values to permanently decline, then an increase in the local property tax rate may be required to offset the loss of revenue and reduction in the tax base. Such an increase in the tax rate, however, if applied to businesses would increase their costs of doing business thereby impacting output, employment, prices and profits. The reduction in firm profits would cause a fall in the value of the firm and possibly reduce the level and rate of net investment. Finally, the pressures on the local banking community could conceivably lead to an increase in bank insolvencies.

## 2.4 IMPACTS ON THE ENVIRONMENT

It is convenient to treat the environment in terms of four categories: recreational areas, natural resources, aesthetics, and wildlife. In general, there would be interactions among these in response to changes in any one of them. However, during the initial phases, no direct environmental damage is likely to occur, except under special or unusual circumstances.

Indirect impacts could occur if recreational areas are within the impacted area. In this case, evacuation means lack of use of the recreational facilities, but it also means that the facilities would not be maintained during the evacuation period. Recreational areas surrounding the impacted area might get more intensive use, if they are used by the evacuees, either as a shelter area or as a recreational area.

These impacts on the environment would generally continue during the intermediate phases, although in varying degrees. Indeed, the impacts on the environment during the intermediate phases could be very severe, and the decontamination process could meet with only limited success. The contamination of large areas containing wildlife could be destroyed, possibly over the long term, and the damage could spread via the food chain to environments not directly impacted. Similarly, recreational areas could also be lost.

Losses to the environment would be conditioned by the extent and success of decontamination. However, even if decontamination were completely successful, there could still be some irreplaceable losses--e.g., the loss of an endangered species during the period of interdiction.

In the next section, we consider the long-term economic impacts from major radiological disasters. Since there have been no such events in the United States upon which to base our experience, we draw instead upon the literature concerning the long-term economic impacts of severe natural disasters. A discussion of these is presented in Appendix A. The following section is based upon the conclusions contained in this appendix.

## 2.5 LONG-TERM IMPACTS FROM MAJOR RADIOLOGICAL DISASTERS

In this section, we consider the extent to which the patterns observed for major natural disasters are likely to hold for severe radiological disasters. Since there has been no experience in this country with disasters of the latter type, the conclusions of this section must be conjectural.

The most fundamental question faced by most urbanized areas following a major disaster is whether or not the area should be rebuilt. But since in almost every natural disaster, the value of what remains is almost always greater than the value of what has been destroyed (Dacy and Kunreuther 1969, p. 138), the decision is almost always to rebuild the city. On the other hand, the loss from a severe radiological accident is virtually total within the interdiction zone, an area that covers at least the path of the plume out to a distance of 20 to 30 miles. Out to about 100 miles for most property, and at least twice this distance for crops and milk there is the considerable cost of decontamination. Consequently, if major portions of a city are within the interdiction zone, there is serious doubt whether or not the city would be reestablished after the accident.

Should the city not be reestablished, then the major economic impacts--other than the loss of economic activity within the city's borders--would tend to be diffused among the various areas in which the disaster victims resettle. If the city is reestablished, then its new location may be several miles removed from its former location, given the size of the interdicted area. For a disruption so severe as to necessitate the relocation of a major populated area, the impacts would be difficult to predict.

On the other hand, the city may only be peripherally affected by the accident, with some portions of its area in the decontamination zone, but none or little within the interdicted area. In this case, assuming that most of the former residents are willing to return and live in the area once it has been decontaminated and declared safe for habitation, the impacts would consist primarily of: 1) relocating businesses and residences that were within the interdicted area; and 2) decontaminating the contaminated areas. These activities are similar to: 1) preventing rebuilding in floodplains following a flood or in unstable areas following an earthquake; and 2) cleaning up the other damaged areas so that they can be reinhabited. Thus, in these circumstances, the patterns and impacts described in Appendix A would likely apply.

The major possible exception to the above conclusion might occur in cases where significant numbers of prior residents refused to return because of health concerns, even though the area had been officially declared safe. Public scepticism with regard to such pronouncements is not uncommon. Additionally, cancer is not an uncommon cause of death; it is also the most likely health effect from a severe radiological accident. Thus, the public may have difficulty in discerning the difference between accident-caused cancers from those that would have occurred even had there been no accident. It should also be noted that a major factor in the willingness of prior residents to return to their homes is the extent to which they would be compensated for their property. One would expect abandonment in these circumstances to be relatively rare if no compensation was provided. Much more likely would be some property sales at prices somewhat discounted from pre-accident levels.

In summary, the long-term economic impacts of a severe radiological accident near a city are likely to depend critically on how much of the city is within the interdiction zone and on the extent of contamination and the cost of cleanup in the decontamination zone. If the interdiction zone contains major portions of the city, then the city would probably be totally relocated or dissolved.

If, on the other hand, restoration could be fully accomplished through decontamination, then the city's future would depend largely on whether the residents would be confident that the area was safe to live in, official pronouncements on the safety of the area notwithstanding. Unfortunately, our knowledge of how an American community would respond in such a situation is limited to the experience at Three Mile Island; and even though the contamination of off-site property from this accident was virtually nonexistent, there were still high levels of concern among the local population.

## 2.6 CONCLUSIONS

Based on the discussion in this chapter, a number of conclusions can be drawn regarding the economic impacts from a nuclear accident. First, depicting such economic impacts requires a fairly involved series of "models" spanning both the local and the nonlocal economy as well as the interrelationships between the economy and other impact categories (e.g., social/psychological).

Second, the impacts flowing from any perturbation--even just a warning--can have consequences that alter the long-run equilibria existing prior to the perturbation both within and outside the accident-impacted region. Table 2.1 depicts the relative importance and predictability of the economic effects. The potential long-run impacts are shown by the lines drawn from the warning phase through the post-resettlement phase.

Third, in many cases, the extent of the impact is determined by the interactions of several variables. For example, following a nuclear accident, the level of long-run migration is, in part, a function of the employment opportunities within the impacted area. The latter, however, are in part determined by the state of the local economy (e.g., business sales), which are in turn partly determined by the demand for goods and services, which is itself partly determined by the level of population in the service area. Table 2.1 indicates that the most important impacts are likely to be large losses of plant and equipment and other capital equipment and facilities, individual wealth, the infrastructure and expenditures of government, and environmental impacts.

Finally, it should be emphasized that the costs of a nuclear accident are borne by economic units (i.e., individuals, businesses, and government) both within and outside the directly impacted area. These costs are both a direct and an indirect consequence of the accident. For example, direct costs of power may rise as substitutes are sought to replace the loss in generating

TABLE 2.1. Importance and Predictability of Economic Impacts

| Impact | Accident Phase | | | | | | |
|---|---|---|---|---|---|---|---|
| | Warning | Evacuation | Release | Interdiction | Decontamination | Resettlement | Post Resettlement |
| **Business** | | | | | | | |
| Input Factors | I2/P2 → | → | → | → | → | → | → |
| Products Supplied | I2/P2 → | → | → | → | → | → | → |
| Prices | I2/P2 → | → | → | → | → | → | → |
| Revenue | I2/P2 → | → | → | → | → | → | → |
| Costs | I2/P2 → | → | → | → | → | I1 → | → |
| Value of Firm | I2/P2 → | → | I1 → | → | → | → | → |
| Key Facilities | | I2/P1 → | I1 → | → | → | I2 → | → |
| Investment | I2/P2 → | → | I1 → | → | → | I1 → | → |
| Plant & Equipment | | I3/P1 → | I1 → | → | → | I2/P2 → | → |
| Loan Needs | I2/P2 → | I1 → | → | → | → | → | → |
| **Individuals** | | | | | | | |
| Income | I2/P2 → | → | → | → | → | → | → |
| Expenditures | I2/P2 → | → | → | → | → | → | → |
| Wealth | I2/P2 → | → | I1 → | → | → | → | → |
| Employment | I2/P2 → | → | → | → | → | → | → |
| **Government** | | | | | | | |
| Expenditures | I2/P2 → | I1 → | → | → | → | → | → |
| Revenue | I2/P2 → | → | → | → | → | → | → |
| Key Facilities | | I1/P1 → | → | → | → | I2 → | → |
| Infrastructure | I2/P2 → | → | I1 → | → | → | → | → |
| Bank Reserves | I2/P2 → | → | → | → | → | → | → |
| Tax Base | I2/P2 → | → | → | → | → | → | → |
| **Environment** | | | | | | | |
| Recreation Areas | I3/P2 → | → | I1 → | → | I2 → | → | → |
| Natural Resources | I3/P2 → | → | I1 → | → | I2 → | → | → |
| Aesthetics | I3/P2 → | → | I1 → | → | I2 → | → | → |
| Wildlife | I3/P2 → | → | I1 → | → | I2 → | → | → |

NOTE: Horizontal lines indicate the phases in which the impacts occur. I1 (I2, I3) indicates that, in the authors' opinion, the impact is very important (moderately important, of minor importance); P1 (P2, P3) indicates that it is relatively easy (moderately difficult, very difficult) to obtain a reliable prediction of the impact. I1-2 (P1-3) indicates that importance (predictability) spans the indicated categories. Symbols indicating importance and predictability (e.g., "I1/P2") are placed at the beginning (left side) of the line. If the degree of importance and the degree of predictability do not change in the subsequent phases, then no other indication of importance/predictability is given. If there is a change, then only the change is noted. For example, if importance remains I1 but predictability changes from P2 to P1 in the Interdiction Phase, then only a P1 is written in the Interdiction Phase; the I1 is not repeated.

capacity; indirect costs to consumers may increase as costs of intermediate goods embodied in final goods increase, or as taxes increase to cover the additional increase in government transfers and expenditures.

# 3.0 HEALTH IMPACTS FROM A NUCLEAR POWER PLANT ACCIDENT

There are a variety of health effects that could result from a nuclear power plant accident, and there are also a number of environmental pathways by which individuals can become exposed to the radionuclides. In this section, we discuss first the environmental pathways and then the events, actions and mechanisms pertaining to the health effects for each of the seven phases of a nuclear power plant accident.

## 3.1 ENVIRONMENTAL PATHWAYS

The health effects from a nuclear power plant accident can occur as a result of exposure to radionuclides through any of several environmental pathways. These pathways are routes of exposure for atmospheric and waterborne releases of radionuclides. The pathways of exposure for airborne releases are:

- o external exposure to the plume
- o external exposure to contaminated ground
- o inhalation of the plume
- o contamination of skin and clothing
- o ingestion of contaminated crops (direct deposition onto crops and root uptake)
- o ingestion of animal products (contaminated feed or forage)
- o inhalation of resuspended radionuclides.

The pathways of exposure for waterborne releases are:

- o ingestion of drinking water
- o external exposure while boating or swimming
- o external exposure to shoreline
- o ingestion of aquatic foods
- o ingestion of crops contaminated by irrigation
- o ingestion of animal products contaminated by drinking water
- o ingestion of animal products contaminated by irrigated feed or forage.

The time of exposure can vary greatly for the pathways involving ground contamination. Exposure can be significant until the radioactivity decays, is removed by decontamination methods, or is reduced because of downward migration, chemical binding or runoff. Plume exposure is limited to the time of plume passage. Movement of the waterborne radiation through the surface water system can also result in exposures over extended times, depending on radioactive decay and transfer between water and sediment.

## 3.2 TYPES OF HEALTH EFFECTS

Radioactive materials released to the environment may result in exposure of the public to radiation. Health effects from this exposure can be categorized into three general classes:

- early somatic effects
- latent somatic effects
- genetic effects from chronic exposure

### 3.2.1 Early Somatic Effects

Early somatic effects of significance are mortalities and morbidities that occur within days and up to one year after exposure. These effects generally involve doses of 100 rads or more. The early somatic effects include death due to bone marrow damage (blood-forming organ), lung damage (pneumonitis and pulmonary fibrosis) and gastrointestinal tract injury. Nonlethal effects include less severe cases of the above plus prodromal symptoms (anorexia, nausea, vomiting and diarrhea), loss of hair, radiation dermatitis, cataract formation, immunological impairment, fertility impairment and radiation thyroiditis.

### 3.2.2 Latent Somatic Effects

External exposure to radiation and intake of radionuclides may produce health effects that appear years after the initial exposure period. These are referred to as latent health effects from acute exposures. Internal contamination would continue until the radionuclides have decayed away or have been eliminated from the body. Latent effects are calculated for external exposure received during the first year and for internal doses from radiation taken into the body during the first year. Also considered is the internal dose received after the first year.

Latent somatic effects include leukemia, lung cancer, gastrointestinal tract cancer, breast cancer, bone cancer, thyroid cancer and hypothyroidism.

### 3.2.3 Genetic Effects

Genetic effects of radiation exposure result from gene mutations and chromosome aberrations. These effects are manifested as an increase in frequency of various abnormal traits among the exposed population. A National Academy of Sciences study (BEIR 1980) indicated the range of effects was from trivial to tragic; some of these effects occurred very soon after exposure while others did not show up for generations.

A representative estimate of the range of health effects following chronic radiation exposure can be obtained using the method employed in the Reactor Safety Study (USNRC 1975). The Reactor Safety Study considers three types of genetic effects (resulting from chronic exposure):

- o autosomal dominant disorders
- o multifactorial disorders
- o disorders due to chromosomal aberrations

Autosomal dominant disorders result from chromosomal mutations associated with dominant traits. Multifactorial disorders result from mutations at more than one genetic locus. These disorders include a variety of congenital malformations and degenerative diseases. The consequences of chromosomal aberrations result from having the wrong number of genes or the wrong type of genetic material rather than from intrinsic changes. The majority of chromosomal aberrations result in spontaneous abortion.

## 3.3 VARIATION IN HEALTH EFFECTS BY ACCIDENT PHASE

In this section we consider the events, actions and mechanisms associated with potential health effects resulting from a nuclear power plant accident.

### 3.3.1 Warning Phase

During the warning phase there would be no off-site health effects. However, as the accident progresses, notification of appropriate authorities could be required, and health-related decisions might be taken based on the plant's monitoring instruments. Estimates of the course of the accident would be made, including consequences that would result from potential releases. For minor accidents--those without radionuclide releases to the environment--no remedial actions would normally be required to protect the public. However, abnormal radiation exposures to plant personnel could still result from direct exposure through walls with low levels of shielding or from leakage of radiation from the reactor room to occupied areas. Plant personnel may require evacuation and treatment at local hospitals.

Radiation monitoring during this phase is provided by in-place detectors at strategic locations within the plant and to the stack. Stack and liquid effluent monitors are used to detect beta and gamma radiation and sometimes alpha radiation. The expected releases during a radiation emergency would consist mainly of fission products that are detectable with beta/gamma monitors. Costs associated with monitoring during this phase are minimal because in-place instruments are used. The monitoring and evaluation of in-plant hazards would continue after the warning phase.

### 3.3.2 Sheltering and Evacuation Phase

During the sheltering and evacuation phase, decisions are made regarding protective actions to reduce the public's exposure to radiation, given the path of the plume and the estimated air concentrations and dispersions in surface water. There are three possible responses to significantly radioactive airborne releases: 1) evacuation, 2) movement to shelters or in-home sheltering and 3) administration of potassium iodide (KI) tablets as a thyroid blocking agent for radioiodine. The need for these actions must be evaluated for each area affected by the airborne plume. It is possible that all three actions may be required (at different locations about the site) for a given radiation emergency. The evacuation might also cause injuries from traffic accidents, and these should be considered among the other health effects.

Besides the exposure threat posed by the airborne pathway, threatened releases to surface waters could put individuals involved in water activities such as recreational or commercial fishing at risk. Timely evacuation in these circumstances would reduce or eliminate this exposure risk. Also, water treatment plants near the accident site might be in jeopardy and have to shut down temporarily to prevent exposure via the drinking water pathway; this could make evacuation the only viable option, especially if emergency supplies of uncontaminated water could not be made locally available. In place to these potential health risks from not evacuating, the evacuating population faces serious health effects if exposed to the plume during evacuation. Possible health consequences from this exposure include early and latent somatic effects.

Sheltering is a preferred alternative if the threatened population could not be evacuated without exposure to the passing plume. After the plume has passed, a decision would have to be made whether sheltering should be continued or, if the area has been heavily contaminated, evacuation procedures should be initiated. Possible health consequences from radiation received during sheltering include early and latent somatic effects.

The decision to administer thyroid blocking agents must be based on identification of radioiodine as a hazard and the amount of thyroid exposure saved by their use. Potassium iodide could be administered to either evacuating or sheltering populations.

Radiation monitoring instruments would provide the information necessary to decide which protective actions should be taken. Portable monitoring instruments would likely be used in deciding whether to evacuate or shelter. If evacuation is ordered, periodic monitoring would need to be continued after evacuation so that decisions on resettlement, continued interdiction and/or decontamination could be made. Monitoring instruments would also be needed to provide inputs to the decision on whether sheltering should be continued after the plume has passed overhead. Radioiodine monitors (at least at the stack) and an estimate of the contamination level and distribution in the environment would be an input to the decision whether to administering thyroid blocking agents.

### 3.3.3 Release Phase

The release phase begins with imminent or actual releases to the atmosphere and to surface water. During this phase stack and liquid effluent monitors are used to measure the quantity of radiation released to the environment. In-place gamma monitors at the site boundary may also be used if available. Additional monitoring with portable instruments would be initiated to determine the extent and distribution of material in the environment and potential radiation dose levels at downwind locations. Monitoring for specific radionuclides, such as radioiodine, may also be warranted. These monitoring activities would result in costs for personnel, equipment usage and possibly for radiochemical analyses.

The significant radiation exposures during this phase of the accident are:

- o external exposure to the plume
- o inhalation of the plume
- o external exposure to contaminated ground.

Doses from these pathways are determined for specific body organs and are associated with specific health effects. These organs include bone marrow, lungs, gastrointestinal tract and thyroid. The thyroid dose is evaluated to determine the need to administer potassium iodide (KI) tablets as a thyroid blocking agent. If estimated doses to an individual exceed protective action guidelines, then decisions on initiation of remedial actions must be made.

For liquid releases to surface waters, an estimate of potential exposures to drinking water and other water uses must be made. The water-borne pathways generally allow more time to make remedial action decisions because of slower dispersion rates. However, on large, fast flowing rivers evacuation of people engaged in recreational activities may be necessary. Potential doses are calculated for the same body organs considered for airborne pathways.

The cost of health effects include the cost of monitoring and treating both early and latent effects from radiation exposure. These costs begin soon after the radiation release and could continue for years following the accident.

### 3.3.4 Interdiction Phase

The interdiction phase includes protective actions to keep radiation and contaminated items isolated from the public. Area monitors are used to define the extent of contamination. Additional monitoring must be performed on any potential pathway of exposure. This includes monitoring and radiochemical analysis of

- o drinking water
- o aquatic foods
- o crops
- o animal products
- o shoreline sediments
- o irrigation water
- o animal drinking water.

The potential exposure from the waterborne and airborne pathways would be analyzed, and appropriate decisions on interdiction made based on the radiochemical analyses. Decisions need to be made regarding the safety of water, including the safety of shoreline, drinking water, aquatic foods, irrigation water, and water for animals.

Waterborne contamination may require interdiction of aquatic food products (fish, clams, etc.) for both private and commercial uses. Diverting these products to alternative uses may be possible (e.g., fish to make fertilizer) if such activities are economically feasible. The main action would be to prohibit the human consumpiton of contaminated aquatic foods. Interdiction of use of contaminated shore areas may also be required to reduce external exposure. Furthermore, interdiction of potable water supplies may be required until the source water can meet established purity standards.

Decisions required during the interdiction phase from airborne pathways relate to: whether the area is safe to occupy; whether the crops are safe to eat; and whether animal products are safe to eat. Also, it may be necessary to relocate people if the area is unsafe for occupancy. Relocation may include moving people who were not evacuated or preventing evacuated people from returning to their homes. Interdiction of contaminated crops may be necessary to prevent human exposure through the ingestion pathway. Some crops may be diverted to other uses (such as animal feed) or processed for delayed uses (such as by drying or freezing), which may allow the contamination to decay to acceptable levels.

Animal products can become contaminated if animals breathe airborne radioactive material, graze on contaminated pasture or drink contaminated water. Animal products contaminated during the early periods of the accident may require destruction. Diverting the use of animal products to allow for radioactive decay may be possible (i.e., using milk to make cheese).

The immediate protective actions are taken during the first hours following the radiation emergency. Additional long-term actions may be required for protection against lower levels of radiation if such levels do not present an immediate short-term hazard. Included in the long-term actions are:

- relocation of people
- interdiction of use of contaminated crops or animal products
- interdiction of use of potable water supply
- interdiction of use of aquatic foods
- interdiction of water use for animal drinking water
- interdiction of water for crop irrigation
- interdiction of use of aquatic recreational areas.

Health effects for the interdiction phase can result from:

- external exposure to contaminated ground/shoreline
- inhalation of resuspended particles
- ingestion of drinking water/aquatic foods
- ingestion of crops/animal products.

High individual doses are unlikely because the radiation has been dispersed and protective actions have been taken. Even if the water, crops, or animal products are safe enough to consume, some health effects could result. However, the health effects are limited to latent effects from early (first-year) exposure.

The interdiction phase may extend for weeks or months and would require periodic monitoring and evaluation of contamination along potential exposure pathways.

### 3.3.5 Decontamination Phase

Health effects can occur during the decontamination phase, when efforts may be made to decontaminate areas previously interdicted. Decontamination decisions are required for areas contaminated through both airborne and waterborne pathways. Decisions to decontaminate are based on both health and economic criteria. The potential value of the land must be balanced by the cost to decontaminate it to acceptable levels. Therefore, the land use (e.g., farming, residential, etc.) must be considered for each area to be decontaminated.

The only land types likely to be affected by waterborne releases are shoreline and irrigated farm land, where decontamination may be difficult. Contamination levels can be expected to decrease over time as the surface water system is naturally flushed.

Health effects for this phase result from worker exposure during decontamination activities and include continuation of the health effects under the interdiction phase. Workers are exposed by external radiation when near the contamination and by inhalation of resuspended dust created during the decontamination process. These latter health effects would be very small because of regulated decontamination procedures and criteria.

Decisions on decontamination activities are based on area monitoring surveys and are concerned mainly with limiting external exposure to deposited contamination. During actual decontamination activities workers would be provided protective clothing and if necessary respiratory protection and special monitoring would be needed. This monitoring would include airborne contamination monitoring in addition to area monitors.

### 3.3.6 Resettlement Phase

Activities taking place during this phase would include resettlement of the interdicted areas and reuse of decontaminated facilities and areas. A large number of decisions about the safety of land, water, crops and animal products must be made during this phase. Health effects for this phase result from exposure to residual contamination and are received through external, inhalation and ingestion pathways.

Public exposure is very low as areas are resettled and food products are declared safe for use; periodic monitoring should be conducted to substantiate the safety of the public. The monitoring for this phase is the same as (but less frequent than) that for the interdiction phase.

### 3.3.7 Post-Resettlement Phase

In the post-resettlement phase, decisions are required regarding the level of safety within each affected area. If the areas are deemed safe, no further actions are required; otherwise, decisions must be made about what to do and these actions carried out. The principal exposure pathways for this period result from residual contamination in the environment. The contamination levels can be expected to be low and would result in very few (if any) health effects. The principal activity during this time is periodic monitoring of residual contamination. The types of health effects for this period are the same as those indicated for the decontamination and resettlement phases. Latent health effects are included as well as genetic health effects from chronic exposures.

Monitoring may continue for a number of years to ensure that low radiation levels prevail in the areas that were contaminated. Persons with known internal contamination (determined by previous whole-body counts) may be asked to have periodic whole-body counts taken to assure a declining count level over time.

## 3.4 CONCLUSIONS

The importance and predictability of health effects following a reactor accident would depend largely on the severity of the health effect in question. Certain health effects, such as death, cancer and major birth defects, are easy to observe, while others, such as subtle genetic changes are difficult if not impossible to observe. The ability to predict and associate a particular health effect with radiation exposure received during a given accident is less closely associated with the severity of the health effect. Table 3.1 indicates the relative importance of each health effect resulting from a radiological accident, and the potential importance of costs for health monitoring and treatment. The table also .ggests the relative ease of predicting these health consequences.

Early somatic effects begin to appear shortly after large acute radiation exposures that may occur during the early stages of an accident. The symptoms are readily detectable, but they may at first be difficult to distinguish from symptoms caused by psychosomatic effects. As the severity of the health effect decreases, so does the ease of predictability and the ease in associating the effect to the radiation received. At longer times after the accident, minor health effects may occur that are difficult to observe.

Latent somatic effects can be described principally as cancers. Most cancers or their effects on the body are fairly easy to observe. However, because of their low incidence rate following radiation exposure, latent cancers are difficult to predict and to associate with radiation exposure. Because latent cancers may not appear until many years after the accident, it may be impossible to associate cancers with the accident, unless a large number of people have been exposed at significant radiation levels. A large population group is required to provide a statistically valid analysis. The health effects incidence rate of the exposed population can then be compared to the incidence rate observed in an unexposed but otherwise comparable population to estimate the excess due to the radiation exposure.

Genetic effects are those effects manifested as an increase in the frequency of various traits among the offspring of the exposed population. Genetic effects can range in severity from premature death to changes in eye

## TABLE 3.1. Importance and Predictability of Health Effects and Related Costs

| Impact | Accident Phase | | | | | | |
|---|---|---|---|---|---|---|---|
| | Warning | Evacuation | Release | Interdiction | Decontamination | Resettlement | Post Resettlement |
| **Early Somatic Effects** | | | | | | | |
| Early Deaths | | I1[a]/P1[b] → | → | → | | | |
| Early Injury (major) | | I2/P1 → | → | → | | | |
| Early Injury (minor) | | I3/P2 → | → | → | P3 → | | |
| **Latent Somatic Effects** | | | | | | | |
| Cancers | | | | | I1/P2 → | → | → |
| **Genetic Effects** | | | | | | | |
| Major (visible) | | | | | | I1-2/P3 → | → |
| Minor (unnoticeable or unimportant) | | | | | | I3/P3 → | → |
| **Health Monitoring Costs** | | I1-3/P1 → | → | P2 → | → | P3 → | → |
| **Treatment Costs** | | I1-3/P1 → | → | P2 → | → | P3 → | → |

a - Importance; I1 very, I2 moderate, I3 minor
b - Predictability; P1 easy, P2 moderate, P3 difficult

See Table 2.1 for explanation of symbols

color. Many are unnoticeable. Because genetic effects are manifested in offspring of the exposed population, their association with radiation exposure is very difficult to verify. Estimates of the number of latent genetic effects attributable to the accident can only be made for instances where large population groups were exposed.

Following a reactor accident involving radiation exposure of the population, an attempt would be made to monitor the health of the population to mitigate the severity of any health effects that may result. Health monitoring costs are easier to define during the early phases of the accident, but become more difficult in later phases as people move away or rely more on their personal physicians. Similarly, the costs for treatment of health effects become more difficult to define as time passes. Because treatment practices change for a given health problem, so do the associated costs. The costs for a given effect also vary from patient to patient because some people can be expected to recover more quickly than others.

## 4.0 SOCIAL/PSYCHOLOGICAL IMPACTS

### 4.1 INTRODUCTION

As early as the fifth century, B.C., the Greek historian Herodotus studied Egyptian evacuations from the flooding Nile, and during the middle ages accounts were kept of evacuations from European cities, when residents fled to escape epidemic diseases, especially the Black Death (Perry et al. 1980, p. 1). In the early twentieth century, histories were written on evacuations due to a wide variety of causes, and during World War II studies were made of the social/psychological effects of the mass bombings of civilian population centers. The study of disasters became more methodological in the 1950's; particularly noteworthy is a thorough study of the 1953 flood in Holland in which systematic interviews were used to ascertain the flood's impact on individuals and families (Lammers 1953, quoted in Quarantelli 1980, p. 200). In the past twenty years, disaster research has become established as a field of professional specialization in a few universities and research centers, and funding for large-scale systematic data collection has gradually increased. The studies of the social/psychological consequences of the 1979 accident at Three Mile Island are among the most systematic and thorough in the literature, even though they have their limitations (Dynes et al. 1979, pp. 152-153).

At the present time, the research base on the social and psychological aspects of disasters and evacuations is limited and uneven: there are many aspects of disasters about which we lack even the most basic information, while on others there are sufficient data and careful research so that we are able to ascertain that certain "common sense" and popular conceptions about what happens are almost certainly wrong (Quarantelli 1980, pp. iv-v). Before considering the potential effects of radiological accidents, it will be useful to review what researchers in the field consider to be the five most common myths about nonradiological disasters:

Panic. The single most widespread myth about disasters is, perhaps, the belief that people will panic in the face of great danger. In an opinion survey, more than 80 percent of the respondents believed that panic is a major problem in disasters (Wenger et al. 1975, p. 41). The notion that panic is the typical response has been perpetuated by the mass media and by popular and journalistic accounts (Quarantelli and Dynes 1972, pp. 67-68; Wenger et al. 1975; Mileti et al. 1975, pp. 43-61; Quarantelli 1981).

Evacuation. Another myth is that all people will willingly evacuate an endangered area. Investigators have found that in many disasters a substantial minority or even a majority of the population does not evacuate, even in the face of great danger (Wenger et al. 1975, pp. 36, 41; Quarantelli and Dynes 1972, pp. 67-68).

Looting and Crime. Many people believe that looters pour over an evacuated area pillaging homes and businesses. Since looting has been so widely publicized in the case of civil disturbances, apparently most individuals believe that it is common during natural disasters, too. Studies show, however, that looting rarely occurs, and that crime rates usually fall during natural disasters (Quarantelli 1980, pp. 109-110).

Shelter Utilization. In an opinion survey, about 40 percent of the respondents believed that most evacuees go to formally established public shelters. Contrary to this belief, however, even in the largest disasters, the majority of evacuees stay with relatives or friends, or stay in commercial establishments such as hotels and motels (Wenger et al. 1975, pp. 42-43). The misconception is probably due to the fact that the news media usually interview evacuees in public shelters rather than those in private homes. The news media also make it a point to inform the public of the location of public shelters.

Accuracy of News Reports. Most respondents to an opinion survey believed that the news media accurately report disaster situations and effects. However, researchers have found that a major source of many of the misconceptions about disasters is the mass media. They have found that news accounts are not very accurate with respect to conveying the extent of physical damage, human loss, and social disruption. News films, photographs and reports generally focus on destruction or upon the unique events of a disaster, but present them as though they were typical (Wenger et al. 1975, p. 37. See also Quarantelli and Dynes 1972).

The refutation of these five myths is based on a careful examination of considerable data; a more systematic discussion of these myths will be presented later in this section. However, it is worth noting here that these data were collected for nonradiological disasters, so the question naturally arises whether the same principles hold for radiological accidents. According to a staff report to the President's Commission on The Accident at Three Mile Island, that evacuation was more nearly like, rather than uniquely different from, evacuations in other types of emergencies: there were no massive traffic accidents caused by panicky evacuees, people did not flee at the first mention of possible danger, but rather confirmed the seriousness of the threat before leaving, and those who evacuated did so with their families (Dynes et al. 1979, p. 156).

On the other hand, one must be very cautious about generalizing from a single radiological accident, and particularly the TMI accident, since the amount of radioactive material that was released from the nuclear plant at TMI was very small, and there was no general evacuation. Yet, we believe that there are a number of relationships that emerged from TMI and from nonradiological disasters that will prove useful in predicting the consequences of a large radiological accident. These relationships will be explored in this chapter.

The major objectives of this chapter are to identify 1) the most significant social/psychological impacts of a nuclear power plant accident, 2) the most important probable causes of those impacts, and 3) the social/psychological factors that are potentially important determinants of health, institutional, and/or economic impacts. A secondary objective is to provide some information about previous disasters, on the assumption that such information could be relevant to the prediction of the impacts of future nuclear power plant accidents, but with the understanding that in some cases any parallels are tenuous.

## 4.2 BASELINE

Within any community and prior to a disaster threat, there are some conditions that affect the response of the community, and some capabilities for meeting the exigencies of an emergency. In addition to material resources, there are some psychological and social resources, such as knowledge, planning and social linkages between individuals, households, and organizations. This total situation defines the baseline, which we assume would have persisted with little or no change in the absence of an accident. The major elements of the baseline are:

- Knowledge and beliefs about radiation and protective actions
- Demographic characteristics of the population
- Total population
- Physical structure of the evacuation route
- Transportation and other equipment available for evacuation

Knowledge and beliefs about radiation and protective actions are an important determinant of evacuation behavior and level of stress. Prior disaster experience as a determinant of disaster response has been studied for many nonradiological disasters; it is particularly relevant because many researchers believe it to be a crucial factor in determining an individual's response to a radiological accident. In many instances prior experience with floods and hurricanes has led to a certain degree of knowledge and preparation that has led to an improved response. On the other hand, there are many other instances in which people relied too much on prior experience. This is especially true in cases where official warnings were given but a severe flood or hurricane did not follow. In some of these cases people subsequently tended to underreact and failed to evacuate during a real emergency. Thus, prior experience with disasters sometimes increases and sometimes decreases willingness to evacuate. A general model that explains the effect of prior experience on the willingness to evacuate is yet to be developed (Quarantelli 1980, p. 42; see also Mileti et al. 1975, pp. 17-22.).

Demographic and other characteristics of the population are also considered important in determining response behavior. Age, sex, family composition, race, socioeconomic status, religion and work ties are all believed to affect disaster response. In addition, population density is obviously important in determining the probability of traffic jams and total evacuation time.

The physical structure of the evacuation route is crucial in assessing how effectively the population can be evacuated within a given amount of time. For example, if there are just a few major exit routes, it would be difficult to evacuate a large population over a relatively short period.

Finally, transportation and other equipment available for evacuation would also affect how efficiently the evacuation can be conducted. For example, are there sufficient buses and other vehicles available to evacuate school children, hospital patients and prison inmates? Would households be permitted to evacuate in their personally owned vehicles, or would alternative strategies be employed to reduce traffic congestion?

## 4.3 SOCIAL/PSYCHOLOGICAL IMPACTS DURING THE INITIAL PHASES

Disaster response is determined in part by specific characteristics of the threat, such as the speed of onset, length of possible forewarning, area of impact and potential destructiveness. Since radiation cannot be sensed by human beings, and since the general public at the present time has little knowledge of the effects of radiation, it must rely on information from authorities or other experts.

### 4.3.1 Warning Period

The method of the official warning, as well as its characteristics, can influence the type and extent of social/psychological impacts. The public can be issued a warning of a radiological abnormality by several methods: sirens, radio, TV, sound trucks, etc. The methods of communication obviously can affect the content of the message. Evidence indicates that sirens by themselves are inadequate as a means to induce people to take immediate shelter. Sirens might be ignored because they have come to be associated with civil defense "tests". In most cases sirens initiate the seeking of additional information, often from the radio.

After the official notification is given, the word is typically spread to coworkers, relatives and friends. The subsequent process of attempting to confirm the warning, attempting to acquire more information, telephoning authorities, and discussing suitable reactions appears to be typical of disasters (Mileti et al. 1975, p. 44). The radio can be used to transmit, verbatim or almost verbatim, official government warnings and information. However, the radio can also broadcast other information, misinformation and opinions about the disaster. Consistency or inconsistency of the information received can have an important effect both on the level of stress in individuals and on their decision to evacuate. Evidence suggests that, unless people can confirm that they are in personal danger, they would tend not to evacuate (Quarantelli 1980, p. 106).

The official warning could contain some information about a suitable response, and the mass media and private discussions would provide additional information or opinions; knowledge and beliefs could change somewhat from the baseline period. Finally, a certain portion of the population might evacuate at this point, before the issuance of an evacuation advisory. The case of TMI demonstrates that in order to estimate the impacts of a radiological accident, it is important to estimate the number of people that would tend not to evacuate before an evacuation advisory is issued.

It is believed that for most reactor accidents there would likely be a delay before any radioactive material is released into the atmosphere. There could be another delay before the radioactive cloud reached populated areas off of the site. If residents could evacuate before the plume arrived, exposure to radioactivity could be avoided.

In considering whether an area could be evacuated in time, it is natural to imagine traffic jams, especially at major intersections and over narrow bridges. However, time lost before even entering an evacuation vehicle can be at least as important as the time actually required to travel outside the danger zone. According to a study of computer simulations of evacuations (NUREG/CR-2300, p. E-7; citing Aldrich et al. 1979), the most effective way to reduce radiation injuries to the public from a radiological accident is to reduce "delay time"; i.e. to reduce the time elapsed before the public enters a vehicle to begin evacuation.

There are many social and psychological determinants of delay time: Some people might not hear of the evacuation notice in a timely fashion, especially if they are isolated and are not listening to a radio or viewing a television set. Others might have difficulty finding means of transportation, especially if they do not own a car, or if the family car is being used by another member of the family at the time. Still other people, such as migrant workers, may not become informed because they do not understand English.

Total evacuation time can be divided into four components, the first three of which constitute delay time:

- Official Decision Time: The time elapsed between the onset of the accident and the issuing of an evacuation advisory by officials.
- Notification Time: The time elapsed between the issuance of the first evacuation advisory and the hearing (and understanding) of the advisory by people in the evacuation zone.
- Preparation Time: The time elapsed between hearing the advisory and entering a vehicle to leave the evacuation zone.
- Transportation Time: The time between entering a vehicle and exiting the evacuation zone.

Official decision time is discussed in Section 5.0, Institutional Effects. This section is primarily a discussion of the social and psychological determinants of notification time (Section 4.3.1.1) and preparation time (Section 4.3.1.2). Transportation time, although primarily a study within the field of traffic engineering, is treated in Section 4.4.

4.3.1.1 Notification Time. Since most nuclear power plants are located in populated areas, federal requirements for emergency notification of the public within about 10 miles of the plant are fairly strict. About two-thirds of the 91 reactor sites in the U.S. have average population densities (based on the 1970 U.S. Census) of less than 100 persons per square mile in the area within 10 miles of the site. Among the most densely settled within 10 miles are Zion with 657 and Indian Point with 651 persons per square mile. However, within 50 miles of Indian Point, the average population density exceeds 2000 persons per square mile (Aldrich 1982).

Federal guidelines for emergency communications for commercial nuclear power plants are found in USNRC (1980b). According to this document (p. 13), it is necessary to be able to communicate rapidly with the public, since the time elapsed between the onset of accident conditions and the start of a major release of radioactive material into the atmosphere could be as short as thirty minutes. The criteria (p. 3-3) require that the emergency communications system consist of both an alerting signal and radio broadcasts. The purpose of the alerting system is to notify the public to turn on the radio (or TV) to receive further instructions. A number of different types of alerting systems are acceptable: sirens are the most common, either a network of stationary sirens distributed throughout the area, or sirens on police, fire and rescue vehicles. Aircraft and helicopters with loudspeakers are sometimes used.

The National Oceanographic and Atmospheric Administration (NOAA) emergency weather system is another type of notification system whose use has been discussed. NOAA provides continuous weather broadcasts on radio frequencies that are not in the regular commercial AM or FM broadcast bands. Special radio receivers for the NOAA broadcasts are commercially available for about the price of a regular commercial radio. A unique feature of this system is that the radios can be put on "standby"; in other words, the radio is turned on but not heard until a special coded signal is sent from the NOAA transmitter. This transmission activates a loud tone or beeping noise from the radio which alerts the listener that an emergency message is being broadcast. The listener then turns up the volume control to listen to the emergency message (Voorhees 1979, p. 12). NUREG-0654 (p. 3-3) clearly states that a system that expects the public to turn on a radio without being alerted by an acoustic alerting system or by some other means is unacceptable.

The notification system must assure that essentially all of the people within five miles of the site can be alerted by the first alert signal (NUREG-0654, p. 3-3). This is a stringent requirement for many areas, because hills and buildings can block the sound of sirens. The notification system must also be able to alert virtually all of the people 10 miles from the plant within 45 minutes of the issuance of the first notification signal (NUREG-0654, p. 3-3).

If principle reliance is placed on sirens, care must be taken to assure that there are enough sirens, that they are loud enough, and that they have the proper pitch so that everyone can hear them (see NUREG-0654, pp. 3-7 through 3-13). In a recent test of the $2 million system of 88 sirens within 10 miles of the Indian Point No. 2 nuclear power plant in New York, sirens failed to operate in several areas and were inaudible or barely audible to many residents in other areas (New York Times, 4 March 1982).

Care must also be taken that the public knows what the sirens mean. Numerous studies indicate that people often misinterpret sirens, believing them to signal routine fire, ambulance or police business, or believing them to be a preliminary warning that requires no immediate action (Quarantelli 1980, pp. 78-79). In several cases in which air-raid sirens sounded accidentally, studies showed that many if not most people did not believe there was really a threat, even though they had no way of distinguishing a real from an accidental alarm (Strope et al. 1977, p. 12). Another study demonstrated that over 56 percent of the people in three separate incidents did not believe that the sirens they heard really indicated imminent danger (McLuckie 1970, p. 31; citing Marks and Fritz 1954, p. 372).

Loud speakers on trucks, squad cars and helicopters can be used to notify people of an emergency, but they, too, have limitations. After an explosion of toxic chemicals in the city of Minutilli (state and date unreported), organizations involved in the evacuation effort originally tried to warn people by use of loud speakers on police helicopters and on squad cars. The speakers were not totally effective: some people living near the chemical plant had their windows closed and air conditioners running, so they did not hear the announcements over the speakers (Gray 1981, pp. 29-31).

In addition to fixed sirens, initial notification can be given by sound trucks, the sirens on emergency vehicles and church bells. The potential problem with all of these methods is that some people may not know what these signals mean.

In order to confirm that these difficulties have been overcome, NUREG-0654 requires that the Federal Emergency Management Agency conduct approximately once every year a survey based on a sample of all residents within about ten miles of nuclear plants. The purpose of the survey would be to assess the public's ability to hear the alerting signal and to understand the notification message (NUREG-0654, pp. 3-3 through 3-4). Given this strict surveillance of the alert and notification systems for people within ten miles of a nuclear plant, it is reasonable to assume that notification times would be lower inside the 10-mile circle than outside it.

In the event of a reactor accident, officials would decide on the size of the evacuation zone based on the characteristics of that particular accident. Even though NUREG-0654 recommends that the plume exposure emergency planning zone (EPZ) extend to about 10 miles from the plant, the wording of the NRC guidance leaves no doubt that emergency-response procedures should be implemented beyond 10 miles if need be (USNRC 1981b, p. E-6). For a severe accident the evacuation zone would undoubtedly be larger than the 10-mile EPZ. During the accident at Three Mile Island, although emergency plans had been prepared only for the area within five miles of TMI, various officials considered evacuating areas within 1, 2, 3, 5, 10, and 20 miles (Rogovin et al. 1980, Vol. II, Part 3, pp. 1013-1014).

Critics of the emergency plan for the Indian Point nuclear power plant in New York State believe that the plan is deficient because it concentrates on the area within 10 miles of the plant; they believe that planning should cover all areas within 50 miles of the plant, or better still within 200 miles of the plant, since they believe that the risk of cancer would be significant at these distances (New York Times 13 March 1982, p. 11).

Whatever the size of the official evacuation zone might be, the experience of TMI and of natural disasters strongly suggests that many living outside the official evacuation zone would also evacuate to places even farther away from the damaged plant, just to be safe. Even though in the case of TMI the Governor suggested a precautionary evacuation for pregnant women and preschool children within 5 miles of the plant, 70 percent of the pregnant women and children between 5 to 10 miles evacuated, and 55 percent of those within 10 to 15 miles evacuated. Furthermore, even though the Governor's advisory applied only to pregnant women and children, many other people also evacuated: pregnant women and children constituted only one percent of the population within 15 miles of TMI, but almost 39 percent of this population evacuated (Rogovin et al. 1980, Vol. II, Part 2, p. 624).

Special efforts must be made to notify transients and those in the population that do not understand English. Transient populations might include workers, guests in hotels and motels, hunters, hikers, boaters and shoppers.

4.3.1.2 Preparation Time. Preparation time is the period that begins when a person hears and understands a notification and ends when he enters a vehicle to evacuate. As will be seen in this section, preparation time for some people might involve some rather time-consuming activities. In this section we will discuss 1) the importance of consistency and clarity in the information provided in the evacuation notice, 2) some of the difficulties in making a decision to evacuate, and 3) the tendency to reunite with one's family before evacuating.

Consistency and Clarity of Information. A major problem with the information received by the public during the accident at Three Mile Island was its inconsistency. Three Mile Island is by no means unique in that respect, however. Indeed, the impression one gets from the literature is that lack of clear instructions, a dearth of information, and conflicting information characterize most emergencies. Sometimes the source of misinformation and conflicting information can be traced to a failure of radio reporters to confirm reports. Other times confusion derives from unexpected sources; for example, during Hurricane Carla, which struck the coast of Texas in 1961, great confusion resulted when people in south Texas listened to radio stations in north Texas, and believed that instructions intended only for north Texas applied to them (Treadwell 1961, p. 51).

NUREG-0654 (pp. 49-51) emphasizes that the public must receive consistent and useful information. Nonetheless, a severe accident could easily require the evacuation of a number of counties that would not have detailed and coordinated evacuation plans. In such a situation a significant degree of confusion seems inevitable. The confusion would be further compounded if there should a occur a shift in the wind direction during evacuation.

Decision to Evacuate. Evacuation decisions are not always simple. Inevitably some people stay who should go; and conversely some people go who should remain. Many people already outside the evacuation zone travel even farther away from the evacuation zone, just to be safe. In some cases people originally outside of the evacuation zone enter it either inadvertently or on purpose. Some people leave immediately without clothes, blankets or toothbrush, while others take the time to load their car trunks and luggage racks with baggage. In most major disasters there is a broad transition zone between the unsafe area and the safe areas; in this transition zone decisions whether to evacuate or not to evacuate are not always clear cut.

It must not be assumed that everyone in the official evacuation zone would evacuate, even in the case of a severe reactor accident. Some people might not learn of the evacuation advisory in time; others would be physically unable to evacuate. In addition, one must not even assume that everyone who knows of the advisory, and who is physically able to evacuate, would dec de to evacuate. The literature cites natural disasters in which six percent to over 50 percent of the population decides not to evacuate, despite real danger (Hans and Sell 1974, p. 48; see also Quarantelli 1980, pp. 112-113). Furthermore, Hans and Sell (p. 48) warn that there is no reason to believe that everyone would evacuate simply because the disaster agent is radiation rather than some other agent. On the contrary, one must assume that even during a radiological accident, some people would attempt to remain within the evacuation zone.

Why would people decide not to evacuate? There have been numerous studies of why people decide not to evacuate from natural disasters (cf. Quarantelli 1980, pp. 112-113). Flynn (1979, p. 21) asked nonevacuees near TMI why they did not evacuate: 36 percent said they saw no danger, and 28 percent said they were afraid of looters. These two reasons appear to be the major reasons for not evacuating in many natural disasters, too (see for example Treadwell 1961, pp. 24-25). For many people the evacuation decision may be made by comparing the risk from the disaster agent with the risk from looting. Perry (1979, pp. 34-35) lists likely determinants of a person's decision whether or not to evacuate. They include the precision of the individual's plan for evacuation, the individual's perception of threat, and the extent to which the family members are together or accounted for.

Baker (1979) analyzed data from four hurricanes, examining over 75 variables grouped into thirteen categories, such as sources of information, confidence in weather forecasting, knowledge about hurricanes, previous hurricane experience, awareness of location of public shelters, site characteristics, age, sex, occupation, income, marital status, and number of children. His analysis failed to support many commonly-believed hypotheses about evacuation decision making. For example, age is often mentioned as a critical variable because of the restricted mobility of older people. The data show, however, that people of age 60 and above were about as likely to evacuate, and sometimes more likely to evacuate than people between age 40 and 60. Furthermore, elderly people who did not evacuate said that they chose voluntarily not to evacuate and were not forced to stay in their homes because of low mobility (pp. 19, 21).

Confidence in weather forecasts and evacuation behavior were strongly related statistically. People who had little confidence were unlikely to evacuate, and people who had a moderate degree of confidence were most likely to evacuate. Given this pattern, however, it is difficult to understand why people who had great confidence were also very unlikely to evacuate (pp. 14-15). Due to a number of problems like these, Baker's stated conclusion is that the data from these four studies fail to identify consistently strong predictors of evacuation. This pessimistic conclusion, however, might be somewhat overstated. Baker himself states that a few predictors are relatively good, their relationship with evacuation behavior is statistically significant, and the article itself gives no indication of problems with the predictors. For example, he (p. 14) states that one relatively good predictor is one's expectation of the severity of the storm. Other examples are expected damage to one's home and the perceived elevation of one's home.

Baker notes (p. 22) that part of the failure to identify powerful predictors might stem from the fact that evacuation decision making is too complex to be adequately modeled by the bivariate statistical tests used in these studies. Finally, he notes that the measurement of evacuation might have been inadequate: without the benefit of hindsight, it is difficult to identify those people for whom evacuation was the rational response, especially considering that some people believed--albeit incorrectly--that their homes were hurricane-proof, and that the severity of the storm was underestimated.

The perceived time remaining before arrival of the radioactive plume would undoubtedly be an important determinant of evacuation behavior. Quarantelli (1980, p. 64) notes, however, that in studies of natural disasters the effect of the amount of time between warning and impact has received little attention. Perceived time remaining could affect the number of persons who reunite families or who go to banks or gas stations before evacuating. It could also influence the efficiency and orderliness of the evacuation.

Staying at work, especially at the request of one's employer, is another reason commonly cited for not evacuating. This is especially true within industries in which a rapid shutdown is difficult and costly. For example, it usually takes a week or two and can cost several million dollars to shut down an aluminum reduction plant. Similarly, it is costly to shut down a pulp mill and requires about 16 hours. If such plants were within the evacuation zone, some very difficult decisions would have to be made. Shutting down an oil refinery can also be very expensive. During Hurricane Carla, some Texas employers tried to fire employees who failed to work during an evacuation that was urged by all local governments. The attempted firings were ultimately rescinded because of a wave of public indignation (Treadwell 1961, p. 44).

Since many emergencies require that a cadre of emergency workers remain in the evacuation zone, the potential problem of emergency workers deciding to evacuate has long been a focus of attention. In a study of over 100 disasters, Quarantelli and Dynes (1972, p. 69) reported they did not find a single instance in which a person left an important emergency-related post out of anxiety for his/her family. On the other hand, there have been reports that during the accident at Three Mile Island hospitals became understaffed, and that at least one hospital administrator was fired for abandoning his post (Maxwell, 1982, p. 277). If an area is unprepared for a severe reactor accident, it might not be immediately clear to many government, hospital and telephone workers, for example, whether they are expected to report to work after an evacuation is called.

Reuniting the Family Before Evacuating. The importance of the family unit has been a pervasive characteristic in a wide variety of evacuations, including the accident at TMI. People have often been willing to increase the risk to themselves in order to reunite with their family and evacuate as a family unit (Dynes et al. 1979, p. 146). This behavior is entirely understandable given the widespread belief that family members have more concern for the welfare and safety of each other than do those outside of the family. As an example of this behavior, in 1965, in the face of an immediate flood threat, fully 92 percent of the families that evacuated Denver did so as a unit (Quarantelli and Dynes 1972, p. 68; citing Drabek and Key). During the evacuation at TMI, most people who evacuated did so with their entire family (Dynes et al. 1979, p. 20. See also Brunn 1979). Indeed, the example in NUREG-0654 (p. 4-14) for estimating evacuation time during a radiological accident assumes that virtually all workers would return home before evacuating. On the other hand, if the head of the household chooses to remain at home and not evacuate, the other members of the family would usually remain at home, too.

How long would it take for workers to reunite with families in the event of a severe reactor accident? If the emergency develops suddenly, rather than over an extended period of time (such as in the case of TMI), then in larger urban areas traffic congestion would be a serious problem. These circumstances could substantially increase the amount of time required to reunite with families. Workers who commute in car pools might have the additional problem of finding alternative transportation home, and the use and availability of public transportation are other factors to be taken into account.

### 4.3.2 Emergency Sheltering and Other Protective Actions

We distinguish between two types of shelter: "Emergency shelter" is shelter taken at the time and place of the threat, for example, while the tornado or radioactive cloud is actually passing overhead; emergency sheltering is treated only briefly here. "Temporary shelter" refers to living quarters with sleeping accommodations that are occupied with the expectation of remaining for a short period and without establishing a household routine. Temporary sheltering is treated in Section 4.3.4.

Emergency sheltering can be an effective action to reduce the risk of adverse health consequences during a radiological accident. Therefore, if an advisory to shelter is given, it would be important to estimate the amount of time it takes for the population to receive the message and find shelter, and the percentage of the population that shelters properly.

Failure to take effective protective actions could cause adverse health impacts. Effective protective actions include: taking shelter in a building or basement; ingesting a compound of iodine, such as potasium iodide, that helps protect the thyroid gland from exposure to radioactive iodine; and breathing through a handkerchief to reduce the amount of airborne radioactive particles entering the lungs. Failure to close windows and ventilating systems might later necessitate decontaminating building interiors.

During a radiological emergency, authorities might reasonably choose to recommend an evacuation only, sheltering only, or a combination of the two. There are numerous possible combinations. For example, people in the pathway of the plume could take shelter until the plume has passed by, then evacuate. Also, people close to the accident site could evacuate while people far from the site take shelter.

NUREG-0654 (p. 46) requires that draft informational messages be prepared as a part of emergency planning:

> Draft messages to the public giving instructions with regard to specific protective actions to be taken by occupants of

affected areas shall be prepared and included as part of the State and local plans. Such messages should include the appropriate aspects of sheltering, ad hoc respiratory protection, e.g., handkerchief over mouth, thyroid blocking or evacuation.

### 4.3.3 Evacuation

Total social/psychological impacts in transit to the evacuation site would depend on the number of individuals within the evacuation zone that for psychological or emotional reasons fail to take proper protective actions, or take actions which put themselves in greater danger. In some instances, dysfunctional psychological reactions to disasters have occurred. The literature refers to "the disaster syndrome," which includes being stunned, dazed, apathetic, immobile, aimless and other manifestations of stress (Mileti et al. 1975, p. 61).

4.3.3.1 Stress. Nearly all evacuations would cause individual stress. Trying to evacuate quickly in traffic, uncertainty over proper route or destination, feelings of helplessness and the uncertainty over the location and safety of family and friends would all contribute to stress. Stress caused during evacuation can also be induced by anger at authorities for failing to prevent the accident, concern over possible looting, concern for housepets and farm animals that were left behind, disruption of one's daily routine, especially if one's daily routine involved special medicines or facilities, and the discomforting necessity of imposing oneself and one's children on relatives or friends.

Stress from the evacuation and stress from concern over the health effects of radiation can both have psychosomatic effects such as high blood pressure, headache, indigestion and insomnia. Hans and Sell (1974, p. 50), for instance, state that stress during disasters sometimes leads to premature childbirth. The Pennsylvania State University Medical Center in Hershey reported many cases of people with psychosomatic problems as a result of the TMI accident. A local physician claimed to be seeing four to five patients a day with serious accident-related emotional problems and most of these patients also exhibited psychosomatic effects such as increased blood pressure, fatigue and insomnia (Green et al. 1979, pp.62-63). One survey (Flynn and Chalmers 1979, p. 51; see also Flynn 1979, p. A9) showed that, compared to people living farther away from TMI, those living closer to TMI at the time of the accident had higher levels of stress symptoms for fifteen indicators, including stomach troubles, headache, diarrhea, constipation, frequent urination, rash, abdominal pain, loss of appetite, overeating, trouble sleeping, sweating spells, and feeling trembly and shaky.

4.3.3.2 Individual Panic. The literature also refers to "panic". An individual can be considered to be in a state of panic when he is so overcome by fear that he takes unreasoned and frantic actions that fail to provide safety or that put him or others in greater danger. The belief that there is a great danger of panic is probably the most widespread myth about natural disasters. Because of this myth, officials frequently withhold warnings until the last minute in the belief that the warning itself would cause panic that would be only slightly less damaging than the disaster itself. After studying nearly 100 different disasters and after reviewing all of the early studies on disasters, Quarantelli and Dynes (1972, p. 67-68) conclude that this belief about panic is essentially untrue: The disaster syndrome only occurs after a sudden, violent disaster; it usually takes the form of apathy rather than wild, uncontrolled action; it only affects a minority of the threatened population, and it does not last long. Hans and Sell (1974, p. 54) state their conclusion even more strongly: there is no evidence that panic or hysteria has ever occurred during a natural disaster.

Despite strong evidence that panic has not been a major problem during natural disasters, it is nonetheless important to estimate the likelihood of panic during a large radiological accident. (Individual panic is defined here as irrational, or nonadaptive, behavior due to psychological trauma. Nonadaptive behavior in this case is behavior that fails to protect one from danger or puts one's self or others in greater danger.) Large radiological accidents could be very different from past disasters. Furthermore, extreme caution on the part of public officials in the past could have been part of the reason for the rarity of individual panic in past disasters.

A more interesting issue relates to the circumstances that are conducive to individual panic. After an exhaustive literature review, Mileti et al. (1975, pp. 61-62) concluded that psychological disruption is most likely to occur if the event is sudden; if the people have little knowledge of it; if the event causes a great deal of physical destruction, death and injury; if it occurs at night, and if people are separated from their families. Evidently these conditions could occur during a large radiological accident. Other evidence suggests that women with dependents are slightly more prone to nonadaptive behavior for a brief period of time (Barton 1969, p. 86; also see Mileti et al. 1975, pp. 43-44 and Quarantelli 1964, pp. 73-78.)

4.3.3.3 Collective Panic. In addition to actions that are dysfunctional to individuals, there are actions by individuals that are dysfunctional to the group. For example, unusual, irrational, and/or antisocial actions of individuals can seriously delay the evacuation of the group, or cause injury or death. The standard image is of a mob running and trampling people underfoot; or of a traffic jam at an intersection or approach to a tunnel or bridge, possibly accompanied by uncontrolled hysteria, heated tempers and violence. In this report such situations will be referred to loosely as "collective panic," although this term misleadingly implies that some of the individuals who caused or are involved in collective panic are themselves acting irrationally. In this regard, it is important to note that rational actions by individuals can also be dysfunctional for the group.

It is commonly believed that such situations often occur during natural disasters. Careful research indicates that such images of mobs and panic are exaggerated or untrue. Our impression of how people behave in a disaster comes primarily from the mass media, but media reports are often sensationalized. As an example, during the massive evacuation in Hurricane Carla more than a half million persons left their homes, and there were no fatalities attributable to the evacuation. But, based on a wire-service report, several newspapers ran the headline: "More Than 100,000 Persons Flee In Near Panic" (Quarantelli and Dynes 1972, p. 70).

The issue of panic was raised again at Three Mile Island. According to Dynes et al. (1979, pp. 96-97), officials at TMI believed that somehow an evacuation would be costly, that the population would panic, that declaring an emergency would create an emergency.

Contrary to this rather persistent belief, however, mass panic almost never occurs on a large scale. As early as 1972, Quarantelli and Dynes (p. 68) reported that in the previous twenty-year period there were only a very few instances of panic behavior in which more than three or four dozen persons were involved. Orson Welles' famous invasion-from-Mars broadcast is often cited as one instance of mass panic. One study of the event, however, reported that 84 percent of Welles's audience was not even disturbed by the broadcast. In the famous case of the Cocoanut Grove nightclub fire of 1942, the evidence clearly suggests that most persons did not panic; the majority calmly found alternate escape routes, with friends. Quarantelli and Dynes found that many alleged instances of mass panic turned out to be situations in which some persons were frightened or concerned, but still were able to function rationally. (See also Quarantelli 1980, pp. 109-111.)

Although it is not the purpose of this report to develop a general model of unusual, irrational and anti-social behavior during evacuations, progress toward such a model might begin by hypothesizing that the following conditions are necessary ingredients for collective panic (for similar conditions, see Mileti et al. 1975, p. 43, 58; Fritz 1957; Quarantelli 1954, 1957, 1981):

- a large number of people in one place
- a belief that time is of the essence in dealing with a life-threatening situation
- a bottleneck.

If these three conditions are in fact necessary and sufficient conditions for panic, one must be careful about simply extrapolating from past disasters for which one or more of these ingredients were missing. Indeed, it is conceivable that all three conditions could occur simultaneously during a radiological accident, say one which threatens New York City with its relatively few escape routes from Manhattan Island.

4.3.3.4 Traffic Accidents. It is often feared that traffic accidents, deaths and injuries are a major problem during evacuations. In a study of 54 events for which data are available, however, although 1,140,000 persons were evacuated, only 10 people died as a result of the evacuations, and seven of these died in one helicopter crash; only two major injuries were discovered. The authors of the study estimated that the risk of death in an evacuation is equal to or less than the average annual risk of death in an automobile accident (Dynes et al. 1979, pp. 144-145). (But this implies that the risk of death during the few hours of evacuation is equal to or less than the normal risk of death while driving an automobile over a 365-day period.)

Although in Hurricane Carla, as was stated above, fewer than one percent of the evacuees reported being involved in a traffic accident, even one percent is a significant number of accidents: one percent of one million evacuees adds up to 10,000 evacuees involved in accidents; it is worth considering the consequences if some of those accidents should occur on bridges or in tunnels along the evacuation route.

4.3.3.5 The Evacuation from TMI. The evacuation at Three Mile Island, according to the study by Dynes et al. (1979, p. 156), was more like, rather than uniquely different from,evacuations due to other types of emergencies. There were no massive traffic jams, no fatal accidents caused by panicky evacuees. People did not flee at the first mention of possible danger, but rather confirmed the danger and sought additional information about the seriousness of the threat. Most of the people who did evacuate did so in family units rather than as individuals and tended to move in temporarily with friends or relatives rather than utilize available public shelters.

4.3.3.6 Other Social/Psychological Effects. Despite assurances that large-scale or mass panic has not occurred in the past, such assurances might be overstated for the purpose at hand. Smaller-scale problems have occurred. Quarantelli and Dynes (1972, p. 70) note that official procedures seldom work out as expected. For example, warnings often go unheeded, and refugees do not always take the evacuation routes that the officials have designated.

Not all psychological effects of evacuations are bad, however. Erickson et al. (1976, p. 203) write that during some natural disasters there is a great outpouring of generous, heroic, selfless activity. The literature also uses such terms as "altruistic communities" (Drabek and Key 1976, p 90), and "therapeutic community" (Quarantelli and Dynes 1976, p. 144).

Community value systems can change during evacuations. Without saying that it is good or bad, Dynes (1974, p. 473) writes that often during disasters a consensus develops that all private property rights are temporarily suspended for the common good. All goods are considered to be community property and can be used as needed for the general welfare. Thus, warehouses can be broken into without the owner's permission to obtain generators necessary to keep hospitals functioning, and the act is seen as legitimate if performed for this purpose.

Although little or no looting actually takes place, there is a great preoccupation with the possibility of looting.

### 4.3.4 Temporary Shelter

As noted earlier, temporary shelter refers to living quarters with sleeping accommodations, and which are occupied with the expectation of remaining for a short period and without establishing a household routine. Three types of temporary shelter are considered in this section: public mass shelters, commercial establishments and temporary shelter in the homes of friends or relatives. Typical public mass shelters are administered by the Red Cross, the Salvation Army, Civil Defense, or religious organizations, occupying public schools, college dormitories, public buildings, churches, and the like. Less common temporary shelters include private recreational vehicles, barracks at military bases, and even living quarters on ocean-going ships. Tent camps are commonly used in developing nations. Mandatory billeting of strangers was widely used in Europe during World War II; in recent decades in the United

States people have on rare occasions opened their homes voluntarily to strangers.

Before examining the types of sheltering that evacuees would seek, however, it is important to consider the likely number of evacuees from a severe radiological accident, since this would affect the types and quantity of temporary sheltering available.

4.3.4.1 Number of Evacuees. The number of evacuees in a severe radiological accident would depend upon a large number of factors such as the severity of the accident, the location of the plant, the population of the surrounding area, the direction of the wind, and the policy towards evacuation at the time of the accident. A quick look at the data suggests that the number of evacuees from a severe radiological accident would probably not be of record proportions.

The populations around reactor sites provide some indication of how many evacuees there might be in the event of a severe accident at a nuclear reactor. According to an NRC report (USNRC 1979, Figures 7 and 8), the projected populations around 111 nuclear plant sites for the year 2000 are as shown in Table 4.1. The NRC considers it safe to plan for evacuations within ten miles. Table 4.1 indicates that in the year 2000 the maximum number of people predicted to live within 10 miles of a nuclear power plant is 290,000.

Estimates of the number of evacuees from disasters are often suspect. For example, estimates of the number of evacuees from Hurricane Carla range from 350,000 (Quarantelli 1982b, p. D-14) to 530,000 (Moore et al. 1963, p. 2; see also Quarantelli 1980, p. 125). No explanation is given for the difference. The estimate of 500,000 evacuees from Hurricane Allen is probably a crude estimate; furthermore it is not clear whether the Carribean area is also

TABLE 4.1. Projected Populations Near Nuclear Plants

| | | |
|---|---|---|
| Within 10 miles: | median: | 34,000 |
| | maximum: | 290,000 |
| Within 50 miles: | median: | 1,700,000 |
| | maximum: | 23,000,000. |

Source: USNRC 1979, Figures 7 and 8.

included in that estimate. For all these reasons comparisons are difficult. Nonetheless, according to the best available data, an evacuation of 290,000 people would not be unprecedented in North America, as is shown by Table 4.2, which lists the number of evacuees in various American and Canadian disasters (Quarantelli 1982b):

TABLE 4.2. Number of Evacuees in North American Disasters

| Disaster | Date | Place | Number of Evacuees |
|---|---|---|---|
| Hurricane Allen | Aug 1980 | South Texas | 500,000 |
| Hurricane Carla | Sept 1961 | Texas and Louisiana | 350,000 to 529,000 |
| Chlorine gas | Nov 1979 | Mississauga, Canada | 220,000 |
| Nuclear accident | March 1979 | TMI | 140,000 |
| Flood from Hurricane Agnes | June 1972 | Wilkes-Barre, PA, and NY | 100,000 |
| Flood from Teton Dam breach | June 1976 | Southeast Idaho | 80,000 |

Source: Quarantelli 1982

Generally speaking, the larger the number of evacuees, the greater the proportion that stays in public shelters. Evacuees usually prefer to stay with relatives or friends; their second choice is to stay in commercial quarters. If the evacuation is large, many relatives and friends would also have to evacuate, and more commercial establishments would be filled to capacity; so a larger proportion of the evacuees would have to stay in public shelters. Even in large evacuations, though, only a minority of the evacuees stay in public shelters. During Hurricane Carla over 500,000 persons withdrew from the endangered coastal regions; 58 percent of them stayed with relatives or friends, 23 percent stayed in public shelters, and 18 percent stayed in commercial facilities (Quarantelli 1980, p. 125).

4.3.4.2 Types of Temporary Sheltering. What types of temporary shelter would evacuees from a severe radiological accident seek? In general, evacuees act as though they prefer to stay in commercial establishments, if they are available and especially if the bill is paid by someone else. Evacuees' second choice appears to be lodging with relatives and friends. Their last choice is to stay in public mass shelters. The following three sections discuss these three types of temporary shelter in order of descending preference, which is also the order of increasing social and psychological difficulties.

Commercial Establishments. It appears that commercial establishments, such as hotels and motels, are the type of temporary shelter that most evacuees prefer, if money is not an issue. This can be inferred from the fact that when the bill is paid by someone else (e.g. the government, insurance, one's employer, or the offending corporation in the case of toxic gas leakage), most evacuees stay in commercial establishments (Quarantelli 1980, p. 125). When such payment is not available, however, the majority of evacuees generally stay with relatives and friends.

Available evidence indicates that, following a disaster, even life in commercial quarters is not considered to be a pleasant vacation: On September 28, 1982, residents of the small town of Livingston, Louisiana were evacuated after a freight train derailed, setting off a series of explosions and fires from cars loaded with dangerous chemicals. Some of the evacuees stayed initially with friends and relatives, but moved to motels within a few days after the railroad company began picking up the tab. After a week, however, the pleasures of the all-expenses paid vacation began to wear thin. One evacuee commented, "It's not like a vacation....it's hard on the family. There is nothing for them to do. You just look at them, and you know they're about to break down and cry 'cause they want to go home." ( Anchorage Times, October 9, 1982).

Shelter with Relatives and Friends. Information about the temporary sheltering of evacuees with friends and relatives is one of the greatest voids in all of the disaster literature. This is the informed opinion of Enrico Quarantelli, expressed in his exhaustive search and summary of the English-language disaster literature. In fact, Quarantelli was unable to cite even one published work that contained any information on the subject (1980, pp. 129-130). Even Quarantelli's own later work specifically on sheltering and housing (1982a) contains no information on the social and psychological aspects of temporary sheltering with friends and relatives.

Thus any inferences on this topic must be made indirectly. It has already been stated that when someone else pays the bill most evacuees stay in commercial establishments; from this it was inferred that if money is not an issue evacuees prefer not to lodge with friends or relatives. Since in most evacuations the majority of evacuees stay with friends and relatives, it is perhaps reasonable to conclude from the fact that we hear almost nothing about any particular problems that the problems are neither widespread nor severe.

On the other hand, there is a fair amount of information on sheltering with strangers during World War II and during the Holland flood of 1953. The literature on World War II indicates not infrequent friction between the evacuees and their hosts, but the sources of friction were often ascribed to differences in race, religion, social class, speech and behavior; these are factors that are much less likely to be an issue in the case of friends and relatives. There were, however, many other minor sources of friction among strangers during World War II that one could easily imagine existing among friends and relatives as well: difficulties in sharing the kitchen and bathroom; loss of privacy; differences in social and moral standards; differences in diet; increased number of children in the house; criticism of each other's domestic skill and child management; and jealousies among parents for the affection of children (Ikle 1958, pp. 89-91).

Public Shelters. Public shelters are typically occupied by a disproportionate number of people from the lower socioeconomic strata, and most of these will be successful within a few days in finding accommodations elsewhere, even with strangers (Treadwell 1961, p. 30). For example, at Three Mile Island the few evacuees that used a public shelter in a sports arena stayed only a day or two while they made arrangements to withdraw to houses of relatives or friends (Quarantelli 1980, p. 127, referring to Flynn and Chalmers, 1979). Churches, schools, municipal buildings, public auditoriums and military bases are typical locations for public shelters. According to Quarantelli (1980, p. 128) schools tend to be the most favored type of facility for mass sheltering, although there are frequent problems in getting them opened, supplied and staffed, even with preplanning.

Quarantelli also notes some of the problems of shelter operations: special feeding problems if there is a large number of elderly evacuees, deviant behavior especially of a sexual nature, tensions and conflicts possibly stemming from having blacks and whites together, the behavior of children, lack of privacy, and boredom. Due to the problems and inconveniences of living in public shelters, many people who evacuate first to a public shelter, later make arrangements to stay with friends or relatives. (See also Bolin 1976; Quarantelli 1980, p. 127.) Below, we indicate the number of evacuees and describe some of the social/psychological impacts associated with public sheltering during the Wilkes-Barre flood, Hurricane Carla and the Three Mile Island accident.

The Wilkes-Barre Flood. During the floods from Tropical Storm Agnes (1972), the public emergency shelters in and around Wilkes-Barre, Pennsylvania were operated by a number of uncoordinated agencies; so it is difficult to know exactly how many people actually used mass shelters. According to one survey, about 55 percent of the families in the community left their homes, but only 6 to 10 percent of those families spent any time in mass shelters. A majority of the mass shelters were located in local public schools and churches and were manned by citizen groups. A private college sheltered an estimated 1,500 evacuees (Quarantelli 1982a, p. 15).

Detailed observations of public shelters during the Wilkes-Barre flood are available for only one shelter, a school that sheltered up to 600 people. At this shelter, bedding materials were not secured for everyone until two weeks after the shelter opened. People had to sleep on athletic mats until cots were acquired. Some racial and sex-related tensions developed, and a few people were so nervous that they could not sleep until they were permitted to occupy an isolated room on the second floor. A night watch committee composed of male evacuees was organized to patrol the halls during the night. Fears were reduced sometime later when two police officers were assigned to the shelter. However, people grew more irritable as time went on, and conflicts, some resulting in fist fights, were not uncommon.

The community's water supply had been contaminated. Despite repeated requests that potable water be brought to the shelter, water was always in short supply (Quarantelli 1982a, pp. 16-17).

These observations on the conditions in public shelters after the Wilkes-Barre flood are contained in Sheltering and Housing After Major Community Disasters: Case Studies and General Observations, by Quarantelli (1982a). This same monograph also describes temporary sheltering conditions during the Xenia tornado (1974) and the Grand Island tornado (1980). Although the physical conditions of temporary sheltering were uncomfortable, there were no social problems reported (pp. 40-42, 67-70).

Hurricane Carla. It is somewhat surprising to learn that social ties were maintained in most mass shelters during Hurricane Carla (1961). This might be partly because the residents of Texas and Louisiana had experienced several hurricanes before Carla and therefore knew how to prepare. And it might be partly because there was a long warning period before Carla; so people had time to contact friends and relatives to make plans before evacuating (Moore et al. 1963, p. 1). According to one survey, 70 percent of the people who stayed in public shelters during Hurricane Carla already knew people who were also there. Fifty-five percent knew in advance whether a friend or relative would be in the shelter. Over 60 percent cited the presence of friends or relatives as their reason for choosing a given area (pp. 98-101)

During Hurricane Carla evacuees in the vast majority of public shelters were orderly and well-behaved; in fact, evacuees and residents of the host areas often developed most cordial relations. Nonetheless, in about 10 shelters out of the 650 that were established, some annoying and some rather horrifying examples of behavior occurred: in addition to the usual confusion of people trying to locate relatives, parents who could not restrain their children, parents wanting to know where to wash diapers, and loud radios, there was also improper use of toilets; drinking; gambling; purse-snatching; peeping; fondling; open sexual activity and prostitution; knife pulling, and fighting. In Houston, 200 persons obtained access during the night to a school not being used as a shelter. Unsupervised, they broke eight cases of soft drinks in the hallways, broke over 100 windows, spattered walls with clay, wrote obscenities on walls, and stole school supplies (Treadwell 1961, pp. 31-34).

After about three days, supervisors of the public shelters were becoming totally exhausted, some of them having worked 70 to 80 hours for lack of any trained replacements, and afraid to leave for fear the situation would again get out of control (p. 34).

Even though behavior in some of the public shelters was shocking, one must also consider that a certain amount of such behavior would occur normally in any three-day period in a city with a population of from 300,000 to 500,000.

Although misbehaving evacuees have always been in the minority in public mass shelters, examples such as these from Hurricane Carla suggest that behavioral problems in public mass shelters are probably the most serious potential problems during temporary sheltering after a large radiological accident. For this reason, an estimate of the number of evacuees in mass shelters after a radiological accident would be useful.

Unfortunately it is difficult to estimate the number of evacuees in mass shelters even for disasters that have already taken place. Again, the data are suspect and sometimes self-contradictory, but it appears as though the number utilizing mass shelters during Hurricane Carla might have been one of the highest. The Red Cross estimated that 200,000 people spent part or all of their time away from home in one of the public shelters (Moore et al. 1963, p. 89; see also p. 2). (There appears to be a contradiction in that 200,000 is 38 percent of 529,000; whereas Moore et al. (p. 92) state that 23 percent of the evacuees stayed in public shelters. Perhaps the latter estimate is based upon evacuee-days, instead of evacuees.

Three Mile Island. By contrast, during the accident at Three Mile Island only a very small number of people used public shelters: out of 140,000 evacuees the maximum number of persons using these shelters in any one day was only 180 people, which is only one tenth of one percent of the evacuees (Zeigler et al. 1981, p. 9). During the Wilkes-Barre flood and the Mississauga hazardous chemical incident, the numbers of evacuees staying in public shelters were about 3300 (3.3% of 100,000 evacuees) and less than 4000 (less than 2% of 220,000 evacuees), respectively (Quarantelli 1980, p. 125).

The accident at Three Mile Island was somewhat unusual also in that the number of days spent in (all types of) temporary shelter was relatively high--half the evacuees stayed away for at least five days. During Hurricane Carla the average evacuee spent only 3.7 days away from home, although evacuees from some parishes stayed away five days and longer (Moore et al. 1963, p. 98).

Finally, the accident at Three Mile Island was unusual in that the median number of miles traveled to temporary shelter was relatively high--85 miles (median distance from the plant was 100 miles). The median distance traveled to temporary shelter during Hurricane Carla was 80 miles, and that was the longest median distance estimated by Hans and Sell (1974, p. 52). The Hans and Sell study, however, was published just before the December 1974 evacuation of Darwin, Australia after a cyclone (i.e., hurricane). Since the only cities large enough to receive evacuees from Darwin were at least 1800 miles away, the Australian government paid for airplane travel from Darwin to those cities for about 25,000 evacuees. About 11,000 others departed by automobile (Haas et al. 1976, p. 61).

## 4.4 SOCIAL/PSYCHOLOGICAL IMPACTS DURING THE RECOVERY AND REENTRY PHASES

The recovery and reentry phases include the following major event categories: 1) premature attempts to reenter the contaminated areas; 2) the occupation of temporary housing while contaminated areas are decontaminated; 3) the return of individuals and households to areas that have been decontaminated; and 4) the relocation of individuals and households who resided in areas that are designated for long-term interdiction. In this section, we enquire into the social and psychological factors that affect the recovery of the contaminated areas. For example, are there problems with people trying to reenter the area prematurely? What are some of the problems associated with temporary housing? To what degree would the accident affect the willingness of residents to return, the ability of employers in the area to attract new employees, the willingness of tourists to visit the area, and the willingness of consumers to purchase agricultural and other products from the area?

### 4.4.1 Premature Reentry

During natural disasters, significant problems can develop during the recovery and reentry period. Quarantelli (1980, p. 131), who states that mass panic during evacuations is a myth, nonetheless also states that return activities particularly seem to generate conflict. For example, during one of the largest hurricanes in the history of the United States, Hurricane Carla (1961), it is very clear that, from the point of view of the authorities, it was much more difficult to maintain public order during the return than during the evacuation (Treadwell 1961, pp. 51-60). The primary problem during natural disasters is that residents attempt to return long before authorities consider it safe to do so.

Following the Livingston train derailment discussed above, barricades were placed along the perimeter of the interdicted zone. Under special authority from the governor, troopers could arrest trespassers, including residents who tried to sneak past the barricades to get home. Evacuees expressed anger and frustration at not knowing the condition of their homes. A workman complained of losing jobs because he was not allowed to return home to obtain his tools. One woman complained of nightmares; another worried about her pet cat in the interdicted zone. One married couple said that after 15 years of marriage they had begun fighting because of the incident. Children feared that they were missing so much school that they would have to make it up in the summer. The school in Livingston was closed, and a nearby high school was closed while being used as a refugee center (Associated Press, October 9, 1982).

To what degree is the experience of natural disasters during the period of recovery and reentry applicable to a radiological accident? Although the evidence is limited, available evidence suggests that the experience of natural disasters is quite relevant, and that it would be a mistake to suppose that a radiological accident would be totally different. An example of this evidence is the fact that for a period of several years prior to 1976 it was a common (albeit illegal) practice for some of the employees at the radioactive waste burial facility near Beatty, Nevada to open containers of contaminated material intended for burial, and to remove items of worth or fancy. Numerous items such as hand tools, electric motors, shipping containers, etc. received widespread and uncontrolled distribution in the town of Beatty, and lesser distribution in other locations. When the practice was discovered by the authorities, an intensive, well-publicized campaign retrieved an estimated 20-25 pickup truck loads of radioactively contaminated equipment as well as several loads of large items returned on a 40-foot flatbed trailer. Nonetheless, it is known that the recovery effort failed to retrieve much of the material (Wenslawski and North 1979). This and other evidence suggests that after a severe reactor accident, some people would be willing to expose themselves to low-level radiation, especially when it benefits them economically to do so.

During the recovery phase of an accident of that magnitude, there would be a large number of decisions with important economic consequences--decisions, for example, concerning the sequence of decontamination of public and private property. Controversy over such decisions could easily continue for years.

### 4.4.2 Temporary Housing

"Temporary housing," as a type of housing, involves a resumption of household routines, and implies the maintenance of family privacy. And yet it is temporary; that is, the occupants plan and expect to move to permanent quarters later, typically before a year has passed. The most common type of temporary housing in recent decades in the United States is trailer housing supplied by the U.S. Department of Housing and Urban Development. Temporary housing can also include vacant public housing, (temporary) rent subsidies, and payments for room in hotels and motels, if daily routines are reestablished.

4.4.2.1 Aid From the Federal Government. The federal government now plays a major role in the provision of temporary and permanent housing for disaster victims. In fact, the federal government is probably the single most important determinant of the social/psychological effects of temporary and permanent housing after disasters. As such, a brief history of the federal role is appropriate here. The following capsule history shows that the federal role is constantly changing, and that the federal role itself is often strongly influenced by *ad hoc* social and political pressures at the time of the disaster (Sorkin 1982, p. 160). The implication is that after a large radiological accident, too, the federal government would very likely provide, on an *ad hoc* basis, a considerable amount of aid (over and above the compensation provided under the Price-Anderson Act) for temporary and permanent housing.

Before 1950, Congress provided aid to the victims of over 100 disasters on an *ad hoc* basis. In 1950, the nation's first permanent program of federal disaster assistance was enacted. The expansion of federal programs for disaster victims accelerated after the Alaska earthquake of 1964, and for the next decade a number of new programs were established. By 1972 less than one-third of disaster costs were borne by the affected individuals (Sorkin 1982, p. 169).

Since 1960, there have been a great variety of legislative initiatives to deal with the problems of post-disaster relief and reconstruction. Each time a benefit was introduced, it became the basis for additional assistance provided by subsequent disaster legislation. The Alaskan earthquake (1964), Hurricane Betsy (1965), the Rapid City flood (1972), and Hurricane Agnes (1972) all brought increased pressure from disaster victims and their elected representatives for more generous federal assistance. Furthermore, the relief provisions in the legislation were often made retroactive to some previous disaster. For example, most of the legislative provisions for the victims of Hurricane Betsy were made retroactive to victims of the Alaskan earthquake; and the benefits made available to the victims of Hurricane Agnes were also extended to the victims of the Rapid City flood. In 1953 the federal government's expenditures (grants and loans) amounted to 1 percent of total losses; by 1965 this figure had increased to about 18 percent, and in 1972 government assistance amounted to nearly 70 percent of total disaster losses. In particular cases it was not unusual for some people to actually be better off after the disaster, due to the generosity of the federal government.

The passage of the Disaster Relief Act of 1974 appears to have slowed the trend toward ever larger compensation for disaster victims (Sorkin 1982, p. 146). Nonetheless, the Teton Dam flood of 1976 provides another example of political pressure for greater federal aid. About 10 days after the dam collapsed President Ford proposed that Congress make available $200 million to begin restitution. The appropriate amendment to the Public Works Appropriation Act of 1976 was signed into law, giving administration of the funds to the Bureau of Reclamation. Meanwhile, Senators McClure and Church introduced legislation to provide full compensation for the victims. However, victims were urged to apply for assistance under existing programs in the event that the bill be delayed in either the House or the Senate. Congressman Hansen declared that the federal government was culpable in this tragedy; and although the federal government did not accept legal responsibility for the dam breach, it did accept "moral responsibility." When enacted and signed into law, the Teton Dam Disaster Assistance Act of 1976 superseded the Public Works Act as well as the Federal Disaster Relief Act of 1974. It determined that full restitution should be made swiftly, in order that the residents and communities return to their pre-disaster conditions. In total, $400 million was appropriated for compensation of losses incurred during the flood.

Federal response might well be determined in part by the political party in power; for example, during the flood of December 1982, residents of Missouri and Louisiana were told that the Small Business Administration (SBA) would not be as generous as it had been after the floods of the 1970's. The Congressional committee with SBA oversight said it was not they, but rather the Reagan administration, that had pushed for the cuts in the SBA's budget (Mannies, January 4, 1983).

It is not the purpose of this section to predict government response in the case of a large radiological accident, except to suggest that the response would probably not be radically different from the past, especially with respect to relocation. Therefore, case studies of government programs in the past should provide useful information. Such case studies indicat that the federal government is willing and able to provide the same quality of temporary housing for an increased number of people. For example, Quarantelli (1982a, p. 4) notes that the temporary housing provided during the Wilkes-Barre flood of 1972 constituted one of the largest such efforts in the United States since World War II. During that flood the government originally ordered 12,500 trailers to be used as temporary housing, but as it turned out only 7,500 were needed. If indeed the government is willing and able to provide the same quality of temporary housing for a larger number of homeless people, one can reasonably expect that the social/psychological aspects of temporary housing for a large radiological accident would be similar to past experience. In the following paragraphs, we examine the social/psychological effects from temporary housing in the case of several recent disasters.

Buffalo Creek (1972). In February 1972, a slag dam of the Buffalo Mining Company collapsed during heavy rains and flooded an 18 mile strip of the Buffalo Creek Valley. Fourteen mining communities were flooded, 124 people were killed, and 1100 were injured. Of 5,000 area residents, 4,000 were left homeless.

The U.S. Department of Housing and Urban Development (HUD) arrived shortly with the intention of providing mobile homes for everyone without accommodations of their own, and permitting them to live rent-free for a year. HUD established 13 trailer camps, supplied almost 700 mobile homes, providing temporary housing for almost half of the original inhabitants of Buffalo Creek. Believing it important to get victims into housing as soon as possible, HUD allowed occupancy on a first-come, first-served basis. Unfortunately, this policy scattered friends and former neighbors all over the hollow (Erikson 1976, pp. 46-47). One young woman wrote in her diary that perhaps living away from friends and among strangers had a lot to do with the problems they were having. She had conflicts with people she did not even know. It seemed as though everyone was on edge, just waiting for trouble to happen (p. 149).

The mobile homes were small and cramped; a family of four could hardly manage to eat a meal together, not to mention inviting friends and family over for a larger gathering. The trailers were poorly insulated and provided almost no protection from the noises of the crowded refugee center. Being made of metal, they amplified the sounds of rain and wind. People complained that they just could not seem to rest.

There was little privacy. Family quarrels could be heard five or six doors away, and the sounds of bedsprings moving or toilets flushing were broadcast to the neighbors. There were almost no play areas. One person noted that the people who were living in the trailers had depressed and worried looks on their faces. One did not see children out playing as before. "We did lose a community, and I mean it was a good community. Everybody was close, everybody knowed everybody. But now everybody is alone. They act like they're lost." There was no privacy inside, and no community outside (pp. 148-153, 196).

Rapid City Flood (1972). Heavy rains and a dam breach caused heavy flooding and extensive damage in Rapid City, South Dakota in June, 1972. 237 persons were killed, and 5,000 persons were left homeless. Again, HUD provided trailer camps for the victims. Hall and Landreth (1975, p. 60) argue that the HUD trailer camps themselves were suspect as a source of stress.

Wilkes-Barre (Agnes) Hurricane (1972). The flood following Hurricane Agnes was one of the nation's largest in terms of property damage. About 14,000 housing units were damaged in the Wilkes-Barre area alone. Accordingly, the temporary housing effort in Wilkes-Barre constituted one of the largest such efforts in the United States since World War II. HUD provided temporary housing for thousands of individuals for months, and, in some cases, even years (Quarantelli 1982a, pp. 4, 6).

Although the preparation of trailer group sites in a disaster sometimes becomes a heated political issue, this was not the case at Wilkes-Barre. Also, HUD allowed the trailers to be placed on the property of owners of damaged homes. This not only made home repair easier, it allowed neighborhoods to remain together (Quarantelli 1982a, pp. 24-25).

Teton Dam Breach (1976). The confusion and despair after the flood but before government aid was available was reflected in the exclamation of one man that he had never been broke before; that his credit had always been good. But now, all he had was two dollars in his pocket and nine kids to feed. It looked pretty bleak. It was certainly good news when he heard for sure that government reimbursement was coming (Golec 1980, pp. 140-141).

Another person said that his family had become vagabonds with no place to go and nothing to do--just wander around in a state of oblivion. They didn't know which way to turn, where to start. He had been married for 25 years and thought that the rest of his life was pretty well set when suddenly everything was gone. It was a really scary feeling (Golec 1980, p. 142).

After living in temporary shelters, residents of southeastern Idaho considered the promise of government aid and the provision of HUD trailers a great improvement. The HUD trailers became a place to close the doors and be a family, a place to be private (Golec 1980, p. 144). But they noted problems, also. Measuring about 12 feet by 50 feet, the trailers were too small for large families. Having been transported from other parts of the country, some were infested with rats.

The Department of Housing and Urban Development was authorized to provide temporary housing with free rental for a period of one year. There were three basic programs offered to victims: occupancy in a mobile home; accommodation in a commercial or private rental unit or home; and a minimal repair program designed to make damaged homes habitable. Approximately 500 families found permanent housing without the assistance of HUD. Of the families that received HUD assistance, 526 had their homes repaired under the minimal repair program, 232 occupied private rental units, and 1,118 lived in mobile homes. At the insistance of leaders in the Church of Latter Day Saints (LDS), which was prominent in the area, the mobile homes were distributed in such a way as to maintain LDS ward boundaries so that the order of the community would not be disrupted. In Sugar City almost every family lived in one of two HUD trailer parks. In other towns and in rural areas, most residents had their HUD trailer parked on their private property close to the building site of their new home. When the HUD program closed in October 1977, 350 trailers were purchased by the occupants for their permanent housing (Golec 1980, pp. 138-139).

During this period of temporary housing after the dam breach, there was confusion about how the future would be constructed. Unfamiliar terms--like FDAA, one-stop center, HUD, BOR, reclamation, demolition crews, writs of entry, forms of confidential release, assessors, verifiers and inspectors--were introduced into everyday discourse. To receive aid one had to apply for it, and one had to follow the rules. There were innumerable forms to fill out, lines to stand in. Sometimes the HUD officials seemed rigid and intrusive (Golec 1980, p. 144).

Grand Island, Nebraska Tornado (1980). On June 3, 1980, a swarm of tornados descended upon Grand Island, the third largest city in Nebraska. A temporary housing effort was initiated by FEMA-HUD on July 27. Because little rental property was available in the community, it was decided to use mobile homes, which arrived within a few days. Although FEMA encouraged everyone eligible to apply for housing assistance, not everyone did. FEMA received 905 applications, of which HUD found 30 ineligible. Another 331 applicants withdrew their applications before they had been completely processed, presumably because they had found something else through their own resources. Six months after the tornado, FEMA had placed a total of 515 households into temporary housing. Of these 361 had been put in mobile homes, 124 in private rental quarters, and 27 in transient accommodations.

A controversy arose over a mobile home park that was created at the boundary of a housing development. A private citizens association of homeowners in that development strongly objected to having the 50-unit park in their neighborhood, fearing it would adversely affect property values. The Grand Island city council settled the issue by promising that the mobile homes would be gone after one year.

There was a steady turnover of residents in the mobile home park, since HUD tried to get occupants into more permanent housing as quickly as possible. The mobile home occupants showed little collective unity. According to one survey, over 36 percent of those occupying temporary housing moved at least two more times before entering permanent housing. Nearly 10 percent of the families occupying temporary housing had to live separately for at least part of the time (Quarantelli 1982a, pp. 70-72).

In the case of a large radiological accident, the federal government would most likely provide temporary housing of the type, and in the manner described in these case studies, with most of the same benefits and problems. The primary benefit, of course, is that the displaced persons would be provided with temporary housing that is considerably more comfortable than the tent cities sometimes provided after natural disasters by governments of underdeveloped countries. Potential problems include local opposition to the location of trailer courts, complaints that preferential treatment was given to certain groups in the selection of occupants of the trailers, racial tensions, complaints that neighborhood social networks have been broken, noise, cramped quarters, cumbersome bureaucratic procedures, etc.

### 4.4.3 Permanent Housing

"Permanent housing" implies that the occupant has no plans or expectations of moving in the near future. A dislocated family can establish itself in permanent housing as a result of its own efforts, with the aid of private insurance, or with the aid of one or more government programs. In addition to the social/psychological aspects of finding permanent housing, this section will also consider issues relating to the permanent relocation of households away from the accident area.

4.4.3.1 Return of People to the Noninterdicted Areas. In the case of a large radiological accident, two types of permanent housing must be considered: permanent housing for evacuees outside the interdicted zone, and permanent housing in the zone that was first interdicted and later decontaminated. In the latter type, the public's psychological evaluation of radiation risks becomes an important consideration.

Prediction must be based upon past events. Past events of severe and widespread radioactive contamination include the bombings of Hiroshima and Nagasaki, the test explosions at Eniwetok, and the nuclear waste accident in the Soviet Union in 1957-1958 (Medvedev 1980).

Examination of these cases might suggest a few principles that could apply to a large radiological accident in the United States. For example, some of the former inhabitants of Eniwetok want to return to their island, despite the fact that the United States government has determined that the level of radioactive contamination is still too high. Similarly, it is reasonable to presume that after a large radiological accident some former inhabitants of a contaminated area will want to return to their homes, despite government condemnation of the land.

There are, however, obvious difficulties in attempting to use these cases to predict the social/psychological effects of a large radiological accident at a nuclear power plant in the United States. For example, the potential effects of low-level radiation were virtually unknown to the inhabitants of Hiroshima and Nagasaki when they began to reoccupy the bombed areas. Also, the Soviet Union has more control over information and over the activities of its citizens than does the United States.

The social/psychological effects of contamination at Love Canal might well provide us with the best basis for predicting long-term effects of a large radiological accident in the United States. Even though the threat at Love Canal is dioxin and other toxic chemicals, instead of radiation, there are important similarities between the two threats. In particular, dioxin is similar to radiation in that: 1) in diluted but still dangerous concentrations, it cannot be seen, felt, tasted or smelled, 2) it has been given wide publicity as an extremely toxic agent, being called "the most toxic man-made substance," 3) it is little understood by the general public, 4) in small doses its effects are little understood even by scientists, and 5) in larger doses dioxin is known to cause some severe health disorders in man (chloracne); it is known to cause cancer in laboratory animals, and it is suspected of causing a large number of other health disorders in man (liver, blood and kidney disorders). In addition to dioxin, there are many other toxic chemicals at Love Canal; there is evidence that the combination of these chemicals might have led to increases in spontaneous abortions and congenital defects (Haughie 1981, p. 51). These threats resemble radiation in that pregnant women and young children are particularly vulnerable. Public warnings at Love Canal, like the warnings at TMI, made the vulnerability of pregnant women and children well known to the public.

Incidentally, Love Canal resembles a radiological accident in that Love Canal also contains radioactive wastes (albeit in very small amounts). This fact was given wide publicity in a report by the New York State Assembly Task Force on Love Canal (Haughie 1981, p. 52).

Even if there are similarities in the physical properties and health effects of dioxin and radioactivity, are there important differences in the public's psychological reaction to the two threats that make them incomparable for present purposes? Witnesses to the public meetings after TMI might well have a strong sense that the public, due partly to ignorance, can become extremely fearful, angry and emotional over radiation. The public meetings at Love Canal, however, were also well-known for their displays of fear, anger and emotion.

A major difference between Love Canal and a large radiological accident at a nuclear power plant is scale: the contaminated area at Love Canal was only a few square blocks, whereas the contaminated area after a large accident could include several hundred square miles. This might well affect the level of federal aid per person in finding new permanent housing. (Love Canal also differs from a large radiological accident in suddenness of onset. Although the characteristics of the emergency evacuation and the search for--and availability of--temporary housing would be affected by the suddenness of onset, it seems unlikely that issues relating to permanent housing would be significantly affected.)

The following discussion draws on the experience of Love Canal, but each separate principle could be predicted on the basis of other experiences as well. For example, the importance of ad hoc political activity can be seen in the history of disaster legislation (see Section 3.1). The predictions concerning politics and area avoidance are also corroborated by the recent experience of Times Beach, Missiouri.

4.4.3.2 The Politics of Permanent Housing. Based upon the past history of disaster legislation (see Section 4.4.2.1), and based upon the experience of Love Canal, it seems clear that government aid for permanent housing after a large radiological accident would be shaped to a large extent by the political action of individuals, grass-roots organizations, local and state governments, and a multitude of other political forces.

Although the federal government has succeeded to a degree in treating minor disasters administratively according to general regulations, major disasters are usually treated politically and ad hoc. In fact, most of our disaster legislation was instigated by particular disasters. At Love Canal, state aid and federal aid were prompted in part by intensive, grass-roots political campaigns. There was no existing legislation at the time of Love Canal that would have permitted federal aid for permanent housing: the legislation that was passed was tailored specifically to Love Canal.

The Price-Anderson Act is the primary attempt by the Congress to deal systematically with compensation for damages due to a radiological accident, but, in the case of a severe accident, it is highly unlikely that compensation under this Act would be considered sufficient or just; intense, grass-roots political campaigns would undoubtedly pressure for additional federal aid for permanent housing.

4.4.3.3 Area Avoidance: Degrees of Danger. Love Canal is circumscribed by three "rings". The first ring includes only the houses closest to the canal; the second ring includes the houses just beyond the first ring; the so-called "Declaration Area" is the area just north of the Canal Area, and so forth. Each ring has its own history and its own set of government policies, partly because the degree of contamination differs for each ring, and partly because people in the outer rings wanted to be included in government programs that had already been established for people in the inner rings.

The following events give an indication of the differing history of each ring. In August 1978, Governor Carey first announced evacuation plans for Ring 1 houses; plans were later expanded to include Ring 2 houses. In October 1980, plans were announced for permanent relocation of residents in the Declaration Area. In June 1982, demolition of the 227 homes in Rings 1 and 2 began. On July 14, 1982, the Environmental Protection Agency (EPA) announced that the

Declaration Area was habitable. Similarly, after a large radiological accident, it seems likely that government policy toward permanent housing (among other things) would be related to rings.

4.4.3.4 Area Avoidance: Individual Differences. After a severe radiological accident, there would undoubtedly be extreme individual differences in area avoidance. It is most probable that some people would not willingly leave the area in the first place. Some others who did leave would undoubtedly want to return even though the area had been declared unsafe. At Love Canal there were extreme differences: some people wanted very much to move out of the area, while other people stayed even though the government had offered to purchase their homes.

### 4.4.4 Out-Migrations of People from the Peripheral Areas

To what extent would fear of radiation cause a loss of population in the peripheral areas that receive little or no contamination. Some idea of this effect can be inferred from the accident at Three Mile Island, in which there was little or no off-site contamination. In the case of a severe reactor accident, however, the peripheral area could be quite large. The area of crop interdiction could extend from the plant for a distance of up to 300 miles away; thus, the peripheral area (i.e. the area that receives little or no contamination) would extend even beyond that.

After the accident at Three Mile Island, there was much speculation that some residents would move away as a result of the accident and that property values would fall for that reason. Opinion surveys confirmed that some people have indeed considered moving as result of the accident. Nonetheless, the existence of this attitude has had no measurable effect on the number of people actually moving into or out of the area, or on property values (Flynn 1982, p. 182-183). The accident had a noticeable effect on hotel occupancy during the first week or so, but that effect, too, soon either disappeared or became unmeasurable. In short, the evidence from TMI suggests that where there is no measurable contamination, there are no long-term demographic impacts.

### 4.4.5 Out-Migration of People from the Relocation and Crop-Interdiction Zones

Between the peripheral area, where the effect of psychological factors on population changes is not expected to be measurable, and the directly impacted area, where economic factors and interdiction are expected to weigh more heavily than psychological factors in the depopulation of the cities, lies a broad intermediate zone, where prediction is difficult. Much of this zone would include the decontamination and crop-interdiction zones. Although prediction is difficult for this zone, a few general observations are relevant.

To a certain extent, data from TMI can be used to help draw a "personality profile" of the type of person who is more likely to perceive radiation as a threat. Women, especially pregnant women and women with young children, were more likely than men to evacuate and to perceive TMI as a threat. On the other hand, older people were less likely to perceive TMI as a threat. There is some evidence that more highly educated people tended to consider TMI more of a threat, but the evidence for this is weak (Flynn and Chalmers 1979, pp. 24, 50).

Perhaps the primary inference to be drawn from this "personality profile" is that the public tends to believe and draw rational implications from what the experts tell them: the Governor's evacuation advisory explicitly stated that radiation is more dangerous to pregnant women and young people. Concerning the degree of risk also, the public generally believed what the experts told them. Some experts did believe the situation was very dangerous (because they believed there might be a hydrogen bubble that could explode), and said so to the public. Confusion among the experts was also reflected in the public. In one survey, 83 percent of the evacuees said they decided to evacuate in part because information on the situation was confused (Flynn and Chalmers 1979, p. 24). Belief in expert judgment, especially if it was unified, could mitigate extreme actions among residents of the decontamination and crop-interdiction zones.

People with residences in the decontaminated zone would reasonably have cause for concern that the area be decontaminated properly and as thoroughly as possible. It is likely, therefore, that government agencies would conduct special campaigns to gain the confidence of these residents and to convince them that their property had indeed been decontaminated to reasonable levels. For example, government agencies would likely develop a Citizen Radiation Monitoring Program, similar to the very successful program developed for the people living near Three Mile Island. The TMI Citizen Radiation Monitoring Program, sponsored by the U.S. Department of Energy, the Pennsylvania Department of Environmental Resources, The Pennsylvania State University, and the U.S. Environmental Protection Agency, was a program for local residents that included a three-week course on the theory and measurement of low-level radioactivity. After taking this course, these citizens then used instruments to measure low-level radiation in various parts of the city during the venting of 44,000 curies of radioactive krypton from TMI-2 between June 28 and July 11, 1980. The Mayor of Middletown stated that this program was one of the most significant activities for alleviating tension during the krypton venting (Baratta et al. 1981).

In addition to the citizens who participated in the Citizen Radiation Monitoring Program, many other citizens near TMI have formed study groups to learn about nuclear power and low-level radiation. Similar initiatives could be expected among the residents of the decontamination and crop-interdiction zones. Presumably such efforts at self-education would moderate any extreme reactions and out-migrations.

Citizen's confidence in decontamination efforts would depend in part on media coverage. At the time of the accident at TMI, there were very few reporters in the nation who knew much about nuclear power and radiation, but many have learned since then. Utilities, too, have learned much about media relations from the TMI accident. Partly as a result of these trends, media coverage of the January 1982 accident at the Ginna nuclear power plant near Rochester, New York, was much more accurate, consistent, and informative than was media coverage of the TMI accident. Since the effects of a severe reactor accident would be long-lasting, reporters would have ample time to become expert.

## 4.5 LONG-TERM PSYCHOLOGICAL EFFECTS

Shortly after a severe reactor accident, people would be frightened of radiation injury--of genetic damage, cancer and other unknown effects. People would be confused by unfamiliar jargon and conflicting reports, frustrated by a host of problems and perceived inequities, and angry at the government for failing to protect them.

Long-term psychological effects are more difficult to predict. It is sometimes supposed that disasters can provoke long-term mental illnesses. Available evidence, however, indicates that disasters rarely provoke long-term mental health problems (Perry and Lindell 1978, p. 114). The one disaster most commonly cited as having caused long-term psychological problems is the breach of the Buffalo Creek dam, which left 125 dead, 1,000 injured and 4,000 homeless. From the Buffalo Creek case, it seems reasonable to assume that the likelihood of long-term psychological effects is higher if there are other long-term effects, such as a death in the family (Perry and Lindell 1978, p. 114). Near TMI, there is evidence of continued stress among some residents; however, this is probably best attributed to the continuing problems of the cleanup of TMI-2 and the proposed restart of the undamaged TMI-1 nuclear unit, rather than to any lingering stress from the original accident in 1979. Thus, for a severe reactor accident also, any long-term mental health problems would most likely result not from the original accident, but rather from other long-term effects, such as latent cancers and the prolonged cleanup of the area.

In addition, if the accident necessitates moving from a neighborhood and community where one has lived for a long time and where one has strong ties of sentiment, it seems reasonable to assume that the likelihood of a long-term impact will be greater.

## 4.6 CONCLUSIONS

One can reasonably predict that some, but not all, of the social and psychological effects of a radiological accident will be similar to the effects observed during the accident at Three Mile Island and for other types of disasters. Certain characteristics of the population in the pre-accident phase --such as knowledge of protective actions and attitudes about nuclear power--can affect behavior during an accident. After a warning is given, people tend to confirm the warning, try to obtain additional information, inform friends and family members and discuss proper actions. The experience of TMI indicates that some people will begin to evacuate during the warning phase. If the amount of radiation released is large enough to cause significant damage to peoples' health, then it will be important to estimate the extent to which people can be expected to take proper protective measures: In case sheltering is recommended, it will be important to predict the number of people that fail to shelter properly. In case an evacuation is called, it will be important to estimate the total evacuation time, and the number of people that fail to evacuate.

The family unit is important during disasters. People are willing to spend extra time in the danger zone in order to unite with their families before evacuating. The decision to evacuate or not to evacuate is typically made as a family. If family members should evacuate separately, they typically try to reunite as soon as they are out of the danger zone.

It is commonly believed that panic is a major problem during evacuation, but careful research on a very large number of disasters including TMI has yielded few cases in which panic is a major problem. From this evidence it is reasonable to predict that for relatively small radiological accidents, panic will not present a major problem. However, a large radiological accident occurring under particularly adverse circumstances conceivably could cause panic or related serious evacuation problems.

Evacuees typically prefer to stay with relatives or friends, or in commercial accommodations such as hotels and motels. In most disasters only a minority of evacuees stay in public shelters, and even those people usually try to leave the shelter as soon as possible to stay with relatives or in other more comfortable quarters.

If an area is interdicted, one can expect that citizens will attempt to influence interdiction, decontamination and resettlement policy, and that these attempts will be stronger the longer the interdiction lasts. Authorities will be faced with a dilemma: if they set interdiction standards loosely, they will risk being accused of failing to safeguard the public--people will lose faith in government standards, and some people might avoid entering areas and avoid purchasing products that the government has certified as safe. On the other hand, if the authorities set interdiction standards too strictly, some people will perceive corrrectly that they can violate government interdiction policy with little danger to their health.

Studies of natural disasters that caused few deaths reveal little evidence of long-term adverse psychological effects. There is some evidence, however, that disasters that cause a large number of deaths and widespread destruction can cause long-term mental health problems. In the case of even a relatively small radiological accident, a change in public opinion toward nuclear power could be an important impact.

A summary of the authors' subjective evaluation of the importance and predictability of the various social/psychological impacts is given in Table 4.3. The format of this table is similar to that of the other summary tables in this report: impacts are listed on the vertical axis; the seven phases are listed across the top of the table; I1 (I2, I3) indicates that the impact is very important (moderately important, of minor importance); P1 (P2, P3) indicates that is is relatively easy (moderately difficult, very difficult) to obtain a reliable prediction of the impact.

The first impact listed on Table 4.3, stress, is considered to be important but difficult to predict during the early phases of the accident. Beginning with the Interdiction Phase, stress is considered to be moderately important and moderately predictable. Public opinion is considered moderately important because it could affect interdiction/resettlement policy, as well as the future of nuclear power in the region and in the nation. An estimate of the number of people that evacuate during the Warning Phase is important for emergency planning and for its effect on a potential subsequent evacuation. If

TABLE 4.3. Importance and Predictability of Social/Psychological Impacts

| Impact | Accident Phase | | | | | | |
|---|---|---|---|---|---|---|---|
| | Warning | Evacuation | Release | Interdiction | Decontamination | Resettlement | Post Resettlement |
| Stress | I1/P3 → | → | → | I2/P2 → | → | → | |
| Regional and national public opinion on nuclear power | | | | I2/P2 → | → | → | → |
| Number of people that evacuate during the warning phase | I2/P3 → | | | | | | |
| Number of people that fail to shelter properly | | I1/P2 → | | | | | |
| Percent of population that is separated from family at time of evacuation notice | | I[a]/P1 → | | | | | |
| Individual panic | | I[b]/P1-3[c] → | | | | | |
| Collective panic | | I1-3/P1-3[c] → | | | | | |
| Injury and death due to evacuation alone | | I1-3/P1-3[c] → | | | | | |
| Length of time required to evacuate | | I[d]/P1 → | | | | | |
| Number of unauthorized people in evacuation zone | | I1/P1[e] → | → | P2 → | → | | |
| Impact on host areas | | I2/P2 → | → | → | → | → | |
| Attempts by citizens to influence policy. Conflict over policy. | | | | I3/P3 → | I2/P2 → | → | I3 → |

See Table 2.1 for explanation of symbols

sheltering is advised, the number of people that fail to shelter properly is important if this substantially increases adverse health impacts.

The number of individuals that become separated from their families at the time of the evacuation notice is important if this increases evacuation time and if a delayed evacuation increases adverse health impacts. Similarly, individual panic is important primarily if it causes or augments collective panic or if it otherwise delays evacuation time. Collective panic might be important or unimportant: In the case of a relatively small accident, experts would likely agree in predicting that collective panic would not occur or would at least be very unimportant. In the case of a large accident under particular circumstances, however, some experts might consider collective panic to be very important. The number of injuries and deaths due to the evacuation, like collective panic, might be important or unimportant. The importance of the length of time required to evacuate depends on whether a delay causes adverse health impacts.

The number of unauthorized persons in the evacuation zone is important if failure to evacuate causes serious health damage, raises concerns about looting, or renders more difficult the attempts by authorities to prohibit unauthorized entrance into the interdicted area. Attempts by citizens to influence policy will most likely be important during later phases of the accident.

## 5.0 INSTITUTIONAL/LEGAL IMPACTS

While the assessment and prediction of the institutional impacts of a radiological accident is a relatively new concern from a legal or regulatory standpoint, the analysis of institutional behavior and change during crisis situations is not. Over the last three decades, the way in which organizations, communities, and individuals respond to disaster has been the subject of extensive research. During this period the nature of this research has gradually changed from journalistic reports to descriptive studies, and, more recently, to analytic studies of organizational and individual behavior during disasters. In keeping with this trend, much of the current work is oriented toward developing and testing theories to explain observed organizational responses to emergencies, and to evaluate the likely consequences of the underlying processes.

With the possible exception of cross-cultural disaster studies, most of the literature that evaluates individual and organizational disaster response recognizes the applicability of a number of general concepts, regardless of the etiology and characteristics of a particular crisis. It is argued that the effects on individuals and organizations of a disaster can be classified to a considerable degree on the basis of such dimensions as the scope of impact, the speed of onset, duration of impact, and social preparedness (see, for example, Barton 1969).

There are also general time periods through which disasters proceed that tend to be common to most natural and technological crises. Bardo (1978) summarizes these phases in the following manner: in the predisaster or warning phase, formal organizations engage in disaster preparation. During the period of threat, action response begins; the organization mobilizes resources and/or transmits warnings to others. In the immediate response phase, formal organizations face the problems of mobilizing members, coordinating their activities, and organizing and engaging in interactions with the public and other organizations. During the period of organized response, coordinating and relational activities are continued. In the final phase, organizations cope with the disaster's effects on internal structure, public relations and interorganizational relations. Each of these phases is marked by problems (or "effects") for the various groups of institutions involved in the disaster.

When a natural disaster or a technological emergency such as a General Emergency nuclear accident occurs, public and non-public institutions are involved in what the sociological literature terms a "situation of collective stress" due to a severe environmental disturbance (Barton 1969) that causes a basic disruption of the social context within which individuals and groups function (Killian 1956). In their research on organizational response to crises, Brouilette and Quarantelli (1971) advanced a typology of organizational behavior to explain the changes that may occur during the emergency, or subsequent to the crisis.

Using this framework, they were able to classify institutional response during emergencies in terms of the effects on the structure of the organization and tasks undertaken during the emergency. The classification scheme includes the following categories of structures and tasks: 1) the established forms (structures in effect and tasks carried out that represent no change from the pre-emergency period); 2) extended or expanding structures or tasks that represent temporary adaptations to situational demands; and 3) emergent structures and tasks that denote new forms of structure or new tasks not in existence before the crisis occurred. This general framework can also be used to describe most of the direct organizational changes that will occur during or after a radiological accident.

As the study of disasters goes, the emergency caused by the malfunctioning of Unit II of the Three Mile Island Generating Station, and subsequent releases of radioactivity into the atmosphere in the spring of 1979, has been one of the most thoroughly examined crises in modern times. The general conclusion that can be drawn from these studies and reports is that in most ways the emergency precipitated responses from and resulted in impacts to the public and institutions involved that were similar to other disasters, natural or technological in nature. However, Three Mile Island is only one case; no other radiological emergencies or near-emergencies related to U.S. commercial nuclear applications have occurred on this scale (at least to the extent of numbers of people and response agencies involved, media coverage, and post-emergency impacts).

There are some important ways, however, in which the overall public perception of the danger of radiological emergencies--versus natural disasters, or even other types of technological disasters--could affect the response of institutions during the crisis, and the nature of post-crisis impacts. As stated by the NRC/EPA Task Force on Emergency Planning (USNRC 1978) "radiation tends to be perceived as more dangerous than other hazards because the nature of radiation effects is less commonly understood and the public generally associates radiation effects with the fear of nuclear weapons effects." These feelings are "exacerbated by the fact that radiation is invisible, so that when an accident does happen, the extent of the accident and the actual hazard involved is usually not clear to the layperson" (Flynn and Chalmers 1979), whether he is functioning as a member of the affected population or as a member of the institution responding to the crisis. As a result, radiological emergency planning is based on public perceptions of the problem and what can be done to protect health and safety (USNRC 1980a). In all likelihood, the expected response to radiological emergencies has been and will be based on these perceptions.

Drawing on the apparent response to and impacts of the TMI accident, then, it would seem that the consequences of a General Emergency class radiological accident would differ quantitatively rather than qualitatively from those of an emergency caused by a different agent. For example, the problems and impacts caused by a large-scale evacuation would differ only in that the former would evoke a more conservative approach to determining the population at risk (larger areas would be evacuated for longer periods of time; similarly, interdiction of the affected area might be enforced more stringently and for longer periods of time).

Paradoxically, the uncertainty with regard to the level of threat and danger posed by a radiological accident also seems to be paralleled by an increase in the unwillingness of authorities to take decisive action. Thus, the confusion and lack of coordination among emergency response agencies, civil authorities, and other organizations in the institutional sector would seem to be greater than usual, or at least it would be perceived to be so by a critical public and by policy makers and legislators. Again, this appears to be a quantitative rather than a qualitative difference in reaction or impact.

In part due to the highly politicized nature of nuclear power generation issues, one might also expect that post-accident impacts of a radiological disaster would be more profound and far-reaching than in other types of disaster. However, the effects still appear to be similar in type to those resulting from other types of crises, so that the framework outlined above remains valid.

The importance of this conclusion for the present study is that, in spite of the fact that there has been only one "TMI" type of accident to use as a model for predicting the consequences of other radiological accidents, more generic models of disaster impacts can be used with a reasonable degree of confidence. The identification and discussion of the impacts of a radiological accident can be raised above the level of mere speculation.

## 5.1 METHODOLOGY

In this report an "institution" is defined as a class of organizations that has a social, educational, religious or "public service" purpose. Under the last category are included utilities, communication systems, and certain financial organizations such as banks. Institutional impacts may be the result of either direct of indirect consequences of a radiological accident. In either case, they include the following classes of change: legal impacts--changes or attempted changes in statutes, regulations and adjudicatory decisions; political impacts--changes or attempted changes in those activities by which opposing viewpoints are reconciled (Cluett et al. 1980); and organizational impacts--changes in the existence, structure and tasks of the institution. Legal and political changes are almost exclusively post-accident impacts; at minimum, they are unlikely to occur until the immediate emergency period (warning and protective action phases) is over.

These impacts can, in most cases, be placed into the following categories: a) temporary adaptations in either the structure of the organization or in its tasks and responsibilities; b) increases in inter- and intra-organizational communication and ties in order to coordinate a desired response (e.g., evacuation or delivery of social services); c) economic effects--costs incurred by an organization due to the suspension of its normal activities or by increase in expenditures for personnel or equipment. Occasionally, social, economic or health costs will be imposed on other sectors of the community as a result of impacts on the institutional organizations themselves. Such costs are noted but not discussed in this section; where significant, they have been treated in the chapters on the other impact areas.

The institutional impacts are described below in a generalized way: contextual or incidental problems that relate to the impact process are not made explicit, although such problems--confusion, dysfunctional responses, failure to achieve adequate coordination of effort--are likely consequences of almost any type of mass disaster. The circumstances that give rise to such effects can be expected to vary significantly from accident to accident and can, therefore, be handled only within a fairly complex model.

Institutional impacts are categorized by four functional "sectors":

1. Emergency response and relief groups or agencies. Three types are identified: a) direct emergency response groups (emergency preparedness and management agencies); b) auxiliary groups (police force, fire department, etc.); and c) social welfare and relief groups.

2. Institutions involving special populations. The three primary groups are: a) schools; b) health care facilities and c) prisons.

3. Public services systems. Four main types are identified: a) communication; b) financial; c) transportation; and d) utilities.

4. Other Government Groups. Includes government entities that are impacted by the accident but that do not fall under any of the above categories. In particular, local government agencies have been included in this group.

## 5.2 THE POTENTIAL INSTITUTIONAL IMPACTS OF A RADIOLOGICAL ACCIDENT

The anticipated impacts for the four institutional sectors will be described at a relatively general level, since it would be necessary to impose a number of site-specific and accident context conditions in order to estimate exact impacts. During certain phases of the hypothetical accident, only minor or negligible responses and effects are to be expected from some of the institutions.

### 5.2.1 Warning Phase

During the warning phase the official emergency response groups receive notification at the onset of the emergency. The immediate response is a mobilization of personnel and equipment according to procedures outlined in existing emergency preparedness plans. The public receives notification through official, pre-specified information networks, and the initial technical assessment of the situation begins. During this phase, it is expected that neither the auxiliary groups nor the social welfare and relief groups would be actively involved, except perhaps for some initial mobilization.

For the other three institutional sectors, activities during this phase center around preparations for a possible emergency. Decisions, such as whether to cease or curtail normal functions or whether (and how) to augment staff and resources, may need to be made. Medical facilities, schools and prisons may have to make preliminary arrangements for their populations. Similarly, it is also important that other institutions respond adequately to the emergency alert. In most cases, responses at this stage can be accomplished within the existing organizational framework.

The severity of post-accident impacts may depend upon how well these activities are carried out--a fact that emphasizes the critical need for rapid and effective communication between the utility and the radiological accident emergency response agencies, and between these agencies and the emergency broadcast media.

### 5.2.2 Sheltering/Evacuation Phase

The Sheltering/Evacuation phase involves two stages of activity: first, the decision-making process by which emergency response groups--primarily state and local, with technical assistance from federal groups--determine whether the public should be protected through sheltering or evacuation measures; and second, the carrying out of those measures. The difference in the level of the impacts between sheltering and evacuation is likely to be very significant. For example, transportation is a key factor during the evacuation phase, but during the sheltering phase it would assume a minimal role at most. Indeed, almost all of the institutional impacts would be greater with evacuation than with sheltering: evacuation requires more coordination, more institutions are involved, a greater expansion or extension of existing structures and functions is required, etc. The opportunity for confusion and mismanagement is also much greater during an evacuation response; these effects also tend to be reflected in the post-accident impacts, when the effort is made to correct perceived shortcomings.

Efforts to coordinate responses among the various institutional sectors constitute a major impact area during this phase. Time factors and the multiplicity of activities that take place in ordering and carrying out an evacuation mean that adequate coordination, both among the many institutional groups involved and within each organization itself, is critical. For most institutions, this extraordinary effort requires modifications to existing structures or the development of new forms of management. Either response can be the result of a planned transformation, or of an ad hoc reaction to the confusion that develops.

Organizational sociology recognizes two main types of coordination processes common to organizations: coordination by standardization or plan, and coordination by feedback (see, for example, Hage and Marrett 1971). The former is based on pre-established rules, schedules and programs to direct and standardize the functioning of organizations; it tends to prevail among those organizations that have strongly hierarchical structures and whose tasks and personnel are not characterized by a great deal of occupational diversity. Within the institutional sector, police departments and hospitals, for example, typically use coordination by plan.

Coordination by feedback, on the other hand, tends to focus on the transmission of new information in order to facilitate mutual adjustments within organizations. This type of coordination is found more often in groups where structural diversity is high, and the variety and uncertainty of tasks lead to a high level of horizontal communication.

In their analysis of emergent phenomena--the tendency for groups displaying new structures and performing new tasks to emerge both within and outside of formal organizations during crises--Dynes and Aguirre (1979) argue that crisis conditions cause organizations to tend toward coordination by feedback and away from coordination by plan. The conditions of an emergency make for uncertainty, diversity, decreased formalization and a certain amount of decentralization within and among organizations. In order to adapt to an emergency, then, it is likely that many institutional organizations will find it necessary to undergo structural expansion, extension of responsibilities and debureaucratization. In many cases, new groups may emerge if the existing structure cannot cope with the demands produced by the crisis or if the demands fall outside the normal range of tasks of the organization. Often these groups may have no purpose other than to coordinate. For example, in 1979 in the town of Mississauga, Ontario, a train carrying liquid fuels and chlorine derailed and a subsequent explosion and release of chlorine made it necessary to rapidly evacuate 250,000 people. Successful coordination was achieved by quickly establishing a "Control Council" consisting of local leaders, police officials, and experts from the Provincial Environment and Labor Ministries, all of whom were under the leadership of the Solicitor General of the province (Knox 1980).

The attempt to coordinate actions among and within the multitude of organizations involved in an emergency response is also accompanied by a significant increase in the amount of communications. According to Dynes and Aguirre (1979), these changes are often seen as a failure of coordination, rather than as a means for improving coordination. Assuming their conclusion to be correct, there are some important implications for assessing the impacts of a nuclear power plant accident. In general, there are three ways in which this conclusion can lead to impacts. First, the increase in communications and the expansion and extension of structure and tasks of a specific institution during the crisis may be viewed as adaptive responses necessary to provide coordination and to perform unusual tasks.

Second, because some institutions that traditionally function under coordination by plan have more difficulty in adapting to the feedback mode during emergencies, such institutions may fail to perform a needed task. The result can be that an emergent group (possibly in a different institution) will "fill the gap" and be legitimized once the emergency is over. In effect, this will reduce the "domain" of the established institution.

Finally, if the changes that lead to coordination by feedback are internally considered to represent some kind of "failure", the institution may respond during the post-emergency period by increasing vertical linkages and centralization in its planning efforts. The effect, then, may be to "overbureaucratize" in compensation for what was seen as structural failure, but what may have actually been a reasonable response to the complex demands of disaster management. There is some indication that the TMI accident has had an impact of this nature on the current approach taken to radiological emergency preparedness planning.

### 5.2.3 Release Phase

This phase represents the actual threat stage, which, due to the nature of the agent in a radiological accident, would be somewhat different in character from other types of disasters. In many other types of disasters the majority of institutions would remain in place and perhaps participate in the effort to contain or minimize the threat (e.g., sand-bagging in the case of a flood, treating victims, etc). However, by this stage of a radiological accident, most institutions will have responded by evacuating or sheltering as a unit, or by disbanding and temporarily ceasing to function as an organization. Therefore, the primary institutional activity seen during this period is the effort to continue monitoring radioactivity levels--including measuring radiation levels and predicting the path of the plume--and to determine if an interdiction of the exposed area is required.

Besides resource expenditures, the major impacts of this phase on institutions are the organizational effects implied by coordinating and monitoring the gathering of environmental information by various agencies, analyzing of data, and decision making with regard to establishing an interdiction area and period. As is the case with other critical decision-making points during the accident response, there may be institutional impacts due to conflict or confusion over roles and authority. Disaster histories, including the accident at Three Mile Island, show that the lack of a clear assignment of roles and powers--or the failure to adhere to a planned format--greatly increases the potential for confusion and poor coordination.

For the emergency management agencies situated in the risk area, this period might also include a physical transfer of emergency operations headquarters to a safe location. Facilities such as hospitals might also be impacted by heavier than normal demands for medical services by victims of exposure to the plume.

### 5.2.4 Interdiction/Contamination and Decontamination Phases

As this phase begins, the institutional responses and impacts shift focus somewhat. The problem is no longer that of responding and adapting to the rapidly changing and complex demands to organize and carry out a community evacuation. Instead, the institutional sector must now deal with: 1) problems associated with the temporary relocation of an entire populace for an uncertain period of time; 2) the requirements of other institutions, and particularly those that had to evacuate; 3) the enforcement of both interdiction of the contaminated area and of vital systems (e.g., sewer, water, utilities) within that area; and 4) the procedures necessary to carry out decontamination. While some of the institutions may attempt to re-establish pre-accident conditions of structure and responsibilities, others may find it neccessary to continue to adapt to the new demands through structural expansion, extension of tasks, or the creation of new organizational forms with new responsibilities that may be required by the situation.

With regard to the types and degree of institutional impacts that might be expected during this phase, the critical variables are the length of time of the interdiction period and the size of the interdicted area. Whereas a short, largely precautionary interdiction period would have relatively few impacts on institutions, a lengthy interdiction of a substantial area that contains a significant portion of the community could have major institutional implications. Since the specifics of an interdiction following a radiological accident would depend on the type of accident, site characteristics, weather conditions at the time of release and the radionuclides involved, the approach here will continue to be to look at a generalized situation. It will be assumed that an exposure area can be determined by monitoring, and that within the larger area, zones of varying levels of contamination can be identified that may require different periods of interdiction and degrees of decontamination. As zones with lesser amounts of contamination become rehabitable, the interdiction for that zone can be lifted and the area resettled.

Many institutions will be impacted during this phase simply because they will be temporarily forced either to relocate their operations out of the interdicted areas or to disband. In the former case, they must find a way to function at least at some minimum level using temporary facilities, reduced resources and possibly limited personnel as well. Examples of such organizations might include local government bodies or nursing home facilities. For an institution that temporarily disbands, the cessation of operations may result in no permanent impacts on it; on the other hand, its pre-accident functions may be so completely reallocated during a lengthy interdiction that the organization effectively ceases to exist.

There will be other types of impacts on institutions that are actively involved in mitigating the adverse consequences of the disaster; i.e., in maintaining the interdiction, carrying out decontamination, or in providing relief to evacuated residents. Impacts on these institutions are likely to be of a temporary nature and related to the effort of providing certain services at heightened levels. It should also be noted that during this phase, institutions in the host areas will be more heavily affected than they may have been during previous phases of the disaster response. For example, it is expected that social relief agencies, schools and medical facilities in the primary host areas would face increased demands for their services as a result of the influx of evacuees from the interdicted area.

The police and other security forces will be expected to perform at an increased level in order to enforce the interdiction of contaminated areas. Some innovation in procedures might be necessary because of the need, for example, to maintain good coordination and communication among the various groups involved (i.e., state, county and local police); however, few other changes should be required.

### 5.2.5 Resettlement/Relocation Phase

Institutional impacts attributable to this phase depend on the type and length of interdiction as well as on how many residents return to their homes and the number that relocate outside of the disaster area. In addition, studies of both public and private institutions involved in disaster recovery activities have shown that such institutions are vulnerable to public criticism in much the same way that emergency management agencies are blamed for "problems" or perceived errors that may have occurred during the warning and evacuation phases. In numerous disaster situations, the recovery effort has involved a multitude of local, state and federal relief agencies, both public and voluntary. Unless the relief agency carefully coordinates its activities, so that its functions are accomplished with a minimum of bureaucratic encumbrances and red tape, it can compound the social, psychological and economic distress of the victims (see, for example, Heffron 1977 and Hall and Landreth 1975). The result can be a negative public reaction to the relief agencies, interagency conflict, "competition" between the agencies to provide assistance, etc. (Bourque et al. 1976).

The disaster literature includes a significant amount of research on the rehabilitation period, which, under the framework of the present study, would include resettlement and at least the initial part of the post-resettlement phases. Continuing to keep in mind the caveat with regard to the applicability of general disaster studies to a radiological accident, some of these observations have apparent relevance.

Quarentelli and Dynes (1976) note that, while there is considerable variation in the degree of community conflict with institutions following a natural disaster, when there is conflict, the pattern is typically a relatively high level of conflict during the post-emergency period and a low level during the emergency period itself. They also note that the conflict in the former period generally has two focal centers: the allocation of blame, and the allocation of resources for rehabilitation. In the context of both natural and technological disasters, the "blame" includes reaction toward those institutions that were directly involved in protecting or aiding the public. In most situations that have been described, the focus is also largely on public as opposed to non-public institutions.

Conflict involving the allocation of blame generally surfaces relatively quickly after the emergency period is over. On the other hand, conflict over the allocation of resources for rehabilitation, when it does appear, seems to take much longer to surface. Quarantelli and Dynes (1976) hypothesize that as the often massive inflow of state and federal assistance into the affected area slows down, different community organizations may begin to compete for the declining pool of money and supplies. Barton (1969) and Thompson and Hawkes (1962) also point to the tendency of relief organizations to compete for "social credit" based on their role during a disaster response. Both voluntarily supported (e.g., the Red Cross) and tax-supported (e.g., social services) agencies must secure public recognition of their services if they are to continue to receive this support (Barton 1969).

In the allocation of supplies and money to the public, relief agencies are often criticized by the public when they re-institute bureaucratic forms and procedures for the dispersal of aid. The "rebureaucratization" that occurs is in contrast to the format during the emergency period, when the tendency is to distribute resources "freely" with only minor attention paid to standard organizational procedures and responsibilities (Stoddard 1969).

The conflict arising from the tendency to assign blame and from competition over rehabilitation resources may not simply involve public versus institution or inter-organizational dichotomies. Sociologists have observed that a typical post-disaster reaction is for hostility to be directed toward "outsiders". The emergency generally creates a community cohesiveness that persists for varying lengths of time. Initially, then, the hostility may be focused on "outside" (i.e., non-local) agencies, affixing to them most of the blame for any inadequacies perceived in the warning and emergency response, and charging them with insensitivity and inefficiency in their efforts to relieve the suffering of the victims. Local organizations and leaders are often absolved from blame, in spite of any actual deficiencies in their operation. Quarantelli and Dynes note that this insider-outsider dichotomy eventually tends to break down, particularly when the dwindling of outside assistance and interest results in local organization and group conflict over the allocation of the remaining resources.

While conflict involving the institutional sector seems to stem largely from the two themes noted above, Heffron (1977) and Quarantelli and Dynes (1976) also note that the conflict can be amplified by other factors. In some instances, Quarantelli and Dynes note, the insiders-versus-outsiders stratification is reinforced by political dimensions. Community officials may be affiliated with one political party, while state and federal officials may represent another--leading to accusations of "political" motivations on one side or the other. (This dimension may also affect local inter-institutional relationships as well.) A second factor noted by both studies is the surfacing of vested interests--conflict augmented by the incompatibility of goals among the various relief organizations, for example, or because of competition with established institutions and groups that emerged or had extended their responsibilities in order to accomplish a needed function during the emergency. In the latter case, an established institution may feel that its domain is threatened, and arguments over who has the legitimacy to undertake certain tasks may ensue. An added dimension to this problem might be the conflict between established institutions and persisting emergent citizens' groups over rehabilitation tasks or roles (Mileti et al. 1975).

A final impact area should be mentioned, although it is somewhat related to the previous discussion. Once the immediate danger--the crisis--has passed and the recovery period begins, there is likely to be a substantial increase in the need for social services and mental health care to relieve the social and emotional effects experienced by the disaster victims. This need could be especially pronounced in the case of a radiological accident. The possible widespread nature of a radiological disaster, the possible need for substantial population relocation, and the general public fear of a radiological threat of any dimension could result in social and psychological problems on a much larger scale than would be typical of most other types of disasters. Heffron (1977) comments on the effect of this suddenly expanded role for such organizations in his study of interagency relationships following the 1972 Wilkes-Barre, Pennsylvania flood. He notes that the traditional human service delivery systems may be either overwhelmed by the demands of the situation, rendered physically inoperable by the effects of the disaster, or simply inappropriate for the situation. In part, the problem may be due to the typical absence of a role for human service delivery in pre-disaster planning efforts.

Most current disaster plans give almost exclusive attention to evacuation, emergency medical attention, and the provision of physical shelter for victims (Heffron 1977). In the absence of clearly defined areas of responsibility for post-disaster human services, confusion and inefficiency in service delivery often result. Ad hoc planning efforts and attempts to coordinate the multi-institutional response during the rehabilitation period can lead to duplication, service imbalances, interagency strife, and inefficient application of human services resources. These problems adversely affect both those in need of the services and the institutions attempting to provide them.

### 5.2.6 Post-Settlement or Long-Term Impacts

While the possible long-term institutional impacts that could develop in the post-settlement phase cover a relatively wide range, it is necessary to place these possibilities in some perspective. In doing so, observations are drawn from both the body of disaster study literature and from the TMI experience. In a number of instances, the conclusions of the literature seem to agree with what appears to have occurred (or not occurred) as a result of the TMI accident. However, there are also some notable differences. The problem, once again, is in determining whether the important differences are the result of the uniqueness of TMI--as the first significant radiological emergency in the U.S. involving commercial generating facilities--or are effects likely to accompany other, subsequent radiological accidents.

The long-term effects of disasters have not constituted a major portion of the disaster literature, although there are a growing number of analytical studies on the subject. By and large, the consensus seems to be that--almost as a paradox to the amount of environmental and social disruption that attends most disasters--long-term major organizational change occurs only to a relatively slight extent (Ross 1978).

In an analysis encompassing some seventy disaster-relevant organizations dispersed among four communities that had experienced a large-scale disaster (explosion, earthquake, tornado and flood), Ross measured a number of variables that are generally recognized as indicative of organizational change. In addition to setting up a number of measurable organizational characteristics, including organizational complexity, autonomy, dispersion, mechanization, size and organizational function as his independent variables, he identified three types of possible "innovation": change in domain, change in structure, and change in resources.

He found that nearly all of the innovation found to occur was of a "rather minor nature, consisting of what has been referred to as 'stand-by change'; i.e., change which manifests itself only on certain occasions" (Ross 1978). While Ross derived a few statistically significant relationships between some of the variables and some types of change in the explosion disaster, he generally was unable to find any in the natural disaster settings. An exception found in one case was that changes in resources were found to be positively related to organizational complexity. However, Ross did find that a significant relationship seems to exist between the likelihood of structural change and the absence of what sociologists refer to as a "disaster subculture" --behavior associated with a community's past experience with similar disaster events.

Bardo (1978) notes an interesting corollary to this observation in his study of the organizational response to flooding caused by Hurricane Agnes in 1972; namely, that the likelihood of long-term functional and structural changes would also be low if the disaster was viewed as so abnormal an event as to be considered a "fluke". While a small amount of institutional change did occur (within the time frame of six years used by Bardo), much of it consisted of informal operational modifications within a particular organization.

In another assessment of long-term changes following a disaster (the Anchorage, Alaska earthquake of 1964) Anderson (1970) concluded that the event served as an impetus for change, to the extent that it brought about certain new environmental and internal conditions that stimulated or required adjustments on the part of some organizations. He noted that for some organizations, changes were the direct result of the disaster, but for others what seemed to have occurred was simply the acceleration of pre-existing trends. He concluded that the following conditions seemed to precipitate major long-term changes: 1) a number of changes were planned in the organization or were in the process of being implemented when the disaster occurred, and these changes became more relevant because of the disaster; 2) new strains were generated or old ones were made more critical by the disaster; 3) the organization experienced so great an alteration in its relation to its environment that new demands were placed on it; 4) alternative organizational procedures and norms were suggested by the disaster experience; and 5) increased external support was given to the organization following the disaster (Anderson, 1970).

The accident at TMI did, without a doubt, precipitate a number of long-term institutional changes. However, many of the changes seem to be more in the nature of institutional focus rather than in structural or functional modification. Emergency preparedness planning is a prominent example. A substantially larger emphasis has been placed on developing adequate radiological emergency plans at the federal, state, and local levels. As a result, staff time and budgets for the development and review of plans has increased accordingly, almost to the point where concern for, and activities related to, radiological accidents planning has eclipsed other basic concerns of some of the agencies involved (notably PEMA, the Pennsylvania Emergency Management Agency, and FEMA to some extent as well).

At the local level organizational changes in institutions within the TMI area are less apparent, in spite of the continuing public interest and the various social and political effects of the 1979 accident. For example, in the three counties closest to the TMI generating station (Lancaster, Dauphin and York), Emergency Management Offices have not increased substantially in terms of staff or budget; according to information obtained in telephone interviews with county and state personnel, in only one county (Lancaster) has NRC-mandated emergency planning been carried out with a significant amount of local input.

Aside from the formal emergency preparedness planning that is taking place locally, several of the institutions (primarily hospitals and schools) have made efforts to improve their own emergency plans. A thorough analysis of the effects of TMI on institutions has not been made; such a study could provide some valuable insight into post-emergency impacts.

Long-term political effects of the accident appear to be somewhat more profound; however, these again may be related to the uniqueness of TMI (the accident that "couldn't happen"); legal effects of the incident may be similarly unique. The interface between the political and legal ramifications of large-scale disasters and organizational change have been often commented on, but rarely examined to the extent that predictable relationships can be made with much confidence. In the case of the Three Mile Island accident, moreover, the overall legal and political impacts seem to have affected the status of the nuclear power industry much more profoundly than they have the various state, federal and local institutions that were involved in responding to the accident.

Table 5.1 summarizes the possible long-term, post-resettlement institutional impacts that could develop from a radiological accident. An attempt has been made to provide a reasonably comprehensive coverage of the likely impacts, but also to limit impacts to those that have been substantiated at least descriptively in the general disaster literature, to avoid highly conjectural conclusions. However, to reiterate from the above discussion, the likelihood of any of the particular impacts falling on a particular institution varies considerably according to pre-accident conditions, idiosyncratic events during the accident response, such institution-specific factors as size, complexity, organizational characteristics, and so forth.

The possible long-term effects that are outlined in Table 5.1 are, in general, causally related to events that take place during the emergency and the rehabilitation periods following the accident. There is an additional aspect that could be relevant to the estimation of long-term effects: the fate of the damaged generating station. The ultimate disposition of the plant (repair and return to service, decommissioning, conversion to other fuels, etc.) could continue to give rise to additional, although indirect, social, economic, institutional and environmental effects. These effects have been determined to be relevant to the assessment of impacts of a radiological accident, but are considered to be beyond the scope of the present report.

## 5.3 CONCLUSIONS

To the casual observer of the way in which institutions respond to the various exigencies of a disaster situation such as a radiological accident, the impacts described in the preceding material might seem a good deal too abstract or "cold". There is no doubt that it would be very difficult to convey a sense of the dynamic and dramatic conditions and events that prevail during an emergency within an analytical framework such as is used in this report. To a great extent, the past emphasis on the descriptive side of institutional response and impacts is a primary reason why so little (relatively speaking) has been done in the areas of predicting institutional impacts and using those predictions to improve disaster policy making and planning.

It is to be hoped, then, that it is clear that the purpose of this analysis is to describe a process: the transformation of various institutions

## TABLE 5.1. Importance and Predictability of Institutional Impacts

| Impact | Accident Phase: Warning | Evacuation | Release | Interdiction | Decontamination | Resettlement | Post Resettlement |
|---|---|---|---|---|---|---|---|
| Increase in resource demands (equipment, facilities, manpower, costs, etc.) | I1/P1 → | → | → | [a] → | → | → | I3/P1 → |
| Increase in manpower demands (reserves, volunteers, etc.)[b] | I1/P1 → | → | → | [a] → | → | → | I3/P1 → |
| Increase in interactions (coordination efforts)[c] | I1/Pw → | → | I2/P2 → | → | → | I1/P2 → | I3/P2 → |
| Structural adaptations (within or among organizations) | I2/P2 → | I1/P2 → | | I2/P2 → | → | I1/P2 → | I2/P2 → |
| Disruption of normal operations[d] | I1/P1-2 → | → | → | → | → | I2/P1-2 → | I2/P1[e] → |
| Inter-organizational competition/conflict | | | | I3/P2 → | → | I1/P2 → | I2/P2 → |
| Changes in domain/reallocation of roles | | I1/P3 → | | I3/P3 → | → | I1/P3 → | I1/P3 → |
| Regulatory changes | | | | | | | I1/P2 → |
| Programmatic changes | | | | | | | I1/P2 → |
| Legitimization of emergent groups | | | | | | | I1/P3 → |

See Table 2.1 for explanation of symbols

from a state of relative equilibrium, by various adaptations which may be either temporary or long term in nature, to a new equilibrium (Gillespie and Perry 1976). This new equilibrium may be qualitatively different from the original state, or, as is more often the case, it may be only slightly different. Like other disasters, a radiological accident creates a situation in which a number of extraordinary demands are made on institutions. These demands may occur both simultaneously and separately during the various phases in which a disaster can be analytically separated. The institutional response to the organizational stress caused by these demands may be either functional or dysfunctional. In general, however, this discussion has avoided the use of scenarios to cover all of the literal impacts that could be associated with either functional or dysfunctional responses. It was felt that a preliminary understanding of the nature of the impacts on institutions was required first.

Brouilette and Quarantelli's (1971) typology of change served as the basis for the attempt to provide that understanding. Thus, it was shown that, in order to adapt to a particular demand or series of demands, an organization might have to temporarily alter its mode of operation through the extension or expansion of existing organizational structures or tasks, or by adopting new ones. Throughout the accident and its aftermath, the need to coordinate actions is one of the most critical demands. The degree to which a particular institution meets this demand, and others such as timely decision making, adequate public warning, effective monitoring of environmental conditions, and efficient delivery of relief to the victims of the accident, in turn, influences the likelihood that long-term institutional impacts will occur. These factors also are reflected in the type of long-term impact that may be felt by a particular institution.

The relatively "abstract" nature of the impacts described in this report should not be underestimated, however. As the events following the Three Mile Island accident have shown, disasters can and do profoundly affect the social, economic and political environment of institutions, and, not uncommonly, the institutions themselves. While the "health and well-being" of institutions is a significantly different type of concern than that for individuals, families, communities and so forth, it is both a valid concern and one which cannot be casually omitted in an investigation of the consequences of a radiological accident.

Table 5.1 summarizes the various temporary and long-term impacts that might be felt by institutions as a result of a radiological accident. This material makes clear the relatively transitory nature of many of the impacts and the fact that some institutions may be heavily impacted during some phases of the accident response, but scarcely at all during other periods. The table also serves to highlight the probability that events during the evacuation phase, in most cases, will cause the greatest number of impacts to the greatest number of institutions. This fact will be particularly true in the event of an evacuation marked by lack of coordination, extensive confusion and indecisiveness on the part of institutional authorities. In such a case, adverse legal and political repercussions during the post-resettlement period are more likely, as are organizational changes prompted by these effects.

## 6.0 CURRENT METHODS FOR ASSESSING NUCLEAR REACTOR ACCIDENTS

Partly because of concern over the effects of the accident at Three Mile Island, recent policy of the NRC has been to include a consideration of the environmental consequences of an accident in the Environmental Impact Statement (EIS) of each nuclear power plant being licensed (45 FR 40101, June 13, 1980). The Site Analysis Branch (SAB) of the Division of Engineering in the NRC's Office of Nuclear Reactor Regulation has responsibility for including an evaluation of the socioeconomic consequences of an accident in the plant's EIS. This chapter presents a discussion of the methodology and techniques used to evaluate site-specific consequences of severe nuclear power plant accidents.[1]

Any estimates of the potential socioeconomic impacts of a nuclear power plant accident will be highly uncertain. For example, the process of the physical accident, the radioactive release, and the plume dispersion are all complicated physical occurrences that greatly affect the resulting socioeconomic impacts. Even given a release scenario, the linkages between the release and the resulting health, psychological, sociological, institutional, and economic consequences are not accurately known. Fortunately for society, but unfortunately for the task of attempting to forecast the consequences of such events, there is a lack of directly relevant historical experience with severe power plant accidents. This makes it especially difficult to describe many of the social/psychological and health effects. Some impacts must be inferred from studies of natural disasters, although it is not certain to what extent such literature is relevant.

The primary purpose of this chapter is to provide a description of what has been included in the evaluations of the socioeconomic consequences of an accident, what data have presently been identified, and how the data are used in estimating accident consequences.

Computer models have played an important role in estimating off-site accident consequences. It is therefore appropriate to review these models as well as others that have the capability of providing estimates of reactor accident consequences. The model most commonly used is CRAC2 (Calculation of Reactor Accident Consequences, Version 2), a computer model developed for and used by the NRC specifically to evaluate the off-site socioeconomic impacts of a reactor accident. Two other models that were also prepared for the NRC to be used in accident consequence evaluation are HECOM and DECON. HECOM takes the health consequences of a reactor accident, as computed by CRAC2, and estimates the direct health care costs and indirect costs attributable to lost earnings. DECON computes accident decontamination costs and provides decontamination schedules; it, too, relies on CRAC2 inputs.

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[1] Pacific Northwest Laboratories (PNL) has applied this methodology at various levels of sophistication to Limerick, Shearon Harris, Bellefonte, Catawba, Skagit-Hanford, and Seabrook generating stations.

In addition to CRAC2, HECOM and DECON, other models reviewed include a Bureau of Economic Analysis (BEA) input-output model that is currently being used by the NRC; MASTER, a regional impacts model; and an economic dynamics recovery model that is being restructured at PNL for the Federal Emergency Management Agency. The purpose of discussing these latter models is to provide information on modeling efforts elsewhere and to evaluate to what extent these efforts could be useful to the NRC.

## 6.1 ORGANIZATION

The following section consists of a discussion of the data requirements and the availability of data for describing the region surrounding an accident site. An accurate description of the accident site provides an important baseline for estimating the types and potential magnitudes of socioeconomic impacts following an accident. Section 6.3 presents a brief description of how the accident scenarios are modeled. Finally, in Section 6.4, the linkages and models used to identify and estimate accident socioeconomic consequences are discussed.

## 6.2 REGIONAL DESCRIPTION AND PROFILE

An important first step in evaluating nuclear accident impacts at a specific site is to develop a geographic and demographic profile of the area near the nuclear plant. This provides a baseline against which to estimate the impacts of an accident and to discuss those impacts that are difficult to quantify. This section discusses the data requirements for describing the region surrounding the plant and known data sources that may prove helpful in completing the baseline.

### 6.2.1 Data Requirements

Table 6.1 presents an outline of demographic, economic, recreational and institutional data useful in describing the area near a nuclear power plant. The data help to identify any unique regional or national resources. Not all of the data will be available for each plant since some of the data--e.g., land use data--are of local origin.

In addition to the availability of useful data, another difficulty concerns the form in which the data are generally available. The computerized analytical approach used at the NRC requires a radial accident grid, while local data are usually available only for political subdivisions. This accident grid consists of a set of 16 sectors, each of 22-1/2°, with a series of concentric circles superimposed on them. The grid is centered on the accident site and is portrayed in Figure C.1 of Appendix C. The geographical incompatibility between the accident grid and the political subdivisions means that the data have to be translated from one geometry to the other.

Since the size of the baseline population plays a crucial role in determining a number of socioeconomic effects, including health effects, costs of evacuation and relocation, and social and psychological effects, it is important to obtain accurate population counts (Section I of Table 6.1). Data regarding sex and age distributions enhance the specificity of forecasted

TABLE 6.1 Outline of Data Requirements for Nuclear Power Plant Accident Analysis

I. POPULATION (1980)

   A. Permanent residents by sex, age
   B. Transients by sex, age
   C. Institutionalized population (identify institutions)
      1. Schools
      2. Hospitals/Nursing homes
      3. Prisons
      4. Religious facilities
   D. Households

II. LAND USAGE

   A. Property values by type
      1. Agricultural
      2. Recreational
      3. Commercial/Industrial
      4. Residential
   B. Land area by type
   C. Recreational/Cultural/Historical

III. LOCAL GOVERNMENT DATA

   A. Expenditure
   B. Tax revenues (especially those likely indexed to the plant)

IV. INDUSTRIAL ACTIVITY

   A. Employment (by SIC Code)
   B. Sales and/or value added (by SIC Code)
   C. Payroll (by SIC Code)
   D. Identification of critical industries
      1. Financial institutions
      2. Utilities
      3. Transportation facilities
      4. Defense facilities
   E. Value of crops and milk

health effects and costs, while data on institutionalized populations, the number of households, and transient populations make possible more realistic evacuation scenarios.

Property values and land area by type of land usage are important in determining the costs of interdiction and decontamination following an accident. These are included in Section II of Table 6.1. Also, since contaminated crops and milk may need to be destroyed, the value of crops and milk in the surrounding area are useful baseline statistics. It is important to identify industries, services and operations that are important to the evacuation as well as major on-site activities. Threatened resources involved in the nation's well being and the characteristics of the region surrounding the accident site should also be identified. Impacts to the regional and national economy of evacuation and lost facilities can be estimated using regional impact models.

The description of the economic baseline includes information about both the public and private sectors of the economy. Local government expenditures and tax revenues--including revenues dependent upon the plant's operation, such as property taxes and utility sales taxes--might be dramatically affected by an evacuation or lengthy interdiction following a severe accident. Similarly, the disruption on the local, private economy could be substantial.

Data relating to the private economy are shown in Section IV of Table 6.1. Discussion of these impacts is facilitated by information on value added, sales, and employment by SIC codes for the area surrounding the plant. This information, coupled with estimates of economic damage and losses, can be used in regional and/or national models to provide estimates of the secondary impacts of the power plant accidents.

### 6.2.2 Data Availability

Estimating the site-specific consequences of the impacts of a power plant accident requires data on a number of topics. These data are useful for qualitative discussions of both the effects of the accident on the regions surrounding the plant and as input to models which provide quantitative estimates of the accident's consequences. This section discusses the data sources that have been identified and used to date.

6.2.2.1 Applicant Documents. The most complete sources of information on site location and description are documents submitted by the applicant during the licensing process. For example, Chapter 2 of the Environmental Report (ER) may include the following:

- o population estimates for the 16 directional sectors within 10 miles of the plant (current and projected);
- o population estimates between 10 and 50 miles from the plant (current and projected);
- o regional information on institutions such as schools, hospitals, and prisons close to the plant;

- o land use information such as areas of crop and milk production;
- o historic, scenic, cultural and natural landmarks; and
- o industrial activity close to the plant.

Although the information may occasionally need to be verified, the applicant's data is accessible and provides a relatively detailed description of the area within 10 miles of the plant. Disadvantages are that 1) the data are occasionally outdated; 2) often they are limited to 5 or 10 miles surrounding the plant; and 3) data not required by the NRC, such as land use and land value, are often lacking. Land use and land value data are especially important in estimating the economic consequences of an accident.

Some additional information is available from the on-site and off-site emergency plans. On-site plans include information on how site personnel will handle the emergency procedures and interact with off-site emergency personnel. Unfortunately, the off-site emergency plans, which are prepared by the state or local agency responsible for emergency planning, are often still in preparation while the NRC impact analysis is taking place. The off-site emergency plans contain information on evacuation planning; this should be of direct help in determining the site-specific effects of an accident.

6.2.2.2 Demographic Sources. Numerous sources, other than applicant data, can be used in constructing a demographic profile of the area. These include computer-generated estimates based on Census areas--such as centroids, blocks or tracts--aerial photographs of the site area, and Census Reports. The NRC possesses photo composites of United States Geological Survey maps that depict the area within 10 miles of a nuclear plant. These maps are used in emergency planning and show the location of populations near the plant; they are available for all sites.

The SAB is currently providing demographic estimates for use in accident consequence analysis. This work attempts to verify applicant data through analysis of applicant techniques and by comparison with other demographic data sources. Studies funded by the NRC are currently underway for developing computer interpretation techniques for use on high-altitude photography. When operational, these techniques will provide standardized and detailed demograhic data for all sites.

6.2.2.3 Economic Sources. Economic data come from various sources. Information regarding industries can be found in the applicant's ER and in data provided by the Department of Commerce, Bureau of Economic Analysis (BEA). The ER provides data on specific firms, while BEA information provides aggregated data for specified regions.

The Bureau of the Census publishes the County and City Data Book, which contains data by city and county for employment, earnings, and for many other economic and demographic variables. Other useful Census publications are the Census of Governments, last published for 1977, and the Census of Mineral

Industries. Volume 2 of the Census of Governments ("Taxable Property Values and Assessment/Sales Price Ratios") provides information on assessments for SMSAs, states and counties. In addition, the ratios of assessments to sales are included for many counties. These data allow one to estimate the market value of property surrounding the plant. Volume 4 of the Census of Local Governments includes information on the taxes, revenues and expenditure patterns of county governments. The Census of Mineral Industries was also last published for 1977. This document contains data, by county, on mineral production. Local Area Personal Income: 1975-80, produced by BEA, provides useful data on earnings and income for each U.S. county.

Several sources for agricultural data are available. For example, state agricultural agencies typically publish production statistics by county for major crops. A similar publication from the U.S. Department of Commerce, The 1978 Census of Agriculture, lists agricultural production by county. The Census of Agriculture is used to compile agricultural values used as input parameters to the NRC's computerized accident consequence model, CRAC2.

6.2.2.4 Institutions. Information about financial institutions is found in three sources. Lists of banks are found in Polk's World Bank Directory (R.L. Polk and Co. 1982) This reference lists banks by city and county and provides information on assets and liabilities. The 1981 Directory of Savings and Loan Associations (T.K. Sanderson 1981) lists locations and assets of S&L institutions. The A.M. Best Co. publishes two volumes of Best's Insurance Reports, listing life-health and fire-auto insurance companies by location (A.M. Best 1982).

Other institutions included in the analysis are medical facilities, schools and prisons. Lists of these institutions (within 5 or 10 miles) can often be found in applicant documents, such as the Environmental Report, or applicant-supported documents such as evacuation time studies. Additional information for medical facili ies can be found in the American Hospital Association's annual guide issue (AHA 1981). The guide lists hospitals by incorporated area and county and provides information on hospital size and service capabilities.

Additional information on school systems and prisons may have to be acquired through local planners or boards of education and prison boards. Listings for these can be found in local telephone directories.

In developing the institutional data base, information on institutions is collected for areas within 10 miles of a nuclear plant and for large cities that may be physically affected by a severe accident.

6.2.2.5 Recreational/Cultural/Historical. Recreational, cultural and historical facilities are important resources that partially characterize a particular area. Cultural and recreational areas can usually be found in information distributed by local counties. The National Register of Historic Places offers information on historical facilities within an area.

## 6.3 ACCIDENT DESCRIPTION

The NRC relies heavily on models to estimate the essential features of serious reactor accidents. These models are used, for example, to predict the physical processes that take place in the reactor core following the failure of one or more reactor components and/or human error. One of the major uses of these models is to predict the quantity and type of radiological materials that would be released to the atmosphere in the event of a reactor accident. This information can then be used as input to other models, which simulate the dispersal of radioactive materials off-site, and which calculate the off-site health and economic consequences of the accident.

The following section describes accident scenarios developed within the NRC. These accident scenarios are used to evaluate nuclear reactor operation safety and the effects of certain plant and equipment malfunctions. As noted above, these specific scenarios are also used in consequence models to obtain estimates of the health and economic consequences of a particular accident. One such model, CRAC2 (Calculation of Reactor Accident Consequences, Version 2), is described in Section 6.3.2.

### 6.3.1 Accident Classifications

Many of the release assumptions used in the NRC regulatory and safety requirements are also used as specific accident scenarios in evaluating the consequences of power plant accidents. Types of accidents may be described by reference to the "class" of the accident, the siting source term (SST), or accident sequences. The last category is the most prevalent today, given its flexibility in describing accident processes. This section briefly summarizes the nomenclature and assumptions surrounding the scenario descriptions.

An early analysis of the consequences of a reactor accident was conducted by Brookhaven National Laboratory as a part of WASH-740, "Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants." Three scenarios were defined, and in the third scenario--the most serious of the three--50 percent of fission products are released to the atmosphere. WASH-740 led to the concept of the Maximum Credible Accident, which attempted to describe an accident scenario that could be used to place limits on safety considerations and designs. The scenario contained a serious rupture of a major coolant pipe, a meltdown of the fuel, and partial release within the containment structure. The containment structure was assumed to be effective, with only one percent of the fission products assumed to have leaked.

A system for classifying accidents on a scale from 1 to 9 was initiated by the Atomic Energy Commission as part of an environmental assessment of the impacts of reactor accidents. An analysis was completed for all of the accident classes except 1 and 9. The effects of a Class 1 were not considered to be of sufficient magnitude to warrant analysis; the effects of a Class 9 accident were acknowledged to be severe, but the probabilities of occurrence were considered too low for an environmental impact assessment. Partly as a result of the incident at Three Mile Island--a Class 9 accident--the NRC now considers the risk and effects of all types of accidents, including Class 9, in the Environmental Impact Statement (EIS).

Recent EIS's have analyzed the consequences of four types of severe accidents. These accident scenarios are described by a sequence of events that lead to releases of radioactive material. For a pressurized water reactor (PWR) plant (for example, Comanche Peak), the sequences are designated Event V, TMLB', PWR-3, and PWR-7. Event V is a scenario involving a loss-of-coolant accident that could not be contained by the mitigating features of the building or by the building itself. NRC believes that the possible occurrence of this event contributes significantly to the total accident risk in the PWR design used in the Reactor Safety Study (Comanche Peak, Draft Environmental Statement, p. D-2).

The TMLB' scenario consists of a loss of all AC power along with the steam turbine-driven auxiliary feedwater train, which is required to remove shutdown heat from the reactor core. This failure would cause the uncovering and melting of the reactor core.

The PWR-3 sequence involves a failure of the building containment due to a failure of the containment heat removal. Core melting would following, and the containment failure would allow the release of radioactive materials to the atmosphere.

The PWR-7 scenario is less severe than the other scenarios. PWR-7 involves a core meltdown, but with containment sprays operating to reduce containment pressures and temperatures. Radioactive materials are leaked into the ground with some subsequent leakage into the atmosphere via the ground pathway.

The sequences used to describe an accident in a boiling water reactor (BWR) plant are designated TWγ', TWγ, TCγ', TCγ, and two four-component sequences: TQUVγ'/AEγ'/$S_1$Eγ'/$S_2$Eγ' and TQUVγ/AEγ/$S_1$Eγ/$S_2$Eγ. In each of these sequences, radiation may be released directly to the atmosphere (denoted by γ') or to the reactor building (denoted by γ). If radioactive materials are released to the reactor building, they are eventually discharged to the atmosphere with some deposited particles remaining in the building. Thus, a sequence followed by γ is less severe than a γ' sequence due to decreased radioactivity released to the atmosphere.

In TW sequences, a transient event occurs after the reactor has shut down. Containment fails, but the process takes many hours, thus allowing for possible warnings and evacuation. A TC sequence involves a transient event requiring shutdown of the reactor while operating at full power. Ultimately, containment is breached and the core melts. This sequence is estimated to be one of the more dominant sequences in terms of public risk. The TQUV/AE/$S_1$E/$S_2$E sequence involves failure to deliver makeup coolant to the core when necessary. Eventually the core melts, leading to a failure of containment.

An alternative grouping of accidents was used in an NRC examination of accident source terms and of the effect of alternative assumptions regarding accidental releases on licensing practices, rulemakings, and environmental and risk assessments (USNRC 1981a). Table 6.2 shows the descriptions for each of five groups of accident scenarios. The term "SST" (Siting Source Term) is often used in place of "Group." Thus, a Group 1 accident is the same as an SST-1 accident.

About 100 times more radioactive material is released during a Group 1 accident than during a Group 2 accident. The accident at Three Mile Island was approximately a Group 4 release. A Group 1 accident involves about one million times as much radioactive material as the release at Three Mile Island.

TABLE 6.2. Description of Accident Groups

| Group | Description |
|---|---|
| Group 5 | Limited core damage. No failures of engineered safety features beyond those postulated by the various design basis accidents are assumed. The most severe accident in this group includes substantial core melt, but containment functions as designed. |
| Group 4 | Limited to modest core damage. Containment systems operate but in somewhat degraded mode (TMI-2 equivalent). |
| Group 3 | Severe core damage. Containment fails by basemat melt-through. All other release mitigation systems function as designed (similar to a PWR-7). |
| Group 2 | Severe core damage. Containment fails to isolate. Systems to mitigate fission product release (e.g., sprays, suppression pool, fan coolers) operate to reduce release. |
| Group 1 | Severe core damage. Essentially involves loss of all installed safety features. Severe direct breach of containment. |

Source: USNRC 1981a.

Table 6.3 shows how the relative differences in released materials translate into relative accident consequences. For example, it is estimated that a Group 1 accident results in 10,000 early fatalities for each fatality from a Group 2 accident. Fortunately, the probability of a Group 1 accident is very low.

TABLE 6.3. Relative Consequences of Various Accident Groups

| Accident Spectrum | Early Fatalities | Early Illnesses | Cancer Fatalities | Property Damage |
|---|---|---|---|---|
| Group 1 | 100 | 100 | 100 | 100 |
| Group 2 | 0.01 | 5.0 | 10 | 1.0 |
| Group 3 | 0 | 0 | 0.02 | 0.02 |
| Group 4 | 0 | 0 | $1 \times 10^{-4}$ | - |
| Group 5 | 0 | 0 | $1 \times 10^{-5}$ | - |

Source: USNRC 1981a.

### 6.3.2 The CRAC2 Code

The physical accident process is only one part of the accident scenario. Release of radiological materials off-site and the subsequent health and socioeconomic effects also need to be described. In this section, we briefly describe CRAC2, a computer program for estimating the health and certain economic consequences from a serious radiological accident. A more detailed description of the CRAC2 computer code is presented in Appendix C.

The potential costs to society from an accidental release of radiation from a nuclear power plant range from near zero for chronic but small quantity emissions (e.g., a Class 3 accidental release), to near catastrophic for low probability but high quantity releases (e.g., a Class 9 accident). The CRAC2 computer program has been developed for use in quantifying the potential accident costs from a Class 9 accident. This code was developed by the NRC in the Reactor Safety Study (USNRC 1975). This document and the CRAC2 Users Guide (Ritchie et al. 1982) provide much of the documentation on how the model generates estimates of accident effects. CRAC2 is the primary tool used today by the NRC for the assessment of Class 9 accident consequences at commercial reactor sites.

The CRAC2 Code is a comprehensive computer program designed to produce broad assessments of the potential consequences of reactor accidents. When the code was developed, it reflected the most up-to-date information available for modeling a reactor accident and estimating its health effects. Since then, additional research has led to a better capability in predicting accident sequences and the amounts and types of materi›l released during an accident. For most accident sequences, the research indicated a decrease in the predicted amounts of iodine released as well as a decrease in the magnitudes for cesium and tellurium isotopes. However, no significant improvements were made in the way that CRAC2 estimates the socioeconomic consequences.

## 6.4 SOCIOECONOMIC ACCIDENT CONSEQUENCES

Secion 6.4.1 discusses how the socioeconomic impacts of a nuclear power plant accident are analyzed. Methodologies are discussed for four impact categories: 1) economic, 2) health, 3) social/psychological, and 4) institutional. Section 6.4.2 discusses several methods and models that offer promise of being useful in estimating the effects of a nuclear power plant accident.

As the accident at Three Mile Island demonstrates, events that occur during and following a nuclear power plant accident are a complex interaction between physical phenomena and human responses. In particular, the socioeconomic impacts depend on the nature and severity of the accident, its location, the characteristics of the population, and what people do during the accident.

Evaluating the impacts of a power plant accident requires a model capable of simulating the complicated accident process. Furthermore, if the model is to produce relatively accurate estimates of the potential impacts--including the economic, health, social/psychological and institutional impacts on local, regional and national populations--it should be able to incorporate site-specific information.

### 6.4.1 Estimating Impacts

The following discussion of the methodology for analyzing the socioeconomic impacts from a nuclear power plant accident is presented according to the following four impact categories: 1) health, 2) economic, 3) social/psychological and 4) institutional.

6.4.1.1 Health Effects. The health impacts of radiation exposure were discussed in some detail in Chapter 3. They are reviewed briefly in this section. The health impacts can be divided into three general categories. The first two categories include effects occurring only in individuals who have had direct exposure with radiation. These are called early and latent somatic effects. Early somatic effects are relatively easy to detect and to associate with the accident because the exposed population and the effects are both relatively easy to identify. Latent somatic effects include a variety of cancers. Because of the low incidence rate following most levels of radiation exposure, latent cancers are difficult to predict and associate with the radiation exposure. The third category of health effects, genetic effects, occurs in the offspring of irradiated individuals. These effects are manifest as an increase in the frequencey of various traits, ranging from very severe (premature death) to fairly innocent (changes in eye color). The NRC presently uses CRAC2 to estimate health effects.

A great deal of controversy exists over the relationship between radiation exposure and health effects. In particular, the relationship between low levels of radiation and any resulting cancers or genetic effects is not well understood. Leading doctors and scientists disagree, especially on the relationships between dose and response. Different assumptions would result in different predictions of health effects. For example, the predicted effects using a no-threshold dose-response curve (one that assumes there is no threshold dose below which there are no health effects) are likely to depart significantly from the predicted effects using a dose-response curve with a threshold. The NRC's dose-response curve, as estimated for CRAC2 is a no-threshold dose response curve.

6.4.1.2 Economic Effects. The economic impacts of a severe radiological accident were described in some detail in Chapter 2. They are reviewed briefly in this section. Two categories of economic effects can be defined. These categories, which are not strictly distinct, represent different ways of viewing and accounting for an accident's consequences. The first includes direct economic impacts and costs (such as costs required to evacuate), health effects costs, the losses in property values from interdiction, and the outlays required for decontamination. The second category includes the impacts of an accident on the regional or national ecnomy. These indirect losses would include estimates, by industry, of jobs and revenues lost because materials used in the production process have become contaminated and are not readily available from elsewhere.

The first category of economic effects can best be handled by using a model that can transform a site-specific baseline of demographic information, land use patterns and industrial activity into cost estimates of the accident damages. For example, estimates of the number of evacuating households need to be converted into estimates of the costs per household over the evacuation period to obtain an estimate of evacuation costs. Such a conversion is made within CRAC2. A similar modeling process should be used for:

- evacuation monitoring costs
- food and agricultural production losses
- nonfood goods condemned
- contamination monitoring costs
- property interdiction losses
- interdiction monitoring
- decontamination costs
- health monitoring costs
- health treatment costs

The second category of effects can be analyzed using a regional/national model. Since a severe nuclear accident poses some difficult modeling problems, the model should be able to handle the effects of both supply disruptions, such as the loss of productive capacity by local industries, and demand disruptions caused by evacuation and relocation. Models such as the Bureau of Economic Analysis' (BEA) regional model and PNL's MASTER model are available to provide estimates of regional industrial impacts.

6.4.1.3 Social/Psychological. The current research base on the social and psychological aspects of disasters and evacuations was reviewed in Chapter 4. It was discovered that, with the exception of the TMI accident, existing research deals primarily with natural disasters. While the study of these could help avoid some popular, but apparently erroneous, conclusions regarding responses to disasters, the behavior of local residents responding to a severe nuclear reactor accident cannot be determined with a high level of confidence.

An alternative approach would be to develop a computer model of the social/psychological effects from a reactor accident, but this seems beyond the present ability of the representative disciplines. However, more modest approaches would still be worthwhile to present a range of possible responses.

The approach currently being used is to provide a generic description of social/psychological effects based on existing literature. Even this type of effort is likely to generate comments and questions, especially considering the unique effects caused by a nuclear accident. The second approach generates descriptions of social/psychological effects utilizing actual population and site characteristics. The gains of this approach would need to be closely weighed against the costs and time required to complete a site-specific analysis.

6.4.1.4 Institutional Effects. It is not a difficult task to list institutions that may be affected by a particular accident scenario at a specific site. Such information can be found in applicant documents or other data sources listed in Section 6.2.2. Special population groups, such as school children, patients at medical facilities, prisoners, etc. pose difficult evacuation problems. Other institutions--such as the Red Cross--that are designed to operate during a crisis may find it necessary to expand their functions and responsibilities during a severe radiological accident.

To go beyond this level of assessing institutional impacts, however, is to become involved in very difficult and speculative analyses, as suggested by the discussion in Chapter 5. A severe accident would not only disrupt the individual area institutions, but the area institutional framework as well. There is an intricate set of interactions among community groups: government agents, community groups (such as churches or residential groups), the financial community, the medical care providers, and the area population in general. Relationships within and among these groups could be substantially altered in the aftermath of an accident.

It is difficult to ascertain the long-term or less obvious institutional effects of the accident. One might first attempt to generically analyze the effects of a severe accident without regard to site or severity. Then one could augment the generic description with an analysis of the different institutional effects of a site-specific accident based on the characteristics of the local population, institutions and institutional framework. In the descriptions submitted to SAB, no attempt has been made to go beyond a generic discussion of institutional impacts.

### 6.4.2 Methods Presently Used To Estimate Socioeconomic Consequences

A severe nuclear power plant accident is a complicated event, and the impacts depend upon a large number of variables. Models can be effectively used to reduce the number of variables and events that need to be considered. To be useful for estimating the socioeconomic impacts of a site-specific reactor accident, a model must consider the relevant elements of the accident and the relationships among those elements. Usually, this requires developing a model specifically for the purpose for which it is intended. Models developed for other purposes usually require modification to be useful.

In this section models currently used by the NRC to evaluate the offsite socioeconomic impacts of power plant accidents are discussed. Three models, CRAC2, a regional model from the Bureau of Economic Analysis, and a health effects cost model (HECOM) developed by PNL, are used in evaluating accident consequences. Another model, DECON, which is currently being developed by PNL, will soon be available for determining decontamination methods, costs and schedules. In addition, the BEA RIMS II model and a regional model called MASTER are discussed in the context of their ability to provide estimates of the indirect regional impacts. Finally, the potential usefulness of the Economic Dynamics Recovery Model is addressed.

6.4.2.1 The Calculation of Reactor Consequences (CRAC) Code. The NRC presently uses the CRAC Code for evaluating many of the off-site consequences of a reactor accident. This sophisticated and comprehensive computer program was developed by the NRC for use in the Reactor Safety Study (USNRC 1975). The present form of the code, CRAC2, is a useful tool for comparing the consequences of simulated reactor accidents at different sites. For a given accident scenario CRAC2 determines the area of impact, and from this information and site-specific data collected for the area, various health and socioeconomic consequences can be estimated.

The economic submodels require the user to input a variety of data. Generally, the Reactor Safety Study is used as a reference for the input values. In several cases, these input data may be incomplete, outdated or otherwise lead to inaccurate estimates for the socioeconomic effects of a severe reactor accident. One of the major tasks conducted by PNL was to update input values to CRAC2 and to identify readily accessible sources for site-specific information. A detailed discussion of this activity is provided in Appendix D.

6.4.2.2 Health Effects Cost Model (HECOM). Costs not estimated by CRAC2 include the direct health care costs of radiation-induced cancers, the direct costs of early injuries, and the resulting loss of output due to impaired labor productivity and premature death. Direct health care costs result from hospitalization, medication, special equipment, physician care, and other medical-related costs. The value of lost labor is not necessarily an outlay, but represents a societal cost due to a loss of future production. These costs can be estimated using the Health Effects Cost Model (HECOM), a computer program developed by Pacific Northwest Laboratories. HECOM uses the health effects estimated by CRAC2 as an input to estimating the health costs. See (Nieves et al. 1983).

HECOM assumes that all radiation injuries and early fatalities occur during the first year after the accident, except prenatal injuries, which are assumed to become apparent in the first year and persist over the affected individual's lifetime. Each type of radiation injury has a characteristic duration. HECOM input data assumes that all affected individuals are treated, have productivity losses during the period of illness, and either recover or die within one year. Projections of fatalities from radiation injuries are based on the provision of medical treatment designated as "supportive" by the Reactor Safety Study. This level of care is assumed in developing the treatment cost estimates for the HECOM data base. Treatment facilities are assumed to be available in the proximity to the accident site. More realistically, if 50 or more people were injured, medical facilities in several states might be required to accommodate them all, since only a few patients having radiation illnesses and injuries could be handled by any one hospital.

For cancers, the data-base assumptions are somewhat more complicated. Latency periods differ, to some extent, by cancer type, as do probable durations of treatment and lost work. HECOM applies an average direct cost for each type of cancer to the probability of developing that cancer in a given year; it treats death as occurring at the end of the mean survival period. Direct costs are estimated for each cancer category considered by CRAC2. The value of lost labor is based on the number of weeks of work missed for each type of cancer and the expected income loss for individuals of a given age and sex. The model takes into account the probability of death from other causes in the time period following exposure. Since the direct costs and the value of lost labor occur over a number of years, the costs are discounted to a base year.

6.4.2.3 Decontamination Cost Model (DECON). Pacific Northwest Laboratory (PNL) is currently developing a computer model for planning decontamination activities and for estimating the decontamination and land interdiction costs. The model, utilizing a data base compiled primarily by PNL, contains the characteristics of over 25 distinct decontamination operations, such as vacuuming, sandblasting, high-pressure hosing, etc. The characteristics include the efficiency of the operation (and combinations of operations), the cost per square meter, the factor inputs and the area decontaminated during an average work shift. Decontamination of roofs, lawns, concrete surfaces, asphalt surfaces, agricultural land (orchards, grain acreage, land in vegetable crops and grazing land), wooded areas, vacant land, exterior walls, interior floors (carpets, linoleum tile, wood and concrete) and vehicles are all considered. (See Tawil 1983.)

Given a user-supplied radiation standard, DECON identifies the least costly decontamination method that will at least meet the standard. DECON contains the decay and weatherization models from CRAC2, which reduce the exposure levels over time. This means that by waiting, one may be able to use decontamination methods that are effective but less costly. On the other hand, deferral means foregoing the use of potentially valuable property. DECON incorporates these concepts to determine the optimal time to decontaminate each property unit. Since the factor input requirements are known, DECON can also provide an estimate of the manpower and equipment needed to carry out the decontamination schedule.

Another useful feature of this program is its ability to accept county-based data and "re-map" it onto the CRAC2 accident grid described above. Thus, the output of DECON is in the same geographical units as the output from CRAC2. Other features of DECON include:

- a submodel for calculating equilibrium indoor contamination levels based on outdoor contamination levels
- the ability to restrict the use of any decontamination method; e.g., the use of water to leach contaminants through soil where underground water supplies would be threatened

- o a fixative submodel for identifying what fixative to apply, if any, to each surface and/or property area
- o the ability to assess the impact of precipitation prior to any decontamination (vacuuming of most surfaces is a very low cost and moderately effective decontamination operation; rain, however, renders it relatively ineffective).

6.4.2.4 The BEA RIMS II Model. The Regional Input-Output Modeling System (RIMS II), developed by the Bureau of Economic Analysis (BEA), is used by the NRC to estimate the private-sector effects of an accident. The impact estimates are based on inputs provided by the NRC on the probabilities of wind direction and the size of the interdicted and contaminated areas. Additional methodological developments were necessary to take into account the reduction in production capabilities and other unique characteristics of a nuclear reactor accident (Cartwright, et al. 1982).

Recently the BEA has developed the capability to estimate accident consequences in the 16 wind directions considered by CRAC2. This capability, used first for the Limerick EIS, allows the BEA model greater compatibility with CRAC2 results and other NRC accident consequence methods. In addition to Limerick, the BEA industrial impact analysis has been used in the Shearon Harris and Bellefonte EISs.

The BEA analysis estimates only the first-year industrial impacts. Longer term impacts such, as increased out-migration and decreased regional investment, are not considered. Longer term effects would depend on the specific mitigating actions undertaken by the government following the accident. Thus, estimates of the regional effects beyond one year would be highly speculative. For example, through rapid decontamination efforts and generous government programs to aid the affected area, recovery could take place quickly. Alternatively, resources for site restoration and other recovery activities could be more limited, causing a much slower recovery.

The area considered by BEA is defined to consist of a physically affected area and a physically unaffected area. The industrial impacts are estimated for the total area since an accident that causes a decline in output in the physically affected area could also affect output in the physically unaffected area. For example, a decline in agricultural output in the physically affected area could reduce the production of processed food in the physically unaffected area. The BEA analysis constructs regional models identifying industry-specific trading activity between the physically affected and unaffected areas. Three types of linkages between physically affected and unaffected areas are identified.

1) A decrease in demand for output previously produced in an unaffected area for shipment to the affected area.

2) A decrease in tourism in the physically unaffected area due to concerns about the accident and damage in the affected area.

3) A decrease in supplies or inputs previously imported from the physically affected area. (This could constrain output in the physically unaffected area if an alternative source of supply could not be found.)

Use of the RIMS II model requires assumptions about the magnitude of the physical damage, the length of production losses and the extent and length of tourist avoidance. These assumptions are provided by the NRC.

6.4.2.5 The Metropolitan and State Economic Regions (MASTER) Model. The Metropolitan and State Economic Regions (MASTER) Model is a unique multi-regional economic model that was developed by researchers at Battelle, Pacific Northwest Laboratories. MASTER was designed to forecast regional economic activity and assess the regional economic impacts caused by national and regional economic changes (e.g., nuclear-related accidents, energy price changes, construction and operation of a nuclear waste storage facility, shutdown of major industrial operations). MASTER can be applied to any or all of the 268 Standard Metropolitan Statistical Areas and 48 non-SMSA rest-of-state-areas (ROSAs) in the continental U.S. The model can also be applied to any or all of the continental U.S. counties and states.

MASTER is a simultaneous equation econometric model. Development of the model involved specification of the equations, data collection, and estimation of the parameters. Economic theory was used in specifying the model. The MASTER simulation computer file can be set up for any county, SMSA/ROSA, or state in the continental U.S. The fully automated simulation procedure is divided into four steps. In the first, historical data for the relevant regions(s) to be simulated are gathered from the computer files. In the second step, the intercepts of each stochastic equation are adjusted on an SMSA-by-SMSA basis to better reflect actual historical trends in each SMSA/ROSA. In the third step, residuals are calculated for each stochastic equation for use with the autoregressive parameters in the forecast step. The net result of the second and third steps is an improvement in the predictive power of the model. Finally, the modified equations are used to produce an economic forecast.

6.4.2.6 The Federal Emergency Management Agency's Economic Recovery Dynamics Model (ERDM). PNL is currently engaged in the restructuring of an economic dynamics recovery model for the Federal Emergency Management Agency. The purpose of this model is to develop a planning and evaluation tool for the Federal Emergency Management Agency (FEMA) that simulates recovery of the United States economy following a nuclear attack. Since a nuclear attack may result in huge capital and human losses, the model attempts to provide good representations of individual and group behavior under extreme conditions. Thus, the model can be used for a major nuclear attack, pre-attack mobilizations or government policy scenerios. FEMA claims the model is particularly useful in evaluating the immediate post attack behavior of the economy, testing and improving civil defense and recovery policies, and analyzing U.S. nuclear attack policies. The objective of the current restructuring of the model is to integrate a monetary sector into the model and alter the structure of the model to adhere to National Income and Product Accounting conventions. Specifically, the model will include investment determination, productivity changes, changes in technology, interest rate determination, certain banking and financial operations, and balancing of the national income accounts.

Despite the flaws in the current version of the model that this project is structured to correct, the model has been used for exercises that stress mobilization in preparation for war and in exercises that are designed to test our ability to respond in case of major disasters.

An important feature of the ERD model is the explicit incorporation of many psychological effects. These effects not only include estimates of the impacts of the nuclear attack but they also help determine the rate at which the economy recovers from the attack. The model also allows a number of government policy options to be specified as exogenous variables. Thus, the model can be used as a planning tool. It is impossible to describe exactly how psychological relationships and government policy options are incorporated without careful analysis of the actual computer language, but it seems that they are based on hypothetical conjectures rather than historical data or analysis.

An analysis of the impacts of a nuclear attack has some similarities to an analysis of a power plant accident. For example, many of the possible attack scenarios are beyond the scope of historical experience. Thus, the model uses extrapolation of historical data and other modeling techniques to simulate the post-attack economy. Similarly, there is little evidence of how people will react following a large nuclear power plant accident. Simulation of individual and group responses will require drawing evidence from sources other than power plant accidents.

There are other similarities between a simulation of a nuclear power plant accident and a nuclear attack. For example, many of the same agencies would likely be involved. FEMA, state and local emergency personnel, the Red Cross, state and federal law enforcement personnel, the National Guard and a number of other agencies would participate in both types of emergency. Also, evacuation responses could be similar, such as the sheltering of evacuated individuals, the need for emergency medical care and radiation protection, and the possibility of panic. Finally, both catastrophes would lead to extensive property damage and loss of productive capacity.

There are also some notable differences. First, the potential magnitude of the impacts is different. There is a higher probability that impacts of a nuclear attack could be spread accross the entire country. The major impacts from a power plant accident would likely be smaller and only regional. Similarly, the nature and timing of responses would differ. The emphasis following a nuclear attack might be retaliation or military defense. The emphasis following a power plant accident is more likely to be on mitigation of the impacts.

## 6.5 CONCLUSIONS

The ability of the NRC to evaluate the socioeconomic consequences of hypothetical, severe accidents at nuclear reactors has been substantially enhanced with the recent development of some specialized computer models, the improvement of existing models and improved data gathering techniques. The greater use of site-specific information has the potential of significantly improving estimates of off-site accident consequences; and a site-specific approach is imperative if consequences at various sites are to be compared.

In this chapter, we have provided the sources of site-specific information being currently used by the NRC and its contractors in developing EIS's. Because data developed by the federal government would usually be available for all reactor sites, we have relied on it whenever it was available. In other instances, we have had to draw upon state- or locally-developed data sources.

The model most commonly used by the NRC to estimate accident consequences is the CRAC2 code. With the exception of meteorological data, CRAC2 was designed to be used with generic information; however, a considerable number of inputs to the program can be developed from site-specific information. CRAC2 is relatively crude in the way that it estimates accident consequences other than those relating to health effects.

Other models available to the NRC or currently under development serve to complement the information provided by CRAC2. The BEA RIMS II model is particularly useful for providing estimates of the indirect effects of an accident. It does this through an impact analysis of an "affected" and an "unaffected" region. HECOM is a health effects cost model that takes CRAC2's estimates of the health effects of an accident and uses these to provide estimates of the direct costs of health care and the societal losses due to impaired productivity and premature death caused by the accident.

DECON is a computer model currently under development that takes the CRAC2-produced ground concentrations of contaminants and identifies cost-effective decontamination procedures. DECON selects the method, computes the decontamination cost and develops a decontamination schedule so as to minimize the accident consequences, given a user-supplied level or standard of clean-up.

Finally, a model that is being developed for FEMA is examined. Named the Economic Recovery Dynamics Model (ERDM), it has the potential to investigate the consequences from various policy decisions that might be made following a severe reactor accident. The model is currently being designed to simulate recovery of the U.S. economy following a nuclear attack.

# 7.0 EVALUATING RADIOLOGICAL ACCIDENT RISK

Up to this point we have discussed various types of impacts that could result from a severe radiological accident at a nuclear power plant and have examined several models for estimating these impacts. These impacts are simply changes induced by the accident. An impact assessment of an accident can provide a useful description of the accident, but there are no hard and fast rules about what should or should not be included in the assessment. Where policy issues are involved, a more rigid and rigorous framework may be needed to make sound policy decisions. For this reason, the amount and type of information provided by an impact assessment may be inadequate. Policy issues relating to reactor safety, for example, generally focus on accident risk, which is defined as the probability of an accident times the accident consequences. A strict interpretation of accident risk requires that the accident consequences be identical to the social costs of an accident. As we shall see, accident impacts often provide a misleading picture of the social costs of an accident--sometimes overestimating them, sometimes underestimating them and occasionally double-counting them.

The primary objective of this chapter is to elucidate the distinctions between accident impacts and accident costs. The approach that is recommended for assessing the accident costs is present discounted value analysis, a widely accepted method that provides a structured way of determining the costs and benefits to society from investment projects and specific events.[1] This approach involves identifying the temporal flow of all social costs and benefits that are attributable to an accident. Then, to the extent feasible, these costs and benefits are quantified in commensurate units, such as dollars. Finally, the stream of costs and benefits is discounted to arrive at a single number, which is the present discounted value.

The content of this chapter is largely theoretical in nature in that it attempts to explain the major concepts of social cost as related to accident consequences. Little attention is given to the problem of actually estimating the various social costs of an accident. The reader who is interested in the estimation problems and solutions is referred to (Cronin et al. 1983) for an excellent review of the literature on estimating nonmarket costs and benefits, and for a comprehensive review of the benefit-cost methods used within a number of federal agencies.

The exposition in this chapter presumes the reader is familiar with major

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[1] The present discounted value method is equivalent to benefit-cost analysis. The only distinction is that the term benefit-cost analysis usually is meant to apply to projects, whereas present discounted value analysis includes events. The techniques applied in both are identical. For a comparison of the present discounted value method with other evaluation methods, see (Mishan 1976, Chapters 27-30). The methods of benefit-cost analysis are used extensively by many government agencies and by private sector entities.

concepts of microeconomic theory. Readers unfamiliar with these concepts are encouraged to read Appendix B, where they are briefly described. A discussion of the difference between an impact and a social cost is also included in this appendix.

## 7.1 ORGANIZATION

A number of different types of impacts are typically--but not always--included in an impact assessment. In the next section several of these are examined, and the usefulness of each impact as a measure of social cost is indicated. In the third and final section, we identify and analyze the social costs and benefits likely to result from a severe radiological accident at a nuclear power plant. Detailed categories of costs and benefits are identified with households, businesses and the public sector, and each category is discussed.

## 7.2 IMPACT ANALYSIS VERSUS NET PRESENT VALUE ANALYSIS

Several types of impacts are typically included in an impact analysis of some significant activity or event. While such analyses are often presented within a regional context--that is, only the regional impacts are emphasized--impact analysis is also applied at the national level. The justification for using an impact analysis approach at the regional level would appear to be significantly greater than at the national level, because many of the impacts that are costs for the region are not costs within the national economy. The reason for this is simply that from a national perspective the misfortunes of one region become the fortunes of other regions through a transfer of impacts. For example, if a military base is closed in one area and military bases in other areas are expanded as a result, the region containing the closed base may suffer considerable economic hardship, but the regions whose bases expand all enjoy greater economic activity. The net result of the action is that the regional impacts may largely offset each other.

However, even at the regional level, the use of impacts rather than costs can be misleading if the impacts are meant to provide more than a description of the consequences of some event. A major flaw with impact analysis as an analytical tool is that not infrequently social costs or benefits are double-counted. In other instances, commonly used techniques cause the social costs or benefits to be seriously under- or overstated. If one is trying to get at the losses to society, then one must provide a strict accounting of social costs and benefits attributable to the event.

It should be added that social cost analysis alone does not indicate the distribution of the costs or benefits, although such a distributional analysis can--and usually should--be provided as supplemental information. Impact analysis, on the other hand, often does provide some information on the distributional effects.

In what follows we examine several types of impacts that are typically presented in an impact analysis. It is indicated how appropriate each impact is as a measure of social cost, when it overestimates or underestimates social costs, and to what extent the measure is useful for distinguishing regional impacts from national impacts.

### 7.2.1 Sales Impacts

Impact analyses typically report how business sales volumes would be affected by the event in question. For example, it may be reported that $10 million in department store sales are lost over a 1-year period because of the destruction of the store building. In this case, the $10 million sales loss is a poor indicator of a social loss caused by the event. The social losses are the opportunity costs of the resources affected. If the store inventory is destroyed, then the inventory's wholesale cost plus freight should be included; valuing the lost merchandise at retail value overstates its opportunity cost. In some impact analyses, both lost sales and property losses that include the lost inventory are reported. Adding the lost sales to the inventory losses is clearly a case of double-counting. Furthermore, a large proportion of the $10-million figure in the example above may represent goods that were not yet received from the supplier. The loss of sales from such goods represents little or no social loss. Either the goods could be sold to other retailers elsewhere, or, if the goods have not yet been manufactured, the resources used to make the goods could be diverted to other uses.

The loss of sales may represent a social loss to the extent that the future earnings of the department store have been diminished and that change is not offset by wealth increases at other stores. A reduction in the future earnings stream is equivalent to a loss in the firm's wealth, since wealth is just the present discounted value of the expected future earnings stream.[2] However, one firm's loss may be another firm's gain, as sales are redistributed after the accident. The only legitimate use of sales losses in present discounted value analysis is as an intermediate input in calculating estimated changes in earnings, even if the analysis is at the regional level. The analyst is also cautioned that unless the physical production possibilities of the affected firms are altered, the effect will likely be a pecuniary externality and should therefore be excluded entirely from the present value analysis (see Appendix B, section B.2).

### 7.2.2 Loss of Production

A production loss is similar to a sales loss, the differences being that 1) production usually refers to a process in which a tangible commodity is produced, whereas sales include both tangible commodities as well as services; and 2) production of a commodity will exceed or fall short of sales of that commodity to the extent that inventories increase or decrease, respectively.

The production impact measure suffers from the same deficiencies as a sales loss; consequently, it is not usually a good indicator of a social cost.

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[2] It should be pointed out that earnings are equal to revenues less economic costs; they usually differ from accounting profits. See (Alchian and Allen 1969, pp. 335-6) for a discussion of the difference.

If production losses are valued at product selling price, the loss will be overstated, except in the rare case of a declining-cost industry. Also, the social consequences of a production loss are mitigated to the extent that the production factors find alternative productive uses elsewhere in the economy, but the regional effects are obviously greater if the production factors relocate outside of the impacted region.

#### 7.2.3 Loss of Employment/Income

Typically, an impact study will report the number of jobs lost and the lost payroll. Reporting both of these impacts is suggestive that the loss of jobs is a loss in addition to the loss in payroll. To the extent that this idea is conveyed, social costs are overstated, for in competitive equilibrium, factor payments (on the margin) are an accurate measure of the social value of the factors' marginal contribution to output.

If the impact-causing event has more than a small effect on the regional economy, then the factor payment will likely overstate the social loss. For example, if the event has a large impact on physical plant, relative to the impact on the labor supply, then using the lost wage bill as a measure of the social cost will overstate the true social cost, as will be explained in the Section 7.4.

#### 7.2.4 Loss of Property

Property losses from catastrophes are commonly estimated by using the market value of the property just prior to the catastrophe. Such practice can seriously understate the social costs if property damage is widespread, particularly in the case of real property. An example of how this technique can produce paradoxical results is illustrated by a fire which burns half of a forest and causes the price of timber to triple. If the common method of assessment is applied--i.e., multiplying the relevant quantity by its corresponding price--we discover that the value of half a forest is greater than that of whole forest. The faulty reasoning underlying this paradox will be exposed in Section 7.3.3.3.

#### 7.2.5 Welfare Payments/Unemployment Insurance

One temptation to which analysts occasionally succumb is to count increases in payments for welfare and unemployment as costs, and decreases in these payments as benefits. Money represents a claim to unspecified resources; but costs are only incurred when resources become committed to specific uses. Thus, welfare and unemployment payments are transfers of claims to resources; they are not social costs. (However, if such payments are from the national Treasury to a regional economy, they will provide a social benefit to the region; but, for the nation as a whole, there is neither a social cost nor a social benefit.)

#### 7.2.6 Undiscounted Impacts

It is not unusual for impact analyses to report the total dollar losses that occur over a period of several years without discounting the stream of costs and benefits (or impacts). If the effects occur over a period of several years, the impacts can be greatly overstated by failing to use discounting. To illustrate, a $1 million cost occurring at the end of each of seven consecutive years might be reported as a $7 million cost, but this cost stream discounted at 6 percent has a present discounted value of only $4.66 million. In other words, if one were to deposit today $4.66 million in an account paying interest at the rate of 6 percent, then one would be able to pay out from the account $1 million at the end of each of the next seven years. Failure to properly discount the benefit and cost streams can be misleading; it also makes it difficult to draw accurate comparisons between alternatives having streams of costs and benefits that occur at different points in time.

### 7.2.7 Indirect and Induced Income Effects

Indirect effects are those effects that arise as a result of interfirm linkages in an economy. For example, an increase in the sale of automobiles will require increased output from the steel industry, which will in turn require more output from the coal industry, and so on. Induced income effects are those effects on industry which result from higher levels of income. If a project causes an increase in incomes, then the demand for goods and services will increase; total employment and output will be increased, the former giving rise to an additional increase in incomes; and so on. An initial decrease in incomes, say, caused by an accident at a nuclear power plant, would tend to operate in the opposite manner: The demand for goods and services would fall, inducing a decline in total employment and output, the former causing a further decline in income; and so on.

The inclusion of indirect and induced income effects as additional benefits (or costs) usually makes sense only when there is significant unemployment of resources within the economy. Otherwise, if resources are already fully employed, there can be no additional benefit to society, by definition. However, if resources are destroyed by an event, there can be repercussions throughout the economy. If the economy was operating at full employment when the event took place, then any loss of employment may be only temporary as resources shift to other uses. If there is unemployment, the outcome is less clear: demand may simply switch to other goods and services, in which case the indirect and induced income effects would be small or even negligible.

Alternatively, aggregate demand could be reduced over an extended period of time, in which case the indirect and induced income effects could be significant. At any rate, when these effects are included within an analysis, the burden should be on the analyst to demonstrate why such effects would not be offset by other changes that could be expected to take place in the economy (see Treasury Board 1976, pp. 22-24).

### 7.2.8 Taxes, Subsidies, Interest and Depreciation

The loss (gain) of tax receipts to the public treasury, while of interest to policymakers and other parties, is not a social cost, as is sometimes suggested, but rather a transfer of claims to resources from (to) the treasury to (from) the taxpayer. Also, factor income should be reckoned on a before-tax, before-subsidy basis, since this measures the true factor cost to society.

Similarly, interest payments to finance capital are also transfers rather than costs. If a plant is built at a resource cost of $10 million, then the 'cost' of financing the plant does not use up resources (except for those expended in administering the transaction); rather, it is a premium for the use of money. Depreciation allowances for accounting and tax purposes also do not represent real costs. However, changes in the market value of property as a result of wear-and-tear or technological obsolescence are true economic costs.

#### 7.2.9 Loss of Infrastructure

In the event of a severe catastrophe, much of the public infrastructure could be lost. The infrastructure is a sunk cost, and its value to society is not its replacement cost or book value; rather it is the (long-run) cost in resources to replace the value of services--i.e., the total value in use--provided by the infrastructure. This may mean replacing the infrastructure at a new site, recovery and restoration of the old infrastructure, or marginal additions to infrastructure at several other locations to accommodate the relocated population. It could also mean replacement with a different set of services that are equally valued, but that can be provided at lower cost.

### 7.3 SOCIAL COSTS OF A SEVERE RADIOLOGICAL ACCIDENT AT A NUCLEAR POWER PLANT

In this section we analyze the off-site, socioeconomic consequences of a severe radiological accident. Table 7.1 presents a list of the major costs and benefits that could be expected from the accident. The list is organized according to whether the immediate consequences occur within the household, business or public sectors; it is neither exhaustive nor are its elements mutually exclusive. For various elements in this table, we define and discuss the appropriate measure of social cost (benefit). Before discussing the social costs that would occur in each of these sectors, we describe below a model of the economy from which our conclusions are derived. The major economic results from the model are also presented.

#### 7.3.1 The Accident Model

The underlying model used here assumes that 1) the accident impacts are confined primarily to a regional economy and have little effect on the national economy; 2) the loss of capital is significantly greater than the loss of labor; 3) at the time of the accident, the economy is in long-run equilibrium; 4) the accident leaves individual tastes unchanged; 5) there is no technological change over the relevant period; and 6) the accident does not materially affect credit opportunities, so that between credit and transfer payments individuals maintain total consumption expenditures, even though jobs have been interrupted or lost. While this last assumption is not entirely realistic, it allows for a relatively short, easy-to-determine transition period between the accident and the return to long-run equilibrium. After the transition period, this assumption does not affect the results. This assumption is also useful in providing a lower bound estimate on the social

TABLE 7.1. ECONOMIC COSTS AND BENEFITS OF A SEVERE RADIOLOGICAL ACCIDENT AT A NUCLEAR POWER PLANT

| Type of Economic Cost (Benefit) | Accident Phase* |
|---|---|
| **Households in Impacted Areas** | |
| Foregone earnings | I, II, III |
| Transportation to and from shelter area | I, II |
| Changes in sheltering costs | I, II |
| Changes in food costs | I, II |
| Foregone schooling | I, II |
| Foregone leisure time/activities | I, II |
| Health effects, including stress and other psychological impacts | I, II, III |
| Vandalism, theft and other property loss | I, II, III |
| Costs associated with real and personal property - interdiction or decontamination and/or relocation costs; changes in property values not elsewhere accounted for | I, II, III |
| **Households in Host Areas** | |
| Increased congestion | I, II, III |
| Reduction in per capita quality/quantity of public services | I, II, III |
| Cost of sharing of shelter and/or food | I, II |
| Changes in the value of real property not elsewhere accounted for | I, II, III |
| **Businesses in Impacted Areas** | |
| Changes in earnings (or wealth) | I, II, III |
| Changes in the level of competition in affected area not elsewhere accounted for | III |
| Vandalism, theft and other property loss | I, II |
| Property - interdiction or decontamination and/or relocation | |
| Real - land and improvements | II |
| Equipment | II |
| Raw materials and partial assemblies | II |
| Office supplies | II |
| Inventories of finished product | II |
| **Businesses in Host Areas** | |
| Changes in earnings (or wealth) | I, II, III |
| Changes in the level of competition in affected area not elsewhere accounted for | I, II, III |
| **Public Sector** | |
| Security personnel and equipment | I, II, III |
| Evacuation personnel | I |
| Evacuation equipment and supplies | I |
| Personnel and equipment for monitoring radiation levels | I, II |
| Personnel and equipment for decontaminating and treating individuals, pets and livestock | I, II |
| Personnel and equipment for decontaminating property not elsewhere accounted for | II |

TABLE 7.1. ECONOMIC COSTS AND BENEFITS OF A SEVERE RADIOLOGICAL ACCIDENT AT A NUCLEAR POWER PLANT (Continued)

| | | | |
|---|---|---|---|
| Shut-down costs for relevant activities | I | | |
| Start-up costs for relevant activities | | II, | III |
| Impacts on public services in host areas not elsewhere accounted for | I, | II | |
| Property - interdiction or decontamination and/or relocation | | | |
| Real - land and improvements; recreational facilities | | II | |
| Equipment | | II | |
| Infrastructure - bridges, roads, tunnels, utilities, port facilities, dams, etc. | | II | |
| Office supplies | | II | |
| Drinking water supplies | I, | II | |
| Other impacts on institutions not elsewhere accounted for | I, | II, | III |

*Accident Phases: I - Evacuation; II - Decontamination/Interdiction; III - Relocation costs during the transition period.[3] Where appropriate, we will indicate the effect of relaxing this assumption.

### 7.3.2 Summary Results from the Model

If the national economy is operating at full employment--by which we mean that anyone who wishes to work can obtain work at some positive wage, or simply that there is no involuntary unemployment--then contamination of workplaces would have the following results:[4] 1) involuntary unemployment would be only temporary, although total hours worked may change from pre-accident levels; 2) the initial loss of output would be made up in part as those who become involuntarily unemployed find jobs elsewhere in the economy; 3) the prices of goods whose production was adversely affected by the accident would rise relative to the prices of other goods, so that less of the former would be demanded and produced than prior to the accident; 4) wages would drop relative to the price of capital because the greater loss of capital to the economy, relative to the labor loss, would lower the marginal physical product (marginal productivity) of labor, while marginal returns to capital would increase; 5) steps would be taken to replace or recover the lost capital, provided that the losses did not occur in a declining industry;[5] there would be a loss of consumers' surplus associated with products produced by the directly affected industries.

If the national economy is not operating at full employment then contamination of workplaces would have the following results: 1) additional involuntary unemployment caused by the accident would be only temporary if aggregate consumption remains constant (it could remain constant first by drawing down inventories and then by inducing additional production from elsewhere in the economy); 2) since less efficient capacity would be substituted for the lost capacity, it would be more costly to produce and sell the previous output combination; 3) the prices of goods whose production was adversely affected by the accident would rise relative to the prices of other goods, so that less of the former would be demanded and produced than prior to the accident; 4) wages would fall because the use of less efficient capital would lower the marginal physical product (marginal productivity) of labor, but

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[3] The Bureau of Economic Analysis computer model that the NRC uses to estimate regional accident impacts can operate under either of two assumptions: 1) that aggregate consumption is unaffected by the accident, or 2) that consumption of those affected by the accident falls to zero.

[4] This is not the usual meaning given to full employment, which the author of this chapter believes suffers from serious definitional problems.

[5] A declining industry is one in which long-run marginal costs are greater than expected long-run revenues; that is, expected revenues within the industry are insufficient to cover replacement of fixed investments. When the useful life of these investments has expired, the capacity of the industry will diminish as firms withdraw their resources.

the decline would be less than under full employment; 5) although the economy would be operating at less than full capacity, steps might still be taken to replace or recover the lost capital, depending upon the expected profitability of the restored capacity relative to that of the remaining capacity; 6) there would be a loss of consumers' surplus associated with products produced by the directly affected industries, but this loss would be less than the loss under full employment.

The magnitude of the effects described above would depend upon the relative share of an industry's output that was affected by the accident: the greater the share, the more significant would be the effects. Replacing any of the lost production through imports would alter the above results in degree but not in direction.

The model that is being used here suggests two relevant periods: 1) a transition period beginning immediately after the accident, followed by 2) an "equilibrium" period, which begins once the national economy returns to long-run equilibrium. During the transition period, steps would be taken to replace or recover the damaged capacity--unless it were within a declining industry, but this would violate the assumption that the pre-accident economy was in long-run equilibrium. Replacement of this capacity would return the industry--and the national economy--to its pre-accident long-run equilibrium. However, the one-time loss of capacity and output would cause the economy to shift to a lower growth path, even though the rate of growth of the economy would eventually return to its pre-accident level. This effect is illustrated in Figure 7.1. Prior to the accident, total output is growing at some rate g. The accident at time $t_a$ causes destruction of a part of the capital stock, and output drops from $Q_1$ to $Q_2$.

The actual path that the national economy takes during the transition period would depend in part on whether or not there is full employment at the time of the accident. If there is continuing full employment, then there would be labor/capital adjustments taking place after time $t_a$. Adding labor from the accident-affected part of the economy to the factors of production in the unaffected part of the economy would cause output in the unaffected part to grow at a rate greater than g during the transition period. In addition, some of the capacity that was contaminated in the accident would be recovered and put into production, and some of the lost capacity would be rebuilt using post-accident savings. The output growth path is shown by the solid line in Figure 7.1. Given that the pre-accident economy was in long-run equilibrium, the post-accident economy would grow along a path such that all relevant economic variables at time $t_e$ would be identical to those at time $t_a$. In other words, the pre-accident per capita output would be produced at pre-accident prices using pre-accident marginal factor input combinations and pre-accident technology (which we assume not to change in our simple model).[6] The broken

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[6] Although, older capital that was destroyed in the accident would be replaced by the most efficient capital that was in use at the time of the
(CONTINUED)

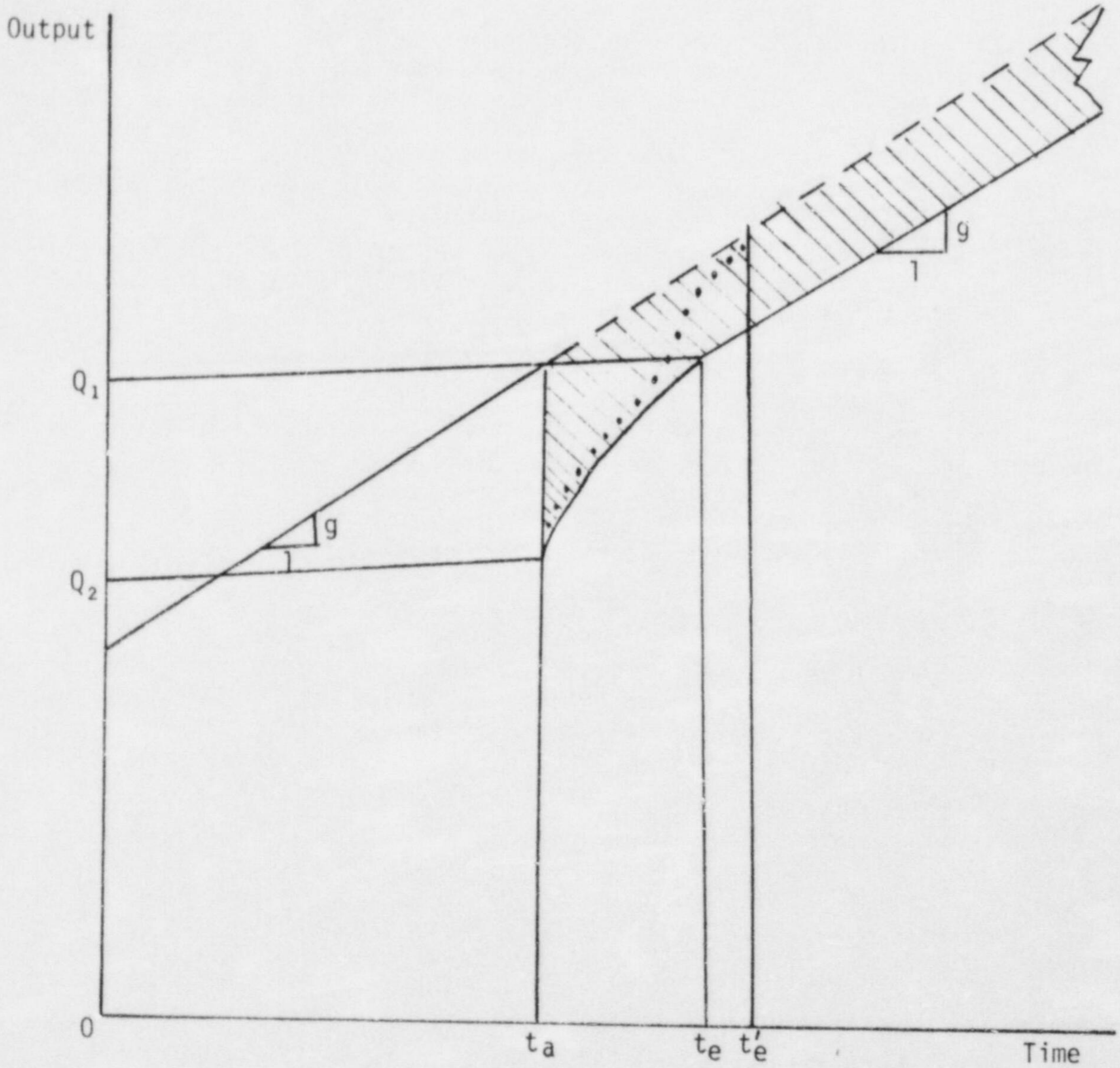


Figure 7.1 Output Loss From An Accident

line above and parallel to the post-accident growth path shows the growth path of the economy in the absence of the accident. The shaded area between the two growth paths is the amount of future output lost as a result of the accident. The present value of the output stream--where output is measured by its total value in use--is one of the social costs attributable to the accident; if output is meausured by total value in exchange, an estimate of consumers' surplus needs to be added (see footnote 8, page 199).

If the pre-accident economy is operating at sufficiently less than full employment, then the post-accident economy would grow at some rate greater than g until it reached the pre-accident growth path; this is shown by the dotted line in Figure 7.1, which rises until it coincides with the broken line at $t_e'$.[7]

The social loss in output in this case is the present value of the area between the broken and dotted lines, provided that output is measured by total value in use and adjustments are made for changes in the employment status of production factors (see footnote 8, page 199). It is clear that with unemployment, the loss is less than with full employment. If there is unemployment but it is relatively low, then the post-accident equilibrium path would lie somewhere between the broken and solid lines.

Finally, if total consumption expenditure levels are not maintained during the post-accident period, the transition period would be prolonged. In fact, immediately after the accident, the overall economy could grow at a rate less than g, before accelerating toward the equilibrium period growth path. This could significantly increase the social costs of the accident.

### 7.3.3 Losses Among Households In Directly Impacted Areas

In the event of a severe radiological accident, members of the household sector would suffer a variety of losses, including loss of employment, loss of property, and costs associated with evacuation, relocation, medical treatment and decontamination; in addition, they would suffer adverse health and psychological effects. These and other impacts on households are discussed below.

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[6] (FOOTNOTE CONTINUED)

accident, factor income shares would return to their pre-accident level by the beginning of the equilibrium period. This result follows from the fact that the value of all older capital is determined by the value of the most efficient capital in use. (Since the ratio of the marginal physical product (MPP) to factor price is the same for all inputs under a competitive equilibrium, given the MPP for both the older and newer capital and the price of the newer capital, the price of the older capital is determined.)

[7] Time $t_e'$ may occur before or after time $t_e$; their relative position is a function of the amount of excess capacity in the economy before the accident.

7.3.3.1 Loss of Employment: Hours and Earnings. In this section we identify what social costs attributable to the accident arise because employment conditions have changed. We then look more closely at the type of employment changes that could be expected to occur, particularly during the early and later stages of the transition period. Whether or not the pre-accident economy is operating at full-employment is also found to be relevant.

Social costs can arise from several different employment effects. Two effects arise from the loss of output right after the accident. First, if there is a one-time loss in output that is not subsequently made up, there would be a social cost from this foregone output.[8] Second, if output falls right after the accident, but then is subsequently made up, there is a social cost associated with the deferral of the output.

A third effect arises because the accident is assumed to affect the nation's capital stock more adversely than the supply of labor. This change in factor proportions means changes in the marginal productivity of factors. On the margin capital will be more productive and labor will be less productive as labor is used more intensively with capital currently in use and/or less efficient capital is brought into production to utilize the 'extra' labor.

Because, on the margin, labor has become less productive and capital more productive, real wages will fall while returns to capital will increase. Since marginal returns to labor and capital under a competitive equilibrium are an accurate measure of the opportunity costs of these factors, the social cost of using them is changed: the social cost of using labor falls, while the social cost of using capital increases.

A fourth effect relates to the time spent at various activities, which are valued differently. Leisure time is usually valued more highly than work when wages are excluded. Because total weekly hours would decline, at least immediately after the accident, it is necessary to determine the social costs of (or benefits from) exchanging work for post-accident activities. In the following paragraph, we elaborate on this fourth effect.

The social cost of reduced hours, especially during the beginning of the transition period, is simply the value of employment less the value of activities undertaken while not working. The value of employment is measured

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[8] The social cost attributable to the foregone output can be measured as the loss in consumers' surplus plus the post-accident opportunity cost of affected labor (and other factor inputs) plus either 1) the total value in exchange of the lost output, or 2) the loss in factor payments, assuming that the national savings rate is unaffected by the accident and that the remaining resources are fully employed. Given these assumptions, marginal changes in total factor payments (wages, rents, interest, dividends and profits) will equal the total change in output value. If necessary, adjustments can be made to account for resources that are not fully employed over the post-accident period.

by its pre-accident value, and the value of time spent while not working depends, among other things, on the activities that are pursued. For example, if the evacuation and subsequent periods are used to take an extended vacation trip, then the subjective value of the vacation trip (net of expenses) should be deducted from the net value (net of the disutility from working) of being gainfully employed. To illustrate this concept further, consider a worker who is indifferent between being employed at $225 per week and remaining at home, while receiving $100 per week in unemployment compensation. He therefore values leisure at $125 per week, and if this is his highest valued alternative, his opportunity cost of working is $125 per week. If, instead of remaining at home, the worker takes a $600, two-week vacation which he subjectively values at $950, then the opportunity cost of working is ($950-$600) = $350, or $175 per week for two weeks; and this is equivalent to the social cost of his reduced opportunity to work for two weeks.

One additional point relating to the accident social costs is whether these costs should be measured as the opportunity cost of labor (and other factors) prior to or after the accident. To answer this, we note that the physical costs of the accident can be divided into two major categories: 1) the foregone output of goods and services, and 2) the cost of recovery. The opportunity cost of the first category is the total value in use of the foregone output prior to the accident. In the second category, the opportunity cost of resources used in dealing with the various aspects of the accident is based upon the alternative uses of the resources, given that the accident has occurred. Paradoxically, if the accident damage is widespread and causes substantial loss of jobs, the opportunity cost of using the affected labor for decontamination and other post-accident activities would likely be quite low; but the cost of the foregone output would be high.

We now consider the relative magnitudes of the effects discussed above. A severe accident would cause many business establishements to be shut down, and a large number of workers would be idled as a result. Shortly after the accident, workers might find that they had several options.[9] They could relocate and find employment away from the accident area; they could wait for their old jobs to become available again; they could accept employment with decontamination crews; or they might find other accident-related employment. The first two options would affect the social cost of the foregone output, while the last two would affect the social cost of the recovery.

Furthermore, if, as we are assuming, aggregate consumer expenditures are maintained at pre-accident levels, inventories of goods would be drawn down immediately following the accident, and producers would seek to rebuild them. This would open up many employment opportunities outside the accident area, and total factor payments (i.e., wages, rents, interest, profits and dividends) could be quickly restored to pre-accident levels. In fact, total weekly hours

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[9] While it is assumed that there would be a large flow of transfer payments to accident victims, there is also an implicit assumption that these payments would not provide strong work disincentives.

would have to be above pre-accident levels during the inventory rebuilding period, even if the labor required for accident-related activities is not counted. We have already mentioned the potentially important effect on the marginal productivity of labor. In practical terms, the changes would likely be minimal, unless the accident incapacitated a significant proportion of some national industry's total capacity and the labor was specialized to the industry. In the longer term steps would be taken to replace or recover the damaged capacity, unless it were within a declining industry. Replacement of this capacity would eventually return the industry--and the national economy--to its pre-accident long-run equilibrium.

While total weekly hours worked and wages could be expected to decline immediately after the accident, it is somewhat ambiguous whether or not hours worked would be above or below pre-accident levels later in the transition period. As noted, declining wages, the increased cost of capital, and the utilization of less efficient capacity imply that output levels of some goods would decrease, while those of other goods would increase. The drop in the cost of labor relative to that of capital makes it likely--but not certain--that total hours worked during the latter part of the transition period (after inventory rebuilding is completed) would rise above pre-accident levels, even excluding the accident-related employment.

With respect to the value of post-accident activities relative to the value of pre-accident activities, in practice, the value of time spent following an accident is likely to be very low or negative, even if compared with time spent working. The disruption of daily routines, the displacement from homes, the unpleasantness of clean-up activities and the uncertainty regarding both future employment and compensation for losses would make it difficult to reap much value from the time available. Finally, if one is attempting to measure the value of leisure activities, it should be remembered that the value will vary with respect to the quantity of leisure time available in each time period; the more leisure time available, the lower the marginal unit value will be.[10]

Two other situations are relevant to valuing the opportunity cost of labor in accident recovery activities. If involuntary unemployment is widespread after the accident and union scale wages and/or the legal minimum wage must be paid to hire labor, then expenditures for labor could significantly exceed labor's opportunity cost. In such cases it may be advisable to use shadow prices, which are the true opportunity costs of these factors, when assessing the social costs of the recovery (see Appendix B, Section B.6.)

The model that is being used here suggests a transition period in which 1) the existing supply of labor is combined with the reduced capital stock, and 2) the productive capacity lost by the accident is either recovered or replaced.

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[10] For a discussion of the theory of the value of leisure time and statistical estimates for the value of various types of leisure activities, see (Owen 1970). A study of the relative value of leisure as a function of the overall national unemployment rate is also included in this volume.

Once the transition period is ended, the national economy will have returned to its pre-accident long-run equilibrium state. Since the social loss will depend upon the actual growth path of the economy during the transition period, it is necessary to estimate the length of the transition period and the course of the economy during this period. These would likely depend on many factors, including:

- the number of workers affected by the accident
- the extent of damages within the business sector
- the extent of damage to infrastructure
- the average level of unemployment within the region and the nation
- the skill and educational characteristics of affected workers
- the mobility of the affected workers
- the availability of employment opportunities within commuting distance of affected workers
- the unemployment payments and/or other transfer payments available
- the optimal waiting period before decontaminating workplaces
- the resources available for reconstruction/reinvestment.

The relative magnitude of the social costs depends in part on whether or not the national economy is operating at full employment at the time of the accident. Inventories are likely to be out of adjustment longer and the marginal productivity of labor fall more under full employment, causing social costs to be higher; job search costs are likely to be lower however. In addition, under full employment there would be the additional social cost from lowering the economy's growth path in the post-accident equilibrium period, as already discussed in connection with Figure 7.1.

Finally, if we relax the assumption about maintaining total consumption expenditures, the demand for labor could fall, causing the transition period to be prolonged and the social costs associated with it to be substantially increased. However, the increase in employment resulting from accident-related activities, particularly the decontamination of property, should serve to mitigate the decline in income and expenditures.

7.3.3.2 Loss in Consumers' Surplus. For simplicity, the model we have been using assumes that aggregate consumption expenditures are maintained; that is, individuals affected by the accident continue to spend at their pre-accident rate. However, we have noted that during the transition period prices of goods whose production was affected by the accident would rise both initially and after less efficient capacity was substituted for the capacity lost in the accident. This would result in a loss in total consumers' surplus (see Appendix B for a description of consumers' surplus). After the transition period, the social loss is computed as the present value of the appropriate area in Figure 7.1. Measuring the loss in consumers' surplus involves estimating in the one instance the extent to which prices rise initially, and, in the second instance, estimating the effect of using less efficient capacity on prices.

Contrary to our assumed model, a real accident would likely cause aggregate consumption expenditures to be reduced for several reasons, including:

- a (temporary) decline in income
- uncertainty about the future
- temporary inaccessibility to savings
- loss of wealth
- unavailability of products customarily consumed
- availability of 'free' housing, food, etc.
- disruption of daily routine

Alternative assumptions could therefore be made regarding consumption behavior following an accident. For example, families might severely restrict consumption until their future employment situation is clarified and/or uncertainty is removed regarding the timing and magnitude of restitution for damages. If the family has suffered heavy asset losses with little or no expectation of restitution, then once income is restored, its savings rate may be higher than the pre-accident rate until some part of the asset loss has been restored; or, alternatively, the savings rate may remain at the pre-accident level. On the other hand, if full restitution is made following a period of restricted consumption, consumption may be increased above the pre-accident rate until assets have been reduced to their pre-accident level; or, alternatively, the consumption rate may settle at the pre-accident level, leaving assets greater than they were before the accident.

To illustrate how some of these alternatives might be incorporated into the analysis, consider the case where income continues but because of, say, uncertainty about the future, the consumption of some quantity of goods is deferred for t periods by saving at a higher rate. Assume that savings earn interest at a real rate i, that consumption opportunities remain constant over the t periods, and that the household's consumers' surplus is a function of the level of aggregate consumption. Then the present value of the social loss, K, caused by deferring consumption to period t is

$$K = CS(C_0)-CS(C_t)/(1+r)^t \qquad (7.1)$$

where $C_t$ = $C_0(1+i)^t)/(1+r)^t$
$CS(C)$ = consumers' surplus as a function of consumption
$C_0$ = consumption deferred in initial period
$C_t$ = market value of consumption after t periods
$i$ = real rate of interest paid on money saved, and
$r$ = rate of subjective time preference

Unless consumers' surplus increases with the level of consumption at an increasing rate, then, other things remaining equal, there will be a present discounted value loss from deferring consumption, since the rate of subjective time preference, r, is often greater than the rate of interest paid on money saved, i;[11] i.e., $CS(C_0)$ will be greater than $CS(C_0(1+i)^t)/(1+r)^t$. For example, if i = 6%, r = 20%, t = 1 year and $C_0$ = \$100, then $CS(C_0(1+i)^t)/(1+r)^t = CS(106)/1.2$. Unless a six percent increase in consumption would provide at least a 20 percent increase in consumers' surplus, there would be a welfare loss from deferring consumption. This consumption loss, it should be emphasized, is less than the loss that would have been incurred had consumption not been deferred: by deferring consumption to reduce the effects of uncertainty, individuals reveal that they consider the cost of deferring consumption to be worth incurring.

The above example can be made more realistic by relaxing the assumption that consumption opportunities remain constant over the t periods. More likely than not consumption opportunities would be severely restricted immediately following an accident, but then improve with time. If we assume that consumption opportunities improve at some rate c(t), as perceived by the individual, then the cost of deferring consumption to period t would be

$$K = CS(C_0)-CS(C_0(1+i+c(t))^t)/(1+r)^t \qquad (7.2)$$

7.3.3.3 Property Losses. The household sector would suffer from a variety of property losses. In the interdiction zone any property that is not removed during the evacuation period is likely to be severely contaminated, including property that is inside of buildings (Yocum 1982, p. 507). This includes real property, automobiles, boats, household furnishings, personal effects, etc. If there is property which is relatively valuable and can be removed from the premises, it may be profitable to retrieve it from the interdiction zone and have it decontaminated. Precious jewelry, negotiable certificates and other valuables are possible candidates.

To evaluate the loss in real property, it is useful to apply a stock concept rather than a flow concept. We therefore evaluate the loss in terms of the "demand to hold real property" ($D_s$) and the "supply in existence" ($S_s$). These schedules are portrayed in Figure 7.2, which also contains the corresponding flow schedules--the "demand to purchase" ($D_f$) and "supply for sale" ($S_f$). The relationship between these two sets of curves is[12]

$$D_f - S_f = D_s - S_s \qquad (7.3)$$

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[11] In a perfectly competitive economy, the rate of interest, i, will equal the rate of subjective time preference, r. However, in most states there are statutory limits on the amount of interest that can be charged on loans to individuals. In many cases, the statutory limit is lower than the rate at which the market is willing to lend, given the credit worthiness of the borrowers. For these borrowers, the rates of subjective time preference may well exceed the statutory limit on interest.

[12] For additional discussion of these concepts, see (Alchian and Allen 1969, pp. 96-97).

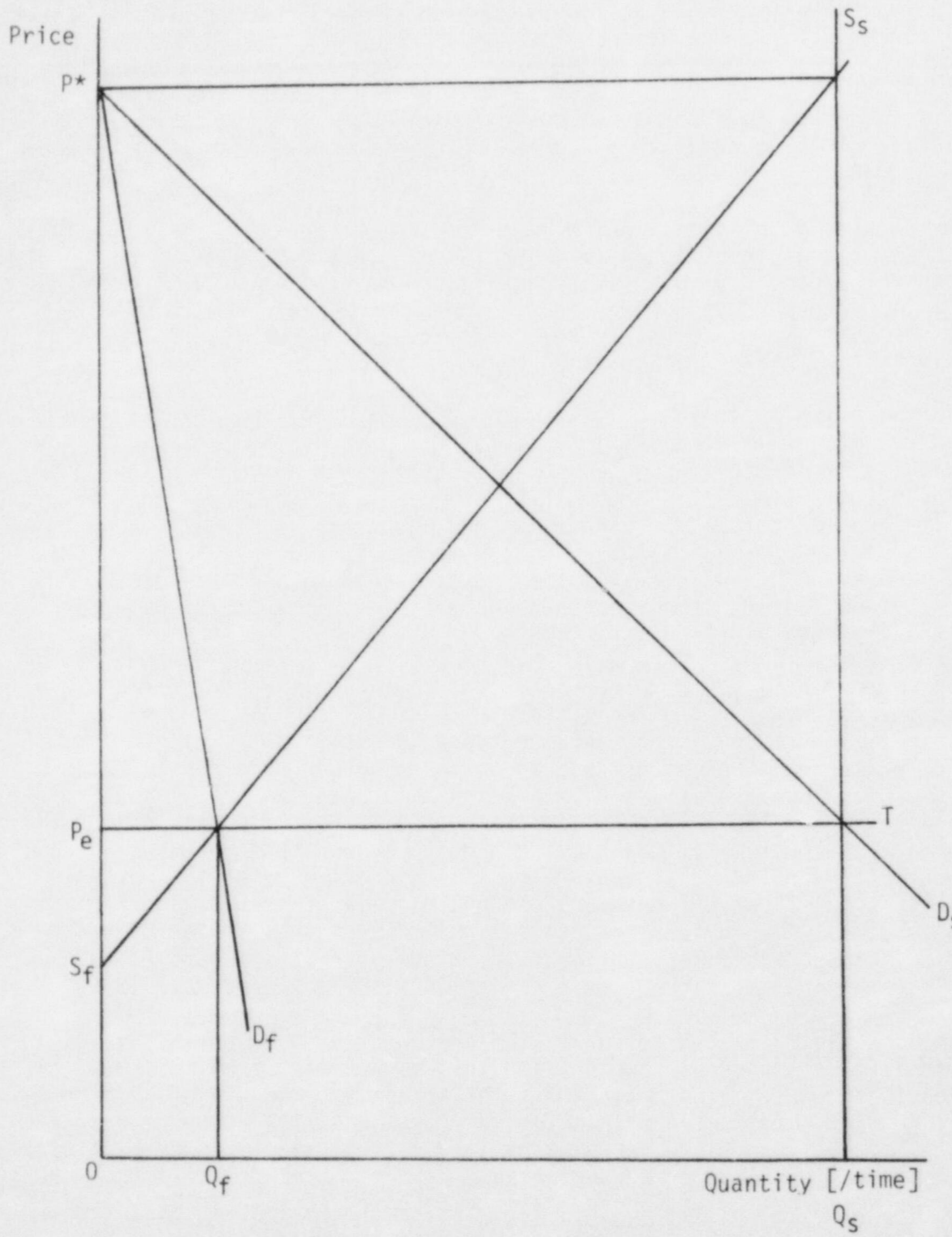


Figure 7.2 The Social Value of the Housing Stock

At the equilibrium price, $p_e$, the demand to hold is equal to the supply in existence, $Q_s$, and the demand to purchase, $D_f$, is equal to the supply for sale, $Q_f$. $P^*$ is defined as the price at which all owners are willing to sell their houses; thus, the demand to hold, $D_s$, is zero while the supply to sell, $S_f$, is equal to the entire housing stock, $Q_s$. The social value of the housing stock is equal to the area $OP^*TQ_s$, the area under the demand-to-hold schedule.

A computer model that the NRC uses to estimate accident consequences, CRAC2, requires as input a single value for property of a given type in order to compute the property losses attributable to an accident. Typically, this value will correspond to the equilibrium price, $p_e$. Thus, CRAC2 erroneously reports property losses equal to the total value in exchange, $OP_eTQ_s$, rather than the total value in use, $OP^*TQ_s$.

The more inelastic is the demand-to-hold schedule, the more seriously will CRAC2 underestimate the social loss in real property. The following characteristics of real property suggest that the demand-to-hold schedule is relatively inelastic: 1) land by definition cannot be relocated and structures can be relocated only at great cost; 2) real property is nonhomogeneous; 3) the utility derived from real property is substantially extrinsic; and 4) the accident-relevant demand curve is less elastic than the "no-accident" demand curve. We now consider the importance of these characteristics with respect to the demand-to-hold elasticity for housing.

Nonrelocatability and Heterogeneity of Housing. The demand for housing can be viewed as the demand for a flow of services provided by a housing unit. These services include living space, privacy, warmth, landscaping, proximity to schools, parks and other amenities, view, neighborhood relationships, etc. Given the nonrelocatability of housing, the heterogeneity of the physical housing stock, and the relative importance of site-specific extrinsic qualities --such as view, proximity to schools and neighborhood relationships--it is apparent that close housing substitutes--i.e., housing units that provide nearly identical flows of services--are not readily available from the existing housing stock.[13] It follows from this lack of close substitutes that the demand-to-hold schedule for housing is relatively inelastic (Stigler 1952, p. 44). For empirical evidence, see (Cronin 1982a, 1982b) and (Mayo 1978).

Accident-Relevant Demand Curve. If one were to estimate statistically the demand-to-hold schedule for housing in a no-accident zone, the estimate would be inappropriate for determining the total value in use of housing within an accident interdiction zone. The reason for this is that the no-accident demand schedule is premised upon the availability of all other housing options which consumers perceive to be available. Prior to the accident, this includes other housing that lies within the zone to be interdicted. Indeed, other housing units within the interdiction zone are likely to be much closer substitutes than housing units outside the zone, given the importance of extrinsic housing characteristics. The accident-relevant demand-to-hold

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[13] Neighborhoods with nearly identical housing units are the exception.

schedule is derived from the no-accident demand-to-hold schedule by excluding all housing units within the interdiction zone, since the latter are not a part of the relevant housing market. The result is that the accident-relevant demand-to-hold schedule will lie to the right of the no-accident demand-to-hold schedule and be less elastic, as shown in Figure 7.3. Total value in use is equal to $OVUQ_S$ if the no-accident demand schedule is used, while for the post-accident demand schedule the total value in use is $OWTQ_S$. The area VWTU represents the value that owners of housing within the accident zone place on the right to acquire other housing within the accident zone if they were to sell their current home--and assuming, of course, no accident. In other words, these owners would require a premium of VWTU to sell their home and forego the option of purchasing a replacement house within the accident zone. The appropriate measure of social loss of housing in a permanently interdicted area is the total value in use of the accident-relevant demand-to-hold schedule, or $OWTQ_S$.

Loss of Real Property Use. A property loss would depend, in part, upon the period of time for which the property is unusable. If the expected life of the property is T years and it is interdicted for $T_I$ T years, then, given some maintenance and repair program M(t), subjective rate of time preference r, and flow of housing services F(t), the property loss would be[14]

$$L = \sum_{t=1}^{T_I} (F(t)-M(t))/(1+r)^t \qquad (7.4)$$

If $T_I$ is greater than or equal to T, then the above formula should be adjusted to include the salvage value, S, of the property at the end of T years, assuming no accident.

In practice, we cannot directly observe the value of the flow of individual housing services, although they have been estimated by using hedonic pricing techniques (Freeman 1979, pp. 121-9). Alternatively, if F(t) can be made explicit, then the property loss can be derived in terms of the accident-relevant demand-to-hold value V, and variables M(t), S and r. To take a simple case, assume that the flow of services remains constant over the lifetime of the property. Then, using the relation that the property value is equal to the present discounted value of the net flow of services from the property, we have

$$F(1)=F(2)=...F(T) = (V+Y)r/(1-1/(1+r)^T) \qquad (7.5)$$

$$\text{where } Y = \sum_{t=1}^{T} M(t)/(1+r)^t - S/(1+r)^T. \qquad (7.6)$$

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[14] This equation assumes that the flow of services and maintenance costs occur at the end of each year.

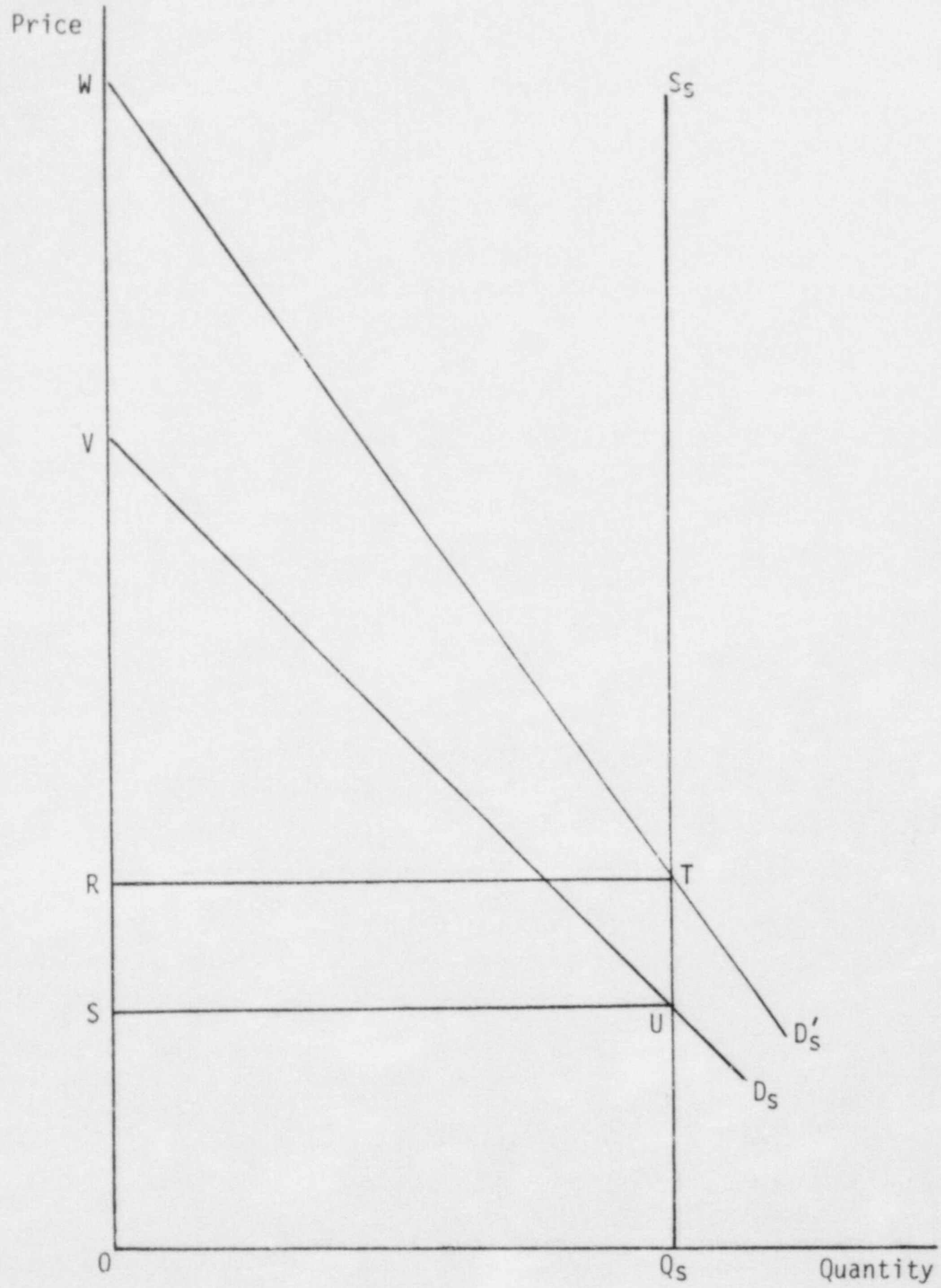


Figure 7.3 The Accident-Relevant Demand Curve

Equations (7.5) and (7.6) can be substituted into (7.4) to give an expression in V, M(t), S and r.

Decontamination Costs. A major loss that would be associated with property is the cost of decontamination. A necessary condition for incurring the decontamination costs is for the present discounted value of the decontaminated property at some time t* to exceed the present value of all of the decontamination costs. The formulas developed above can be used with a schedule of decontamination costs, D(t), to determine the optimal time to decontaminate the property. To do this, choose t*=t such that D(t*), when added to M(t*), minimizes the property loss. For property that is interdicted and subsequently decontaminated, the social loss is the difference between the no-accident demand-to-hold schedule and the sum of: 1) L from equation 7.4, with $T_I$=t* and M(t) = M(t*) + D(t*), and 2) $Z/(1+r)^{t*}$, where

$$Z = \sum_{t=t*}^{T} (F'(t)-M(t))/(1+r)^{t} + S/(1+r)^{T-t*} \qquad (7.7)$$

and F'(t) is the flow of services from the property, given the accident and that the property has been decontaminated. One would expect F'(t)  F(t), for all t.

Relocatable Property. As suggested earlier, it may be worthwhile to salvage property that can be relocated. This decision involves comparing the relevant costs for transporting, decontaminating and installing the property in question with the acquisition, transportation and installation costs for comparable property available in the market place. The latter costs provide an upper bound on the magnitude of the social loss.

Transportation to and from the Shelter Area. If household members travel by private automobile to and from the shelter area, the appropriate cost measure is the marginal cost of driving the car. This cost excludes mileage-independent depreciation, insurance and property or registration taxes; it includes fuel, oil, tire wear, mileage-dependent depreciation and any other costs that vary directly with mileage. Transportation costs at the sheltering area should include only those costs that are above and beyond transportation costs that would have been incurred had the accident not happened. The same principles apply with respect to publicly provided transportation; namely, mileage-dependent costs are included along with the cost of providing the driver.

Sheltering. Most evacuations are characterized by the large majority of evacuees staying with relatives or friends (Wenger et al. 1975, pp. 42-43). Although it is possible that neither the evacuees nor their hosts would incur additional out-of-pocket expenses, social costs are still likely to result. For example, such costs would arise because of overcrowding when evacuees are sheltered in private homes. Furthermore, the costs may increase with time because of the mental strain of living in close quarters with several other people, especially if some were recent strangers. In the case of public sheltering, the opportunity cost of the public shelter and personnel and equipment necessary to man the shelter need to be included.

Food. The economic cost associated with food can be estimated as the change in expenditures necessary to maintain the pre-accident diet both in terms of quantity and quality. This cost is to be included even when the food is paid for by host families. (Strictly speaking, this measure of costs probably overstates the true social cost, especially if meals are purchased from retail eating establishments. If evacuees are given sufficient money to replace their pre-accident meals with equivalent meals at retail eating establishments, they would probably spend some of this money on other goods; although they would not be eating as well, their level of welfare would be increased.)

Foregone Schooling. The benefits of schooling to children would be lost or delayed. Families within the interdiction zone would have to permanently relocate, and for these families the interruption of schooling could persist for several months. There is also the welfare loss associated with children adjusting to a new school, particularly if they begin in the middle of a term.

Foregone Leisure Time/Activities. The value of time spent on various activities after the accident should be compared with the value of time that would have been spent on activities had no accident occurred. This issue has been addressed earlier with respect to the value of work versus leisure.

Health Effects. Three categories of economic costs can be incurred as a result of health effects: 1) direct health care costs; 2) indirect health costs, which are the lost earnings during treatment and convalescence or total expected future earnings in the case of death; and 3) nonmonetary costs, such as pain and suffering, and decrease in longevity.

Assessing the direct health care costs is conceptually straightforward, as it requires adding up the opportunity costs of all of the resources used in treating accident-related health effects. Such resources include physicians, nurses and other medical personnel, hospital facilities, medical equipment, pharmaceuticals, laboratory tests, administrative costs of hospitals, medical offices, health insurers and laboratories, etc. A potential problem in empirically estimating the direct health care costs arises because of the significant degree of free or subsidized health care. Since voluntary services and donated medical supplies have positive opportunity costs, they are true social costs and therefore must be added to the costs that are paid out-of-pocket or through third-party insurers. Also, if hospital bills are used to measure the cost of a hospital stay, care should be taken, on the one hand, to exclude hidden charges for covering the hospital costs of indigents and other nonpayers, and, on the other hand, to include the costs of providing accident-related health care to nonpayers.

The lost output represented by foregone earnings is a true social cost and should be included with the other accident costs. However, the analyst should take care not to include it twice, once as foregone earnings and again as reduced output. In addition, the foregone earnings should include only earnings derived from labor. The power of assets other than labor--such as bonds, stocks and savings certificates--to produce 'utility' is unaffected by adverse health or death. If we assume away the problem of making interpersonal comparisons--i.e., comparing the utility that different parties would derive from the same assets--then it follows that transfers of utility-generating assets would produce zero net social benefits. On the other hand, the rest of society bears a cost if the productively employed are debilitated.

Nonmonetary health costs include a variety of other impacts, including the social cost of pain and suffering, the effects of impaired health and mortality on relatives and close friends, etc. Needless to say, these costs can be very difficult to evaluate.

Another major difficulty is to measure the social cost of premature death resulting from the accident. Typically, three approaches have been taken to valuing altered longevity: 1) measuring the present value of a person's expected earnings stream; 2) estimating the value of life based on expenditures on health and safety by government agencies; and 3) the willingness to pay/accept compensation approach. This last approach is the only one of the three approaches that is consistent with the fundamental principles of welfare economics, since it relies on market concepts relating to individual utility functions.

However, there is a major dilemma when it comes to estimating the social cost of premature death in the present context. The analysis that has been conducted with respect to all of the other costs treated thus far is an _ex post_ analysis. That is, the social costs that have been treated are all premised on an accident having occurred. Social cost analysis in this context is largely one of estimating the compensation that would return individuals to their pre-accident level of well-being. In the case of property loss, we find that there is some compensation that would leave a person indifferent to the pre-and post-accident states. However, in the case of premature death, it is easy to conceive of situations in which individuals would be unwilling to accept any sum as compensation for facing certain and immediate death.[15] In such cases, the principle of adequate compensation breaks down.

The dilemma is less troublesome, though, when one realizes that the _ex post_ analysis is really inappropriate for NRC policy decisions. These decisions are concerned with nuclear plant siting, safety goals and other decisions that are _ex ante_ a power plant accident. In the _ex ante_ situation, the question is not one of facing certain and immediate death, but rather of accepting an increased risk of death. Within the general framework of welfare theory, this is a relatively easy problem to deal with. Every day individuals make a multitude of decisions regarding accepting more or less risk of fatal injury. Such decisions include choice of transportation mode, dietary preferences, cigarette smoking and occupational choices. From their choices, it is evident that individuals can be compensated for increased risk with more convenient travel, better tasting food, smoking enjoyment or increased wages.

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[15] One can also conceive of other situations in which an individual would accept certain and immediate death if given adequate compensation for his/her heirs.

From the ex ante point of view, the social cost problem is to determine an individual's maximum willingness to pay to avoid an increased risk, assuming that he does not have the right to prevent the risk; or his minimum willingness to accept compensation for the risk, assuming that he has the right to prevent the risk.

Unfortunately, it is inconsistent to provide an ex post analysis with respect to property and an ex ante analysis with respect to premature death. For this reason, the issue is left unresolved. Perhaps an appropriate way to frame the problem is to pose the following question: If Z is the social cost, as determined by an ex post analysis, of all effects other than premature death, what is society willing to pay to accept an additional risk, X, of premature death together with an additional risk, Y, of incurring social costs of magnitude Z?[16]

Vandalism, Theft and Other Property Damage. Damage to and theft of property constitute another cost. Although our findings from the literature suggest that vandalism and looting are quite rare during an emergency evacuation, to the extent that these impacts take place, economic costs are incurred (Quarantelli 1980, pp. 109-110). The economic cost of damaged property is the minimum of the cost of repair or the market value of the property; but the economic cost of stolen property is its market value less its post-theft value, for stolen property is still capable of producing satisfaction for its user.

As an illustration, consider a television set stolen from a home during the evacuation period. Assume that the owner can replace the set with another that is comparable in every respect for $250. The most the thief can obtain for the stolen set is $100, since potential buyers are suspicious regarding their ownership rights. They also realize there is a risk of being charged with receiving stolen property if 1) the set was stolen and 2) they are apprehended. The social cost of the theft is $150 plus the opportunity cost of the thief's time.

There are two additional costs associated with vandalism and theft. The first is a result of breaking and entering into private property. The victim is worse off, even if the thief had taken nothing. The second cost relates to the effect of theft on the weakening of property rights. If possession of private goods becomes less secure, the goods will be valued less in the market place.

### 7.3.4 Social Costs And Benefits Among Households In The Host Areas

Members of households living in the host areas could be heavily impacted as a result of the accident. The extent of the impacts would of course depend

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[16] For a more detailed exposition of the approaches to valuing longevity, see (Freeman 1979, Chapter 7) and (Jones-Lee 1976).

upon the number of evacuees moving in relative to the size of the host area. Potential social costs imposed by the evacuees on the host areas include:

- increased traffic congestion
- increased shopping congestion
- temporary shortage of goods in retail establishments
- overcrowding of schools
- inadequacy of police protection
- overcrowding in parks and other public recreational facilities
- reduced per capita supply of welfare services (excluding monetary transfers, which are not social costs)

In addition to the above costs, there would probably be increased employment opportunities for local residents and possibly for evacuees as well. Wages might change but the direction would depend upon the number of evacuees seeking work as well as the amount of extra business resulting from the presence of the evacuees. Costs on host families--such as overcrowded living conditions and sharing of food--have already been mentioned, along with the potential for adverse social/psychological impacts.

In the longer run, there might also be upward pressure on residential property values if a significant number of evacuees decide to take up permanent residence within the host area. This impact would be a pecuniary externality, however, and should not be included among the social costs or benefits attributable to the accident.

### 7.3.5 Losses Within The Nonfarm Business Sector

Social costs arise within the nonfarm business sector because the radiological accident causes otherwise productive resources to be idled. The losses are equivalent to the pre-accident opportunity costs of these production factors. The basis for reckoning the social costs within the business sector has already been established in our earlier discussion of employment losses. If the economy prior to the accident is operating at full employment, then it is assumed that the accident-affected workforce will, after a temporary adjustment period, seek and find employment elsewhere in the economy. By combining this labor with idle capacity or by using productive capacity more intensively, the value of output will increase above the post-accident level. The net result of this shift of labor will be that businesses that have been forced to close will suffer wealth losses, while businesses that can increase output will enjoy wealth increases. The wealth changes in both cases are equal to the present discounted value of the changes in the flow of returns to capital:

$$W = \sum_{t=1}^{T} \Delta R(t)/(1+i)^t \qquad (7.8)$$

where W is the change in wealth
R(t) is the return to capital in year t, and
i is the discount rate

If $W_n$ is the change in wealth of the nth business, then the social cost, K, of the accident to shareholders and other owners of businesses is

$$K = \sum_{n=1}^{N} \Delta W_n \tag{7.9}$$

There are at least two ways to estimate the change in the wealth of a business. The first requires forecasting revenues and costs well out into the future, including the cost of decontaminating the plant and equipment and other start-up costs (but excluding insurance and/or other reimbursements). Additionally, if the earnings of the business depend closely upon the business and demographic environment around it, these will have changed significantly--if not drastically--as a result of the accident. Under the best of circumstances, future earnings are very difficult to forecast; in the aftermath of a highly disruptive accident, forecasting earnings for businesses not forced to shut down permanently would be a real challenge.

Another approach to estimating the wealth loss is possible if the shares of the affected company are traded on a stock exchange. In this case, it is necessary to estimate the demand-to-hold schedule for the stock, both prior to and after the accident. The market place's estimation of the present value of the company's future earnings stream--i.e., its wealth--is equal to the area under the demand-to-hold schedule, and changes in estimated wealth can be measured by changes in the area under this curve. The analysis here is similar to that presented above for housing. Referring to Figure 7.4, $D_s'$ is the demand-to-hold schedule for the company's stock prior to the accident and $D_s$ is the demand-to-hold schedule after the accident. The area VWTU is then interpreted as the marketplace's estimate of the loss in wealth--i.e., discounted future earnings--that the firm suffers because of the accident. The market value of the stock drops from $P_0$ to $P_1$ as a result of the accident. In this case, estimating the company's loss of wealth by multiplying the drop in price by the number of shares outstanding--area $P_1P_0TU$--would clearly underestimate the market's assessment of the loss.

This second approach may be feasible if one is interested in assessing the change in wealth in one or a few companies, *and if there are data available on accident results*; but if one is attempting to assess wealth changes for the hundreds or thousands of companies that might be affected by a severe accident, and *before* an accident occurs, it would be convenient to do the analysis for a representative firm and then to scale the results by the weighted number of firms, where the weights might be each company's total value in exchange for all of the outstanding shares, or some other proxy for pre-accident wealth. It might be added that sales and production are by themselves a poor guide to a company's wealth.

The approaches described above have serious shortcomings. The second approach is only available after an accident has occurred, unless one is willing to risk using data based on some *natural* disaster that has occurred in the past. The first approach suffers because a company's wealth is much more than the sum of the company's real assets. Two companies will be valued far

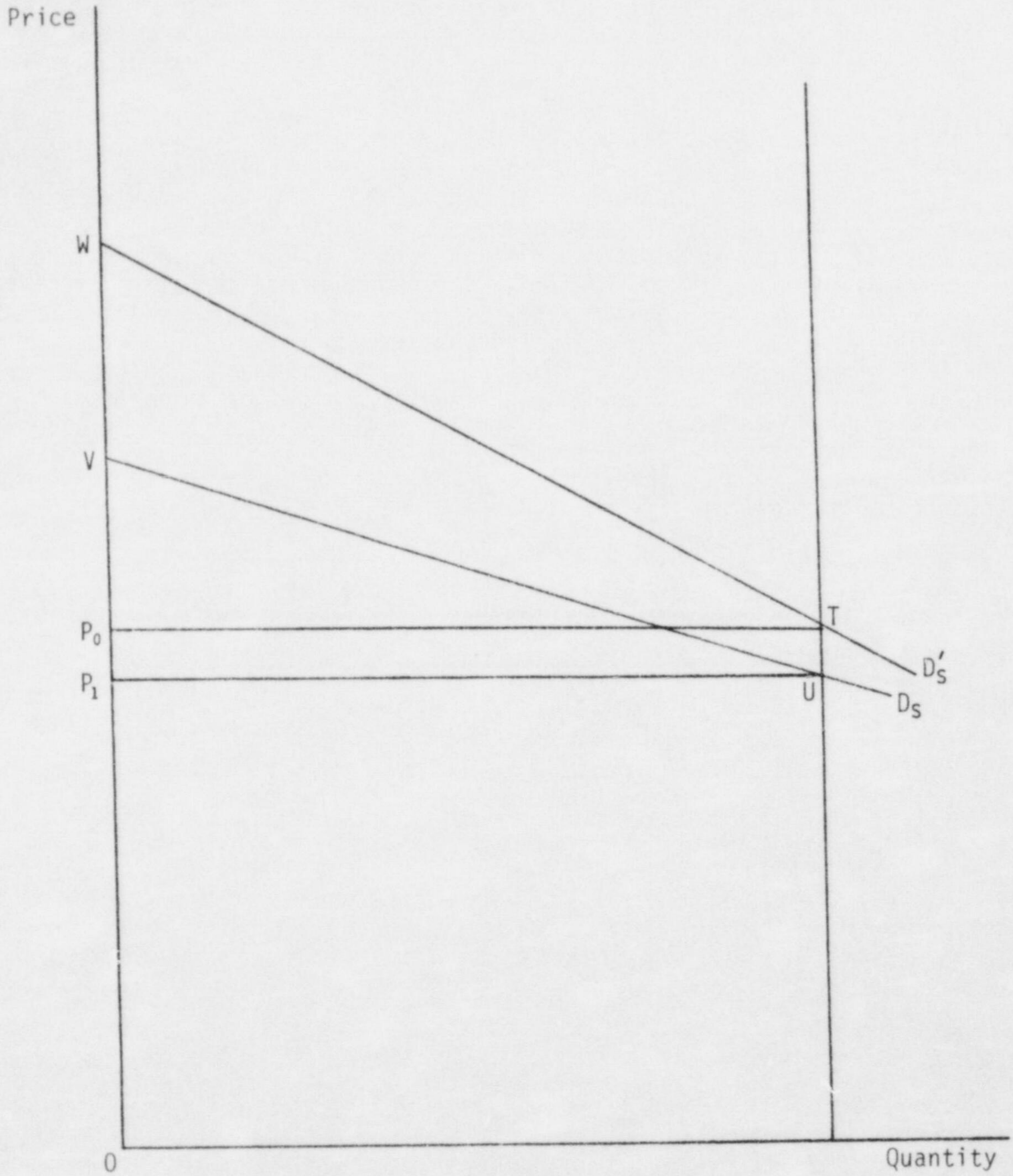


Figure 7.4 Accident-Caused Changes in Business Wealth

differently if through superior entreprenuerial abilities one is growing three times as fast as the other, even if they have identical real assets when they are evaluated. It may be possible to adjust values for growth factors, but assessing how an accident will affect the future growth of a company--even one that has not been physically affected by the accident--is extremely difficult.

A final precautionary note concerns the second approach--estimating wealth loss via stock valuation. This approach together with the earlier treatment for labor, account for total payments to production factors. If this factor payment approach is adopted, then one should not include other business costs, such as those that would be incorporated in the former approach--e.g., decontamination costs, relocation costs, interdiction costs, etc.,--since these would have already been accounted for in the adjusted wealth estimates of the affected firms. The two approaches described above are strictly alternatives to each other. Also, it should be noted that the changes in wealth of a business relate to private costs and benefits, and would be altered by transfers such as insurance payments, proceeds from law suits, government aid, etc. None of these latter represent social costs or benefits, since they all involve transfers of claims to resources from one party to another. Therefore, if wealth changes are used in estimating social costs and benefits with respect to businesses, the effect of these transfers should be netted out.

A third approach is suggested by the analysis surrounding Figure 7.1. If an estimate can be obtained for $Q_1$-$Q_2$, for the path taken by the dotted line, and for the average growth of the economy, then one can derive an estimate of the appropriate area to be discounted. If the output is valued at its total value in exchange (as it is in Figure 7.1), then an estimate of the change in consumers' surplus would have to be added.

### 7.3.6 Losses Within The Farm Sector

The principles for measuring social costs in the farm sector are the same as those for the nonfarm business sector. Social costs are summarized by changes in farm wealth, after adjusting for insurance proceeds, government subsidies and other transfers. Since there is no counterpart to the stock market for most agricultural establishments, the analyst has little choice but to make independent estimates of the accident's impacts on farm revenues and farm costs for several years out into the future.

Given that even a major accident is likely to have little effect on agricultural prices in the national marketplace, the analyst can focus on the accident's effect on farm production and the total value in use provided by it. However, the effect of the accident on farm sales would also have to be considered, insofar as consumers might perceive the farm products to be contaminated. The social cost of producing this farm output is, as usual, the opportunity cost of the resources used up in the process. The benefit to society from the output is the total value in use, which will not be as large if the output is believed to be tainted. The result would be a net loss to society if the perceived benefits are less than the resource costs.

7.3.7 Businesses In The Host Areas

Businesses in the host areas are likely to enjoy a net benefit as a result of the accident. Due to the influx of evacuees, they will face demand schedules that have been shifted out to the right. In the short run they will be able to raise prices. However, the disaster literature suggests that prices do not generally rise during the immediate aftermath of a natural disaster. Basically, there are at least two reasons for this. First of all, the Red Cross usually comes in and makes arrangements for goods to be provided at pre-disaster prices. Because they are usually successful in averting shortages of staple items, prices do not rise (Dacy & Kunreuther 1969, p. 34). The second reason is that businessmen are apparently reluctant to profit from the misfortunes of others, especially if the misfortunate are permanent customers. In the longer run, the ill will generated by raising prices could prove very costly (Dacy & Kunreuther 1969, pp. 110ff).

On the other hand, the price of housing has risen substantially following some natural disasters (Haas et al. 1977 p. 175). The reason is apparently that the housing stock cannot be sharply increased within a short period of time, and price is the most efficient method for rationing the existing stock. Furthermore, the nature of the housing market is such that antagonizing buyers with higher prices is not likely to adversely affect future income, given the infrequency of sales and the long lead times in augmenting the housing stock.

Regardless of whether or not prices rise, however, the real cost to society is represented by the opportunity cost of the goods in question, and this will be the same irrespective of the nominal price. Artificially low prices mean only that a business is transferring income to its customers; it does not mean that the social cost of using the goods is less. The use of shadow prices is appropriate in such situations. (See Appendix B, Section B.2 for a discussion on shadow pricing.)

The potential benefits to businesses in the host areas depend upon 1) how long the evacuees remain in the host areas, and 2) how quickly new firms enter to supply the increased demand. Benefits and costs to businesses in the host areas are reckoned according to the same principles described for businesses in the directly impacted areas.

7.3.8 Social Costs In The Public Sector

Local, state and federal governments can be expected to incur massive costs in the event of a severe radiological accident. These costs include:

- provision of evacuation personnel and equipment
- provision of security personnel and equipment
- provision of a communications network
- provision of personnel and equipment for monitoring radiation levels
- provision of personnel and equipment for decontaminating individuals, pets and livestock
- provision of medical personnel and equipment
- provision of personnel and equipment for decontaminating selected property

As usual, the social costs of providing the above are equal to the opportunity cost of the resources used, given the accident situation. Other potential costs to the public sector include losses inflicted on:

- o recreational areas
- o infrastructure
- o public water supplies
- o publicly owned power facilities
- o agency plant, equipment and supplies
- o other publicly owned property

The cost of providing personnel and equipment to cope with the accident consequences is the opportunity cost of these resources given that the accident has occurred. The social cost of damaged or destroyed public property is to be evaluated in view of the principle established in Section 7.4.9; namely, as the minimum cost of restoring the value in use that would have been provided by those resources had the accident not occurred. For examples and references on measuring the social value of selected public resources, see (Freeman 1979).

## 7.4 CONCLUSIONS

Socioeconomic impact analysis is useful in providing a description of what happens as the result of some event or project. It also can provide a good picture of the distribution of the impacts; that is, which groups benefit and which groups lose because of the event or project. A common use of impact analysis is to show regional distributions of impacts, especially when one region loses substantially while other regions benefit.

While the distribution effects are an important dimension in policy evaluation, another aspect concerns the efficient use of society's resources. Issues such as whether society's resources are best spent on improving reactor plant safety, or alternatively on improving evacuation response, health care, or even the quality of education need to be examined with respect to net benefits to society as well as their distributional aspects. Because these efficiency issues tend to be ignored or even misrepresented by impact analyses, it was felt important to address them in this report, especially if the findings within should provide the basis for policy decisions.

Several conclusions were drawn in this chapter. It was noted that sales and production impacts can be highly misleading; in general, the loss of sales and production resulting from, say, major disasters seriously overstate the costs to society. An accurate measure of losses within the business sector is provided by the loss of wealth, or equivalently, the present discounted value of the earnings stream. It should be observed, however, that this is much more difficult to measure than are sales or production losses.

The reporting of both job losses and loss of wage and salary income overstates the social loss. The loss of factor payments, by themselves, is usually a fairly reliable measure of the social loss due to deferred or reduced production. Factor payments include wages, salaries, rents, interest, dividends and retained business earnings.

In situations where property loss is widespread, assessing the social loss at pre-accident market value can seriously understate the loss. First, if a significant proportion of the housing within a town or city is removed from the usable housing stock, losses may greatly exceed the market value estimate because of the loss of consumer's surplus. Furthermore, because substitute housing opportunities within the town have been significantly reduced by the disaster, the loss of a particular housing unit is even greater.

Losses within the public sector include resources used directly in coping with the emergency and recovering from it. A loss of tax revenues, however, does not constitute a social cost, since tax payments and other purely monetary transactions--such as payments for welfare and unemployment--are transfers rather than costs; no scarce resources are used up.

# APPENDIX A

# LONG-TERM ECONOMIC CONSEQUENCES OF MAJOR NATURAL DISASTERS

## APPENDIX A

## LONG-TERM ECONOMIC CONSEQUENCES OF MAJOR NATURAL DISASTERS

In this appendix we examine the long-term economic impacts that have resulted from major natural disasters. Unfortunately, the literature is not extensive in this area, and the conclusions that can be drawn must be tentative, given that they are based on a small number of case studies.

In Section A.1 the major determinants of the economic impacts from a major disaster are considered. These include

- o the severity of the disaster
- o the amount of disaster aid that is made available
- o pre-disaster trends in the affected area, and
- o the availability of strong community leadership.

In Section A.2 the necessary conditions for rebuilding are examined. The early rebuilding of the stricken area is seen to depend on

- o the prompt commitment by a major financial institution or firm to reinvest in the damaged area
- o the availability of financial resources for rebuilding, and
- o the availability of building permits so that construction can legally take place.

In Section A.3 the patterns of reconstruction are explored. Common patterns are discovered in the reconstruction of several cities following a major natural disaster. These patterns are found to have a rational basis in economic theory, and include

- o the sequence of return
- o the geographic distribution of businesses and households, and
- o the impacts on prices.

The final section considers the extent to which the conclusions drawn from major natural disasters can be reasonably extended to severe radiological accidents at nuclear power plants. Important differences between natural and radiological disasters are identified, and these differences seem sufficiently strong to limit in many cases basing conclusions about radiological disasters on the effects of natural disasters.

### A.1 MAJOR DETERMINANTS OF ECONOMIC IMPACTS

Several factors contribute to determining how well a community recovers from a severe disaster. These include: 1) the severity of the disaster; 2) the amount of financial aid forthcoming and the speed with which it is made available; 3) pre-disaster economic trends; and 4) the availability of strong leadership in the affected community. Other factors, such as the time of year and special characteristics of the area and/or population affected by the disaster, may also play an important role.

A.1.1 Severity of the Disaster

One important factor that affects how quickly a community recovers is the severity of the disaster. Many if not most local establishments rely on goods and services from other local establishments, and this network of important linkages is vulnerable to severe and long-lasting disruption in the event of a major disaster. The extent of the disruption will depend on how quickly the damaged businesses can be restored and/or how effectively new sources of supplies can be obtained. Generally, this network of linkages is more extensive in larger urban areas.

A severe disaster can also seriously impair the existing labor force. Deaths, serious injuries and out-migration would all reduce the number of able bodied workers available for reconstruction.

Haas et al. (1977) examined 26 major disasters in urban places between the years 1141 and 1972 and found a strong relationship between disaster severity--as measured by loss-of-life--and recovery, defined as the number of years before the urban center reattains its predisaster population. In particular, they discovered that the length of time for recovery increased sharply with the percentage of population lost. In addition, the time for recovery was found to be shorter for the 9 twentieth century disasters than for the 16 disasters between 1141 and 1822. They attribute the shorter recovery time to the rapid rates of urbanization and population growth that have characterized the twentieth century. The sample of disasters taking place after 1900 also suggests that a 10 percent loss in population can be recovered within three years, while a 50 percent loss could be recaptured in seven years (Haas et al. 1977, p. 19).

Haas et al. break down the disaster sequence into four major overlapping periods. The emergency period is characterized by those "coping actions" in response to the destruction of property, the incidence of serious injury and the loss of life. The emergency period ends when search and rescue operations are stopped. Following the emergency period is the restoration period, during which utilities are made functional and temporary repairs are made to housing and business facilities. This permits the population to pursue in large measure the normal activities that were prevalent prior to the disaster. In reconstruction period I, the capital stock is totally replaced, and social and economic activities are restored to their pre-disaster level. Finally, in reconstruction period II, the last period, construction projects for improving the city beyond pre-disaster levels, for facilitating the future growth of the city, and/or for memorializing the disaster are undertaken (Haas et al. 1977 p. 3).

The authors have found a remarkable degree of regularity in the time spans taken up by each of these periods. For all of the studies that they examined with but minor exception, the restoration and first reconstruction periods took roughly ten and 100 times, respectively, the amount of time required by the emergency period. They also found the second reconstruction period to be about 50 percent longer than the first reconstruction period (Haas et al. 1977 p. 18).

It is instructive to consider four of the more recent disasters in greater detail. Table A.1 below provides information relating to the severity of the San Francisco, Anchorage and Managua (Nicaragua) earthquakes and the Rapid City, South Dakota flood.

Table A.1. Destruction and Recovery for Four Major Disasters

| Location | Type of Disaster | Year | Number of Deaths | Number of Homeless | Property Damage* | Population | Yrs to Recover |
|---|---|---|---|---|---|---|---|
| San Francisco, California | Earthquake and fire | 1906 | 550 | 220,000 | $350** | 400,000 | 3.0 |
| Anchorage, Alaska | Earthquake | 1964 | 9 | | $180 | 80,000 | 0 |
| Managua, Nicaragua | Earthquake | 1972 | 5,000 | 300,000+ | $500 | 405,000 | 1.0 |
| Rapid City, South Dakota | Flood | 1972 | 238 | 3,000 | $ 80 | 44,000 | 1.0 |

*In millions of current dollars
**Cost to rebuild.

Source: Haas et al. 1977

In San Francisco, over 50 percent of the housing and something over two-thirds of the jobs were eliminated by the 1906 earthquake and fire. Damage was extensive, and rebuilding required an expenditure of approximately $350 million. Free transportation was offered to evacuees, and although women and children were the primary beneficiaries of this offer, significant numbers of working age males must certainly have been among the 300,000 who left (Haas et al. 1977, pp. 6, 71).

In Anchorage, Alaska, before the earthquake, there was a relatively high vacancy rate in the housing sector, and the quake heavily damaged--60 percent or more of total value-- ess than a thousand units (Dacy and Kunreuther 1969, p. 107). Since most of the city's commercial and industrial enterprises were virtually unharmed by the quake, it was therefore not necessary to establish construction priorities, for all of the major projects could be carried on at the same time (Haas et al. 1977, p. 99). In addition, the number of deaths and serious injuries were very small relative to the overall population, so there was virtually no adverse impact on the Anchorage work force. Indeed, by the end of 1964 there were over 2,500 new construction-related jobs, filled largely by workers from the lower 48 (Haas et al. 1977, p. 100). These workers from outside the state were undoubtedly attracted by the large quantity of financial resources that were made available for reconstruction through the agencies of the federal government.

Managua suffered extensive damage from the earthquake of 1972, with ten times the loss of life of the San Francisco earthquake and somewhat greater property damage. All of Managua's central commercial and industrial district was destroyed (Haas et al. 1977, p. 108). Because of Managua's size and the large number of small establishments that were destroyed, the disruption to the linkage network of the local economy was severe. And although a significant amount of manpower became available for reconstruction because of the large number of regular jobs eliminated, the relatively small amount of outside resources available for rebuilding meant that unemployment rather than a shortage of manpower was the central labor problem.

In Rapid City, South Dakota as in Anchorage, serious injuries and deaths represented a negligible portion of the labor force. Furthermore, because Rapid City is relatively small, economic linkages are not extensive. Conseuently, it is not surprising, given the large amount of financial aid that was distributed (see below), that Rapid City's population recovered to its pre-flood level within a year.

### A.1.2 Amount of Financial Aid Available

The amount of aid that is made available to the disaster victims appears to be nearly as important as the severity of the disaster in determining the speed of recovery. First, the victims need to be provided with minimum levels of food, shelter and clothing. Once the immediate short-term needs are satisfied, consideration can be given to meeting longer-term requirements.

Insurance Proceeds. Although, strictly speaking, insurance proceeds may not be considered disaster aid, they can be very important in enabling damaged and destroyed businesses to reopen. Similarly, they can be an important source of financial assistance in rebuilding the housing sector. Typically, however, insurance funds are not a major source of funding for reconstruction from major natural disasters, except in the case of hurricanes and other sources of wind damage (Dacy and Kunreuther 1969, p. 49).

The Red Cross. The American National Red Cross through its numerous member chapters has traditionally provided relief to disaster victims in the U.S. Red Cross operations can be broadly categorized into emergency activities and rehabilitation assistance. While the Red Cross is best known for its emergency operations, significant relief is provided to victims in the form of food, clothing, rental payments, and grants for the repair and reconstruction of owner-occupied housing, replacement of household furnishings, occupational supplies (including tools, equipment, inventories and supplies for small businesses), and medical and nursing care (Dacy and Kunreuther 1969, p. 34). In the Alaskan earthquake, over 70 percent of the $1.27 million in Red Cross expenditures were for rehabilitation assistance, and, if anything, this percentage is somewhat lower than the average for major U.S. disasters (Dacy and Kunreuther 1969, p. 35).

Government Disaster Aid. Government financial assistance has become the single most important source of reconstruction resources in the U.S., with over a billion dollars spent annually. Indeed, in both the Anchorage and Rapid City disasters, total financial assistance--of which the lion's share came from the federal government--nearly equaled or exceeded the total extent of damages. (Haas et al. 1977, p. 18; Dacy and Kunreuther 1969, Tables 6-3 and 6-7.)

Funds from the federal government can come from any of several agencies, the most important being the Small Business Administration (SBA) and the Housing and Urban Development (HUD) Agency. In recent years such funds have been available in the form of grants and low-interest loans for repairing and rebuilding commercial and residential buildings; replacing equipment in businesses and furnishings in homes; and providing businesses with low-interest loans for working capital (Dacy and Kunreuther 1969, pp. 42-3). In the case of Anchorage, the victims were even given access to low-interest SBA money to pay off higher-interest loans that were outstanding, even though these loans had little or no connection with the quake (Dacy and Kunreuther 1969, pp. 135).

There can be little question that the availability of substantial funding for rebuilding purposes expedites the recovery process. In addition to marshalling the locally available resources for rebuilding, it also serves to attract skilled labor and other resources from outside of the disaster area. (However, Harbridge House (1972) found no relationship between the speed of economic recovery and the amount of government financial aid provided in major U.S. disasters between 1960 and 1970 (cited in Haas et al. 1977, p. 19)).

### A.1.3 Predisaster Trends

Haas et al. hypothesize that predisaster economic trends will influence the rate of recovery of a disaster-stricken area (Haas et al. 1977, p. 19). If a community was growing before the disaster, according to them it is likely that this growth will continue after the disaster. Even more, structural changes that were taking place will be highly accelerated during the reconstruction period. (Structural changes such as suburbanization and the centralization and decentralization of businesses will be examined in greater detail below.) On the other hand, communities that are stagnating or declining will not enjoy a permanent reversal in their fortunes as a result of the recovery efforts.

Wright et al. (1979), however, do not support this "acceleration" hypothesis and point to a study of the Alaska earthquake by Dacy and Kunreuther (1969) for support. One town that was virtually devastated by the earthquake was Seward, located about 125 miles south of Anchorage at the edge of the Kenai Peninsula. During World War II, Seward became an important port through which most goods bound for Anchorage, Fairbanks and other points inland were transshipped. Subsequently, however, Seward began to lose its competitive position as a port, with a resulting decline in its economy. Manufacturing employment declined somewhat from a monthly average of 135 to 123 over the two years ending in 1963, and between July 1, 1960 and the period just before the earthquake, Seward's population dropped from 1900 to 1600 (Dacy and Kunreuther 1969, pp. 175ff).

After the earthquake, a political decision was made to rebuild Seward, including its port, at a cost of over $26 million, an amount which excludes federal aid to the private sector (SBA loans, FNMA mortgage forgiveness, and tax write-offs). Yet despite this massive infusion of federal support, Seward's economy has continued to falter. For example, in 1963 over half of the freight tonnage shipped to individual ports in southcentral Alaska went to

Seward, while by 1966 the tonnage had plunged to only 4 percent; and an employment decline, from 900 in 1963 to 610 in 1966, contributed to the population shrinking to 1340 by the latter year (Dacy and Kunreuther 1969, pp. 178 ff.). Yet according to Wright et al. (p. 42), the postdisaster relief "effectively reversed" Seward's economic decline.

While the relatively few case studies investigated by disaster researchers are insufficient to validate the "accelerating trend" hypothesis, the evidence that does exist appears to be consistent with this hypothesis. Furthermore, from the viewpoint of economic theory, the hypothesis is certainly appealing. Federal aid is usually provided to the public sector for restoring infrastructure, and to the business sector in the form of low-interest loans for reestablishing businesses. If an area is in decline, this usually means that many businesses are not covering fixed costs; i.e., business income is insufficient for replacing plant and equipment after they have been fully depreciated. In such circumstances, businesses will not generally make the reinvestment necessary to remain in operation. Now, if businessmen were not covering their fixed costs before the disaster, then for them to justify reinvesting in the area they must find strong reasons why fixed costs would be covered after the disaster. While it may be likely that these costs could be covered during the reconstruction phase, when business activity is abnormally high, after reconstruction the situation is likely to return to the pre-disaster level unless major new and permanent economic enterprises can be attracted to the area. In the absence of such new activity, the area will in all probability continue to decline. For a growth area, the economic argument is just the reverse: businesses are covering all of their costs. If the level of disaster aid plus private investment is sufficient to return the community to its previous level of activity, then the prospects for continued economic growth remain bright.

### A.1.4 The Availability of Strong Leadership

Effective leadership in both the San Francisco and Rapid City disasters has been mentioned as an important recovery factor by participants in the recovery process (Haas et al. 1977 p. 20). Strong leadership can result in quick and effective decisions being made within the public sector, and these decisions provide a basis for crucial decisions within the private sector. According to Haas et al. (1977), this factor plays an important role because of its effect on the level of uncertainty. Indeed, they claim that the rebuilding of a city will usually be as fast or faster if left to the forces of the market place, rather than relying on structured planning by public officials (Haas et al. 1977, p. 29).

Among the decisions that must be made are whether to incorporate major improvements into the rebuilt city. There is a general desire to make the community safer from similar disasters in the future, as well as to beautify it. However, an often stronger desire is to clean up the damaged areas as quickly as possible, to restore residences and businesses to their pre-disaster state and to return the community to normalcy. The desire to improve the city--especially among city planners--is often at odds with the desire to quickly restore the *status quo ante*; hence, the time necessary to formulate and implement any new plan is often met with insurmountable resistance by those in the private sector. Indeed, in San Francisco a plan was already in existence prior to the earthquake--the Burnham plan. But it was never implemented, presumably because of the delays and conflicts that it would have imposed on private sector interests (Haas et al. 1977, p. 66).

In Managua, the central business district was heavily damaged, and authorities closed it off with a high barbed wire fence a few days after the quake. Six months later, a plan for reconstructing this area of approximately 400 city blocks was made public, but after another year and a half, still no construction had been allowed. Meanwhile, owners of property in this area--both of business and residential property--had received no compensation. Because a number of private decisions could not be postponed for such an extended period of time, decisions to rebuild elsewhere in the city were made and implemented. According to Haas et al. (writing in 1977), the master reconstruction plan for the city will have very little real impact on the reconstruction of Managua by the time it is adopted (Haas et al. 1977, p. 64).

In Rapid City, a decision to condemn the flood plain area meant that many houses undamaged by the flood would have to be abandoned. This decision, while providing for the future safety of the area, exacerbated an already serious housing shortage and caused considerable resentment among those who had to leave their undamaged homes (Haas et al. 1977, p. 62, 184).

## A.2 NECESSARY CONDITIONS FOR REBUILDING

Immediately following a major disaster, it is natural to expect a considerable degree of confusion and uncertainty. For example, because the city or community may appear to be largely destroyed, there is commonly great uncertainty whether or not the city or community will be rebuilt. Although destruction may appear to be almost total, in fact the value of what remains almost always greatly exceeds the loss. Thus, reassessment of the damage will invariably lead to the decision to rebuild. (Although occasionally cities get reconstructed on a different site--e.g., Valdez, Alaska--the last "significant" city not to be rebuilt was St. Pierre, Martinique in 1902, in which the entire population of 30,000 was killed during an eruption of Mt. Pelee (Haas et al. 1977, p. 20).

Important to the decision to rebuild the city is a commitment by a major firm or institution to rebuild its own facilities. In San Francisco, Managua and Anchorage, major banks were the first to make this commitment. This is not surprising since financial institutions have the easiest access to capital for rebuilding (Haas et al. 1977, pp. 26-7). Furthermore, because local mortgages may constitute a significant fraction of the portfolios of these financial institutions, such institutions could have a particularly large stake in the future of the community. The desire to rebuild is fundamental to the restoration process, and commitment to the area by a major firm or institution acts as a catalyst to others.

A second requirement for the rebuilding decision is the availability of financial resources. To this end, the prompt payment of claims by insurance companies and the timely distribution of federal disaster aid are crucial to the rate of recovery. With the exception of the San Francisco earthquake, in which about 50 percent of the $350 million rebuilding cost came from fire insurance, insurance did not play a significant role in the (four) major disasters investigated by Haas et al. On the other hand, for hurricanes, tornadoes and other damaging winds, insurance payments are an important source of reconstruction funds (Dacy and Kunreuther 1969, p. 49).

Dacy and Kunreuther (1969) have examined fourteen major natural disasters between 1954 and 1965 and have found that Federal assistance has tended to be highest in those disasters for which insurance has been least. And they have also identified a major trend toward an increase in Federal disaster aid over that time period. In the case of Alaska, PL 875 allocations and SBA approvals accounted for fully 50 percent of the uninsured losses (Dacy and Kunreuther 1969, pp. 48-9).

Once the decision has been made to rebuild and the financing of the construction has been secured, the third requirement is that the public authorities permit the construction to take place. Building moratoriums and other legal restrictions may prevent this reconstruction. We have already considered the tendency of city planners and others to attempt to delay reconstruction until a grand plan can be developed and implemented. To the extent that they are successful, uncertainty regarding the future of the city will persist and result in a postponement of the city's recovery. However, since public authorities usually confine their concerns to the heavily damaged areas, investors, rather than postpone reconstruction, may instead rebuild in places outside the stricken area (Haas et al. 1977, p. 27).

## A.3 PATTERNS OF RECONSTRUCTION

Most urban areas have developed in a way that enhances the conduct of business and promotes the relationship among residential and business functions. Because similar principles apply to all urban areas, one should not be surprised to find organizational patterns that are common to many cities, particularly those of similar size and population. Thus, in larger cities, the central business district is often comprised of subdistricts, each containing like businesses. This centralizing of like businesses within a relatively compact area makes it less time-consuming and less costly for consumers to comparison shop. In addition, the high level of competition keeps prices low and provides another incentive for consumers to shop in such areas. The concentration of similar businesses also makes it easier--i.e., less costly--for related businesses to provide support services. On the other hand, suburbanization of the population has made it more dependent on the automobile. Difficulty in parking in the downtown district and the convenience of shopping within one's neighborhood have consequently lead to the rapid growth of neighborhood shopping malls during the post-war period.

Because such trends tend to be common among similar sized urban places, and because the reasons for these trends continue through a disaster, one should be able to find patterns in the sequence with which businesses and residences return to the stricken areas and their geographic distribution after they resettle.

### A.3.1 Sequence of Return and Geographic Distribution of Businesses

In the four disasters investigated by Haas et al., the sequence in which businesses reestablished themselves shows a clear pattern; the same can be said for their geographic distribution as well. The evidence suggests a hierarchy of commercial and industrial activities, with those activities of higher order being the first to reestablish their positions. The disaster evidence also supports the hypothesis that pre-disaster trends are accelerated by the disaster. In each case the disaster increased the rate at which activities that were already decentralizing left the city center; and, similarly, those activities that had been moving into the center moved in at a faster rate after the disaster. In this section, we compare in some detail the similarities and differences for the four disasters.

A.3.1.1 San Francisco Earthquake. In San Francisco, firms in the same industry had already begun to seggregate themselves within a single district, and the 1906 earthquake greatly accelerated this process. Commercial districts that had comingled at their boundaries became coterminous, and districts that had already separated increased their distance, thereby accommodating new support services and other related activities in the bands between them (Haas et al. 1977, p. 86). There was also a definite sequence regarding the types of firms to resettle first. Initially, the financial district was settled, followed by department stores, women's apparel and jewelry firms. Next came the hotel and theater districts; and these, in turn, were followed by those industries of lesser rank. Also, the leading firms within each industry were the first to stake out their territories, and these territories were then filled in by medium- and small-sized firms of the same type (Haas et al. 1977, pp. 75-78).

Within the financial district, the order of settlement was: major banks, followed by the stock exchange, and major insurance companies; then minor banks, minor insurance companies, major real estate firms and major investment and stock companies; finally, came the loan agents, insurance agents, real estate agents and the stock brokers. Within three years, the financial district was nearly completely resettled (Haas et al. 1977, p. 74).

About ten months after the earthquake, and after the outline of the financial district had become clear, major department stores made their relocation decisions. Then followed medium-sized specialty stores for women and the leading jewelry and men's clothing stores. Hundreds of lesser jewelry and apparel stores settled in the following year, rounding out a well-defined apparel shopping district (Haas et al. 1977, p. 75).

The expansion of the financial district beyond its pre-quake boundaries delayed the return of the hotel district for about two years, at which time several large hotels began to define the boundaries of the new hotel district. Five years after the disaster, a multitude of medium-sized and small hotels had filled in the new hotel district (Haas et al. 1977, p. 75).

A similar process occurred in the other businesss sectors, with the major firms broadly defining the new district and smaller firms filling it out. Additionally, lower-ranked businesses tended to delay their relocation decisions until businesses of higher rank had staked out their territory. Thus, household furnishing retailers waited for definition of the apparel district; theater operators delayed until the apparel and theater districts had been outlined; the general office district was established after the boundaries of the financial district became clear; and the new garment district began to settle after the financial and general office districts. Around these second-order districts was a "gray zone" that consisted of the civic center, clubs and organizations, automobile dealers, wholesale producers, movie theaters, second-class hotels and boarding houses. And finally, in an area outside the peripheral districts but inside the purely residential areas, was a mixed district consisting of bulk wholesaling, industrial, residential buildings for transients, and tenements for lower-income families and ethnic minorities (Haas et al. 1977, p.77).

A.3.1.2 Anchorage Earthquake. The earthquake in Anchorage did slight damage to Alaska's commercial/ industrial sector, when compared with the damage done by the San Francisco disaster. However, similarities in impacts were still in evidence. A week after the Alaska quake, two major decisions were made in the private sector to begin construction on large buildings for which plans had been drawn up earlier. These were the First National Bank building and the $1.75 million Captain Cook Hotel. These two actions gave owners of other destroyed businesses the confidence they needed to decide to rebuild. Only a year after the disaster, nearly all of the damaged businesses had been restored and/or modernized. The only notable exception was the J.C. Penney department store, which waited until December 1964 to take out a building permit for a $2.2 million building (Dacy and Kunreuther 1969, p. 162).

Acceleration of predisaster trends toward centralizing and decentralizing business establishments were apparent in Anchorage as they had been in San Francisco. Financial, office and hotel establishments expanded into the enlarged central business district, which also accommodated subdistricts of apparel shopping and lesser financial enterprises. Because of a relative lack of adequate retail space within the CBD, however, many smaller retailers decentralized into the outlying areas (Haas et al. 1977, pp. 102-3).

As a result of the virtual destruction of port facilities at Valdez, Seward and Whittier, significant growth occurred around the port of Anchorage. During 1964, port handling activity increased 820 percent over 1963 levels, and this sharp growth fostered an expansion in wholesaling and distribution activities within the port area. By the end of 1964, new and growing enterprises had leased half of the port's 74-acre industrial park (Haas et al. 1977, p. 103).

A.3.1.3 Managua Earthquake. The 1972 earthquake destruction in Managua was comparable to that in the San Francisco disaster: both cities lost their entire central commercial and industrial districts, and the proportional loss of housing units was about the same. Both cities had on-going processes of centralization and decentralization within the business and residential sectors, and these processes were accelerated as a result of the earthquakes (Haas et al. 1977, pp. 108-9).

Before the earthquake, separation of Managua into two cities--one for the upper class and one for the lower class--was proceeding at a rate that would have produced total separation after the year 2000. The destruction of the earthquake sharply accelerated this process, enabling it to be completed after only five years. The previously overlapping central shopping areas are now totally separate (Haas et al. 1977, p. 109).

Although this separation brought some clear benefits in the way of greater availability of parking space, more modern buildings, lower rents, and fewer traffic problems, the loss of a single centralized business district has its negative aspects. Wholesaling and distribution activities may be harmed because of the necessity of servicing two geographically separate markets. Similarly, establishments that provide specialized services to other firms may find themselves disadvantaged by the separation (Haas et al. 1977, p. 110).

Another disadvantage is the decrease in competition implied by decentralization. With one central district, purveyors of similar products tended to locate near each other. The concentration of similar establishments attracted shoppers because it was easy for them to comparison shop. The close competition also meant relatively low prices to consumers (Haas et al. 1977, pp. 113-4)

The industrial sector before the earthquake consisted of large industries located mostly on the periphery of the central business district. These industries suffered, for the most part, only minor damage. Haas et al. estimate that industrial production fell only about 18 percent among the medium and large industrial firms. By contrast, the small industries, which were located largely within the old center, suffered heavy losses; perhaps as many as 90 percent of these firms lost inventories, plants and/or equipment. Since the lightly damaged large industrial firms also had relatively easy access to investment funds, recovery and expansion were no problem for them. On the other hand, the small and medium firms had difficulty in collecting on their insurance claims and poor access to financial markets. A large number of these firms either went out of business or had to struggle along with few paid employees. This process, which had been gradual before the earthquake, was greatly accelerated by it, taking two years to complete what otherwise might have taken twenty (Haas et al. 1977, pp. 117-9).

A.3.1.4 Rapid City Flood. Although 100 businesses were damaged or destroyed by the Rapid City flood, the methodology employed by Haas et al.--a sample survey of 125 victim families and 70 nonvictim families--was not designed to elicit patterns relating to the sequence of return and geographical distribution of businesses in the post-flood period (Haas et al. 1977, pp. 170-1).

### A.3.2 Sequence of Return and Geographic Distribution of Households

In the four disasters examined by Haas et al., it was generally found that the residential area became significantly enlarged after the disaster. Certainly, a part of this expansion is caused by the increase in the size of the central commercial area. In the case of San Francisco, the central district expanded by 44 percent during the reconstruction period. As the central district expanded, the uncertainty in the status of the area between the old district boundaries and the boundaries of the residential area caused residences in this zone to relocate to the outer edges of the city. In addition to the areal expansion, there was also a pronounced movement to seggregate previously mixed neighborhoods along socioeconomic and ethnic lines (Haas et al. 1977, p. 94).

In Anchorage, too, the disaster accelerated the trend toward suburbanization. Part of the movement to the suburbs is explained by the fact that the city made available for development land at least four times the size of the damaged and destroyed areas (Haas et al. 1977, p. 103).

A real expansion and seggregation by economic class was also prevalent in Managua. Forty-three percent of the city's housing was destroyed and another 22-28 percent seriously damaged; but only 26 percent of the destroyed housing was low-income, compared with 60 percent and 34 percent for lower-middle and middle- and upper-income housing, respectively (Haas et al. 1977, pp. 129, 137). This extensive damage together with the fact that building was not permitted in the heavily destroyed central area practically guaranteed a major expansion of the city.

Haas et al. do not comment on the change in the geographic distribution of housing in Rapid City as a result of the flood. However, there must have been significant changes because of the removal of the entire floodplain area from the inventory of residential property.

Another major finding by Haas et al. was that higher-income families were able to relocate on a permanent basis more quickly than lower-income families. An exception was Anchorage, which prior to the earthquake had a high vacancy rate among rental properties, particularly at the low end of the scale (Dacy and Kunreuther 1969, pp. 105-9). That higher-income families should recover more quickly is hardly surprising, since they have at their disposal the financial resources for repairing or rebuilding their homes. Furthermore, they are more likely to be insured, and they are also more likely to have used organizational aid to find new housing, probably because they are more adept at working their way through the bureaucracy (Haas et al. 1977, pp. 79, 177)

Similarly, those of higher income tend to suffer shorter periods of job dislocation. For one thing, their employers are more likely to be well-established, their businesses less prone to disaster damage, and themselves better able to obtain financial aid if necessary. In addition, a higher income means that distance to work and the expense of getting there are less important constraints than for those of more modest means. Thus, those with higher incomes are able to select from more widely scattered employment opportunities in the event that their pre-disaster job has vanished.

On the other hand, lower-income workers are more likely to be employed at businesses low in rank. They therefore share in the difficulties that such businesses are forced to face. Because the expansion of the central business district often means that lower-ranked businesses must relocate to the outskirts, the time and expense of traveling to work may increase significantly. The mean distance traveled to work by unskilled and blue collar workers in San Francisco increased by nearly 75 percent from the 1905-07 period to the 1907-08 period (Haas et al. 1977, p. 80). Low-ranked businesses are also more vulnerable to disaster-induced failure. In San Francisco, of nearly 900 small firms to receive Relief Committee rehabilitation loans, only half were self-supporting two years after the quake, while over a third were no longer in business (Haas et al. 1977, pp. 30, 78-9). As a result of these hardships, unskilled and other lower-class workers tended to relocate to other areas. In San Francisco, 74 percent of a 1905 sample of unskilled workers had not returned to the Bay Area by 1907, and the figure was 87 percent by 1910 (Haas et al. 1977, p. 84).

### A.3.3 Impacts on Prices

Apart from accelerating existing pricing trends, considerations of economic theory would suggest that a disaster will cause few if any long-term impacts on prices. The major exception might be housing: in the case of a major disaster, it could take several years to replace the lost housing stock. As has already been noted, major disasters appear to accelerate existing economic trends. Thus, the price implications of centralization, decentralization and suburbanization should not be affected by the disaster except for temporal considerations.

Haas et al. found no evidence to substantiate long-term price increases for any commodity other than housing in Rapid City (Haas et al. 1977, p. 175). In Managua, separation of the central market into two markets--one for the upper classes and one for the lower classes--reduced the travel time to shopping for the upper classes, but not the lower classes. The smaller markets imply less competition and therefore possibly higher prices (Haas et al. 1977, p. 115). However, it has already been noted that the division of the central market into two parts was a trend that was underway before the 1972 quake.

The damage in Anchorage, while severe, left a major part of the commercial/industrial complex unscathed. Consequently, one would not expect to observe significant price changes (Haas et al. 1977, p. 107). Even in the housing sector, a high pre-disaster vacancy rate apparently contributed to preventing any significant change in rents. Other factors were the unwillingness of real estate agents to list any property or rental units showing large increases in price from the pre-quake period, and the pooling of information by these agents on units that were available for occupancy by the homeless (Dacy and Kunreuther 1969, p. 109).

In San Francisco there were no food shortages after the earthquake. Even though the city was cut off from neighboring communities and only a small inventory of food was normally stocked by stores--food supplies were received daily--the Citizens' Relief Committee and the Army were able to meet all of the needs (Dacy and Kunreuther 1969, p. 110). The most long-lived price effects from the San Francisco earthquake were in the housing sector. With more than half the housing destroyed, rents doubled from their pre-disaster levels (Douty 1969, cited in Haas et al. 1977. p. 89). By 1911, however, the stock of housing had reached its pre-disaster level (Haas et al. 1977, p. 73).

Dacy and Kunreuther's examination of several other disasters pointed up no case in which serious food shortages materialized. In Waco, Texas following the 1953 tornado, merchants distributed food without charge to the victims, not knowing whether or not they would be reimbursed. In most other disasters, the Red Cross took charge of food distribution. In Alaska, whose nearest source of supply is 1500 miles away in Seattle, potential food shortages existed. Exhortations to the public not to hoard food were generally followed, however, and prices remained stable (Dacy and Kunreuther 1969, pp. 110ff.).

# APPENDIX B

# SOME MAJOR CONCEPTS OF ECONOMIC THEORY

APPENDIX B

# SOME MAJOR CONCEPTS OF ECONOMIC THEORY

This appendix contains definitions and descriptions of some economic concepts that underlie the discussion in Section 6 on the social costs of severe reactor accidents. Included are a discussion of costs and impacts, externalities, several aspects of economic efficiency, supply and demand, consumers' surplus and economic rent, shadow prices, and the discount rate. The section concludes with a short treatment of equity considerations.

## B.1 IMPACTS AND COSTS: DEFINITIONS

An impact is defined broadly to include any effect; thus, a radiological accident impact may be any effect arising from the accident. A cost, on the other hand, includes only a subset of impacts. Cost is defined as the highest valued alternative foregone, or simply the opportunity cost (Alchian and Allen 1969, p. 40). For example, the building of a dam requires using up scarce resources. The cost of building the dam is equal to the value of these resources in their most-valued alternative uses; it is the maximum that others would be willing to pay to apply these resources to other uses. When costs occur within the market place, price is a convenient and usually accurate measure of the opportunity cost. In this report, the terms "cost", "social cost," "societal cost" and "economic cost" have been used synonymously.

Private costs are costs that are transacted through the market place. The purchase and sale of goods, services and factors of production are examples. There are also costs that do not get transacted through the market place. Such costs are commonly referred to as technological externalities, externalities, external costs or spillover effects. Social costs are equal to private costs plus external costs; thus, the presence of externalities causes private costs to diverge from social costs (except in the case of 'pecuniary' externalities, as explained below). While individuals and firms tend to be concerned only with the private costs of their actions, external costs should always be considered in policy analysis and public investment decisions so that the full costs to society are addressed.

## B.2 EXTERNALITIES

It is useful to distinguish between two types of externalities: pecuniary externalities and technological externalities.[1] Pecuniary externalities are by far the more common and are defined as externalities that leave production (consumption) possibilities unaffected, given the firm's (consumer's) physical inputs; pecuniary externalities cause only product or factor prices to change (McKean 1958, Chapter 8). For example, if a firm requires more of a particular factor, then it will enter the market place and bid up the factor price in

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[1] There is also a category called 'public goods externalities.' (See Bator 1958.)

order to attract it away from current users, who would then have to pay a higher price to retain use of the factor. Although these users are not as well off as before, their production possibilities have not been affected. The important conclusion with respect to pecuniary externalities is that they do not cause private costs to diverge from social costs; therefore, in evaluating social costs, they should not be added to private costs.

Technological externalities do cause private costs to diverge from social costs, as we have already noted. Technological externalities, unlike pecuniary externalities, do affect the production (consumption) possibilities, given a firm's (consumer's) physical inputs. Air pollution may affect a laundry's ability to get clothes as clean as before with the same inputs; or it may affect a person's ability to breathe. Because these costs may not be transacted through markets, there is no price or other direct and objective measure for evaluating them. Not surprisingly, externalities can be difficult to value.

## B.3 ECONOMIC EFFICIENCY

It is useful to distinguish four types of economic efficiency: efficiency in exchange, efficiency in production, utility efficiency and temporal efficiency. Efficiency in exchange refers to the opportunities for mutually advantageous exchange given the initial allocation of goods among individuals. Exchange efficiency is a state in which no reallocation of the goods can make some individual better off without simultaneously making at least one other individual worse off (Scitovsky 1951, Chapter IV). Exchange efficiency is attainable from any initial allocation of goods, no matter how inequitable, and the perceived equity of the efficient distribution will depend in large measure on the perceived equity of the initial distribution. Thus, the concept of exchange efficiency has nothing to do with the equity of the distribution.

Efficiency in production is defined as a state in which, for given factor inputs, the output of any good cannot be increased without simultaneously decreasing the output of at least one other good (Alchian and Allen 1969, p. 200). There are an infinity of output combinations that are production efficient. However, individuals are not indifferent to the combination of goods that they consume. Thus, there will generally be one output combination that is superior to all of the other output combinations, and this output combination is the utility efficient output (Alchian and Allen 1969, p. 231).

The final type of efficiency is temporal efficiency. Temporal efficiency has to do with the production and consumption of goods over time. It exists when no change in production or consumption schedules can make some individual better off without making at least one other person worse off.

The fundamental theorem of welfare economics is that perfect competition provides economic efficiency in the four senses described above. A discussion of the conditions under which an economy is perfectly competitive is beyond the scope of this appendix. The interested reader is referred to (Bator 1957). A great number of important conclusions can be derived from the competitive model, and it is used in Section 6 to analyze the costs of a severe radiological accident.

## B.4 DEMAND AND SUPPLY

The concepts of demand and supply are fundamental to welfare economics. A (Marshallian) demand curve is defined as a schedule relating the maximum quantity that will be purchased in a given period as a function of price, other relevant variables remaining constant. Similarly, a supply curve is defined as a schedule relating the minimum price at which a given quantity would be offered during a given period, other relevant variables remaining constant (Friedman 1962, Chapters 1 and 3). As shown in Figure B.1, the supply curve SS and the demand curve DD intersect at the market-clearing price P.

## B.5 CONSUMERS' SURPLUS AND ECONOMIC RENT

The total area underneath a demand curve between the origin and the output quantity defines the total value in use. In Figure B.1, total value in use for demand DD is the area ODXQ. The total value in use is separated into two parts: the total value in exchange, which is the rectangular area below the price line, or OPXQ; and consumers' surplus, which is the triangular area above the price line, or PDX. Total value in use measures the maximum amount that buyers are willing to pay for a given quantity of the good. Total value in exchange measures what they must in fact pay for that quantity. The excess of what they are willing to pay over what they are required to pay is the consumers' surplus. Consumers' surplus is a measure of the net benefit to consumers provided by the product.[2]

The concept of economic rent is closely related to consumers' surplus, except that it applies to factors of production and is sometimes called producers' surplus. Referring again to Figure B.1, and recalling that the supply schedule relates the minimum price at which a given quantity would be offered on the market, the social cost of producing output OQ is equal to the area OSXQ. The area defined by the triangle SPX is producers' surplus. This can be illustrated using labor as an example. At low rates of production, those workers willing to work most cheaply (or who are most productive at a given wage) will be hired. However, at higher rates of production, it becomes necessary to bid workers away from other uses by offering higher wages. Since all workers (except the last to be hired) benefit from the higher overall wage, they receive a wage that is above the minimum wage that they are willing to accept. The difference between the former and latter is economic rent. Those workers who are willing to work most cheaply--i.e., have the lowest opportunity cost--earn the largest rent, while those with the highest opportunity cost earn

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[2] Because price changes also affect real income, a more accurate measure of the benefit from or cost of a price-changing event is the compensating variation, which is a measure of the effect of the price change with real income held constant. However, in analyzing the effects of events that cause price change, (Willig 1976) shows that consumers' surplus will generally provide a good approximation of the true cost or benefit. For a discussion of these and other similar measures, see (Freeman 1979, Chapter 3).

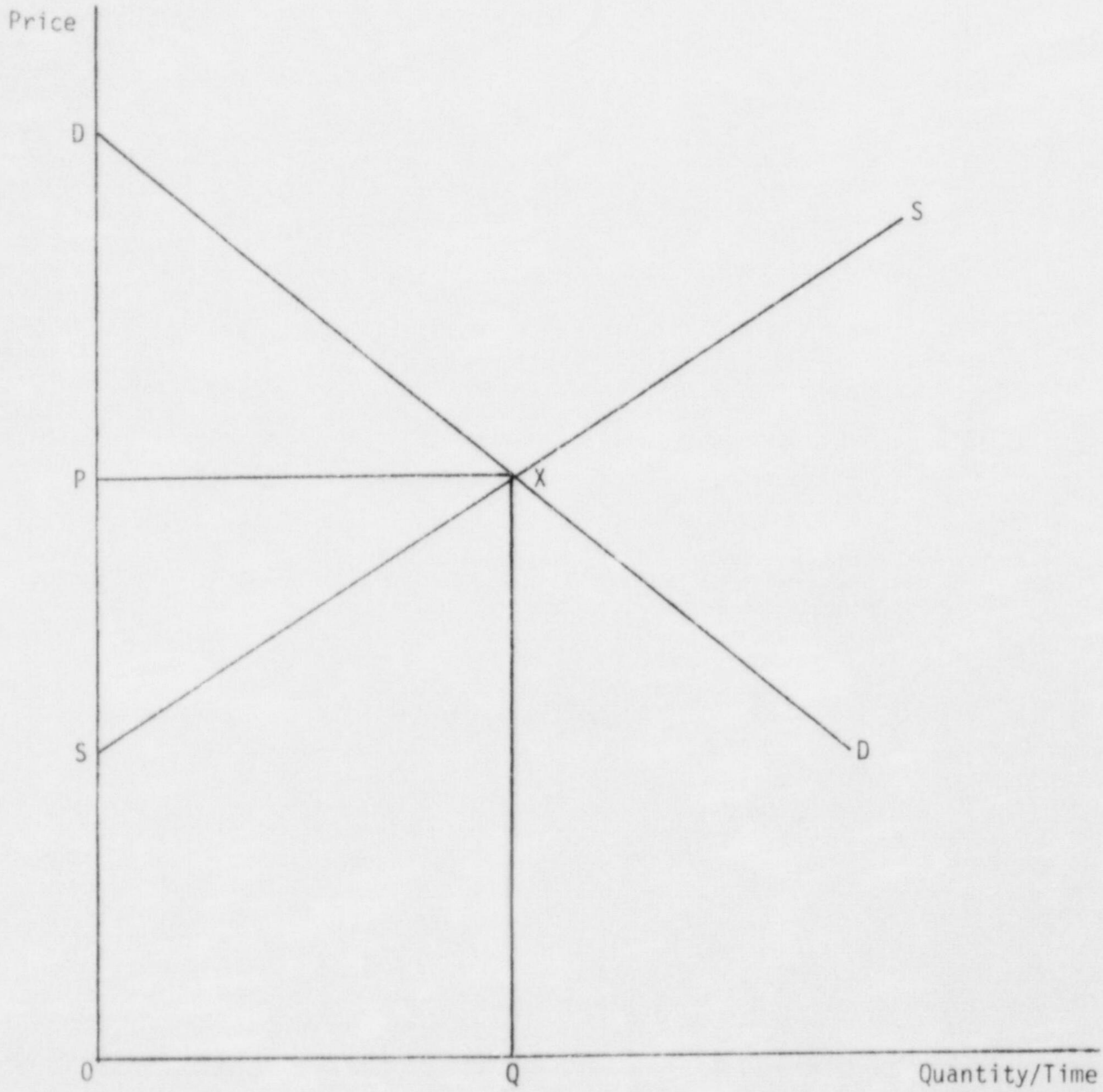



Figure B.1 Demand and Supply Concepts

the least. A net increase (decrease) in producers' surplus is to be counted as a social benefit (cost).

## B.6 SHADOW PRICES

The factor and product prices that would prevail in a perfectly competitive economy accurately reflect the marginal social costs of using these factors and products. In an economy that departs from this competitive ideal, prices may not reflect the true marginal costs of these resources. In such cases, it may be appropriate to use "shadow prices"--i.e., prices that reflect the correct marginal costs of the resources--rather than their observed market prices. For a more detailed discussion on the appropriate use of shadow prices, see (Mishan 1976, Chapters 13 and 14).

## B.7 DISCOUNT RATE

The discount rate is a concept that relates to the tradeoff between current and future consumption, or, as it is sometimes expressed, the time value of money. If money is saved rather than spent on current consumption, it can be invested in productive resources. Such investment enables consumption opportunities in future years to be enlarged. Because of these opportunities, individuals are not indifferent between present and future consumption; rather, they require a premium to forego current consumption, and the discount rate expresses this premium. Also, the required premium will be higher the more uncertain is the prospect for future consumption; that is, greater risk will mean a higher discount rate. The appropriate rate to use in discounting future costs and benefits associated with public policy is the subject of heated controversy. The interested reader is referred to (Mishan 1976, Chapters 31-33), (Treasury Board 1976, pp. 25ff) and (WAE Research Council 1968).

## B.8 EQUITY CONSIDERATIONS

As noted above, economic efficiency is concerned with providing the highest valued output for given resource inputs; but it is also impersonal with respect to how the output is distributed. On the other hand, while policymakers require information on the social costs and benefits likely to result from public policy, they must also be concerned with equity issues. Thus, an analysis based on efficiency considerations only provides part of the information that is needed to make good policy decisions. Since many of the important impacts that would result from a radiological accident involve major consequences or impacts that do not give rise to social costs, it is therefore desirable that an analysis of the distributional effects supplement the analysis based purely on social cost.

# APPENDIX C

# THE CRAC2 MODEL OF REACTOR ACCIDENT CONSEQUENCES

APPENDIX C

# THE CRAC2 MODEL OF REACTOR ACCIDENT CONSEQUENCES

The potential costs to society from an accidental, off-site release of radioactive materials from a nuclear reactor range from near zero for small quantity emissions to nearly catastrophic for a low probability but high quantity release. A computer code, CRAC2, has been developed for quantifying the major socioeconomic consequences of such accidents. This code was developed for the NRC, and it is based on the Reactor Safety Study (USNRC 1975), published in October of 1975. The Reactor Safety Study (RSS) along with the CRAC2 Users Guide (1982) contain partial information on the models used within CRAC2 to generate estimates of the effects of a power plant accident. CRAC2 is probably the primary tool used today by the NRC to assess the off-site health and economic consequences of severe radiological accidents at commercial reactor sites.

The original computer program, CRAC, was designed to be used for broad assessments of the potential consequences of reactor accidents. When the code was developed, it reflected the most up-to-date information regarding the physical parameters of a radiological accident and the resulting health effects. However, the original code was considered inadequate for evaluating site-specific accident consequences. CRAC was revised to improve its usefulness in the assessment of the consequences of reactor accidents, but CRAC2 contained little improvement over CRAC in its treatment of socioeconomic consequences.

The CRAC2 model is reviewed below to facilitate a clear understanding of the workings of the code. More specifically, we examine:

- the key assumptions underlying the CRAC2 model
- the procedures the model uses to assess the potential consequences of a radiological accident
- the types of results on health effects and socioeconomic impacts produced by CRAC2
- the strengths and potential weaknesses of CRAC2.

The sections that follow present an overview of the code based on the RSS and the CRAC2 Users Guide, the consequence estimates it provides and a critique of the model for evaluating site-specific accident consequences.

## C.1 OVERVIEW OF THE CRAC2 CODE

This section contains a review of the CRAC2 code. For purposes of our review, the accident consequence modeling process of CRAC2 has been divided into six major sections: description of the accident and site; dispersion of the released radionuclides; dose to humans; evacuation; contamination of property; and the estimation of resultant damages. Each of these six subjects is discussed in the subsections below.

### C.1.1 Accident Description

The first step required for the evaluation of reactor accident consequences using CRAC2 is the specification of the accident to be modeled. In the CRAC2 code, accident parameters are supplied in two input data sets; one data set, SITE (described under Site Description Parameters), supplies specific variables for the physical site and the other, ACCIDENT DESCRIPTION (described under Accident Description Parameters), contains the parameters for the isotopes released, isotope leakage, and inputs that are used in the dispersion model. The release and dispersion of the isotopes are calculated by CRAC2 based on these input values.

#### Site Description Parameters

Site description data characterize the physical site, the population dispersion, and a limited set of resource values and economic cost figures that are used to compute socioeconomic impacts. The actual release modeling in CRAC2 uses only the physical site inputs and the population data.

CRAC2 represents the potentially contaminated region via a circular grid as shown in Figure C.1. The grid is divided into 16 sectors, 22 1/2$^{o}$ wide, each of which is centered on a compass direction. The sectors are identified by numbers one through sixteen, traveling in a clockwise direction with sector number one centered over due north. The user may specify the number of spatial intervals (rings) in the grid, up to a maximum of 34, and the length of the radius of each interval. By selecting spatial intervals and sectors, the area elements can be identified and their precise location, property values, land area fractions, and population size specified. The assumption is made that the age distribution of the population within each element is equal to the U.S. population distribution.

Meteorological data can be input in two ways. Meteorological data for the accident site can be read from the meteorological data file (file code 27), or input by the user. The meteorological data file contains information on wind speed, wind direction, rainfall, and atmospheric stability for the entire site, for every hour of one year. The user may also input the meteorological data by spatial interval for one trial, or input 5 days of meteorological observations.

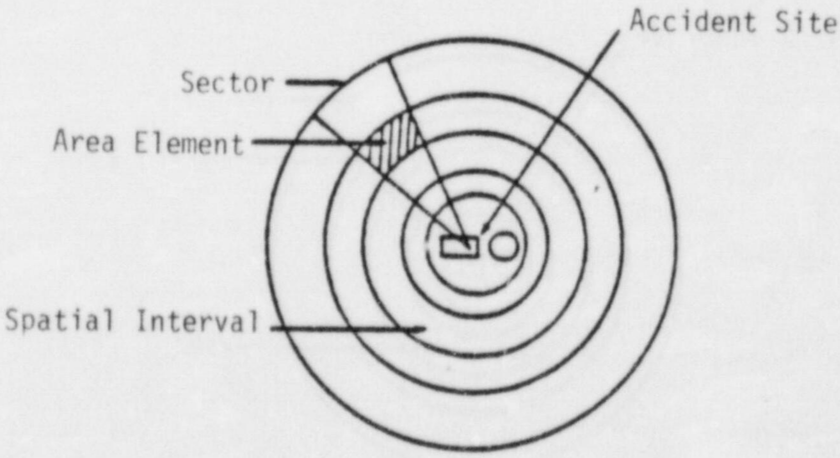



FIGURE C.1. Accident Area Diagram

Accident Description Parameters

The actual accident description data are input by the user and are divided into three groups: ISOTOPE, LEAKAGE, and DISPERSION. Possible radionuclides released may be selected from a list of 54 isotopes. Other isotope parameters are the name of the parent, the amount present in the reactor core at the time of the accident, half-life, and deposition velocity.

The data input category called LEAKAGE contains the descriptions of the physical processes involved in the accident. Up to 15 accident scenarios can be described by specifying the fraction of up to 10 isotope groups released in each scenario. These scenarios describe the system failures, steam bubble explosions, and airborne isotope releases. In addition, the leakage data include the probability (between zero and 1) associated with each accident scenario, the time elapsed between either shutdown or core melt and release of the radionuclides to the atmosphere, the duration of the release, the warning time (time between recognition of impending release to release event), the release height of the plume, and the sensible heat rate due to the thermal heat content of released gases.

The data input group called DISPERSION includes the reactor building dimensions and special wake and rain depletion options. Reactor building length and height are specified because they influence plume travel. If a plume is determined to be affected by building wake effects, the number of spatial intervals over which the effects dominate must be input by the user. Treatment of rain during the accident is also specified in the input at this point. Rainfall can be ignored, simulated from the meteorological data, or set at an incident level of 0.5 mm/hr and then substituted for all occurrences of rain in the meteorological data. Rainfall levels other than 0.5 mm/hr could be substituted by changing the code.

Calculation of the Accident Set

The total accident consequence set is computed as all combinations of the release of radioactive material associated with up to fifteen accident scenarios, weather data, and population distributions. The list of hypothetical accidents is then ranked to generate complementary cumulative distribution functions for each of the potential consequences.

A particular accident consequence can be determined by specifying one accident source term type, setting the probabilities of all others at zero, and using the other input data assumptions to run the code.

### C.1.2 Dispersion and Deposition

The transport of the released radioactive material from the reactor site to the surrounding area is calculated by an atmospheric dispersion model. Potential liquid effluent streams are not modeled by CRAC2. The dispersion model uses accident description, weather and reactor characteristic data as input. The outputs of the dispersion model are the air and ground concentrations of the specified radionuclides for sectors downwind of the accident site, as measured across time.

The primary process in the dispersion model is to describe the size and movement of the released plume over time. This is done by characterizing the plume at its release and monitoring its depletion by deposition and radioactive decay. Factors considered in the model include building wake effects, differences in release duration, buoyant rise of the plume, thermal atmospheric stability, mixing depth, and the growth of radioactive daughters of the released isotopes.

The disperion model used in the CRAC2 code is strictly an atmospheric dispersion model--transport of radionuclides via water or direct exposure is not addressed. Air contamination is calculated directly from the concentrations of radionuclides over time in the atmosphere in a downwind linear direction from the reactor. Ground contamination levels are the result of cloud depletion by wet and dry deposition of radionuclides. The level of ground contamination is used to calculate the economic costs and the health effects. The measurement of air and ground contamination is limited to those sectors downwind from the accident site.

Dry depletion in the CRAC2 model is assumed to proceed at all times at a constant deposition velocity. Particles and gases are treated the same, except in the case of the noble gases, which are assumed not to deposit (zero deposition velocity). Wet deposition is estimated with an exponential formula in CRAC2 that has different removal rates for stable and unstable atmospheric conditions, defined respectively as warm frontal storms and convective storms. Again, particles and gases receive identical treatment, with the exception of noble gases which are assumed not to be subject to wet depletion. The average rain duration is set at half the time specified for any hour of assigned precipitation from the meteorological data file. Any radioactive material remaining in the plume after it has reached the last specified interval is deposited at that interval to calculate the remaining population dose. However, an option exists whereby the user may redefine the last spacial interval to be 2000 miles with a population density of 78 persons/mile (the U.S. average). Any remaining radiation is assumed to be depleted by incidental rain within this interval. This option is usually used any time the plume does not dissipate before the last spacial interval.

### C.1.3 Dose to Humans - Dosimetry Model

CRAC2 translates environmental concentrations of radionuclides into human doses via a dosimetry model. Inputs to the dosimetry model are the air and ground contamination levels calculated by the dispersion model and dose conversion factors. The external exposure conversion factors were generated at Oak Ridge National Laboratory with the EXREM III computer program and tabulated for use in CRAC2. Internal exposure dose conversion factors were generated for two intake modes; inhalation and ingestion. The ICRP task group long model is used for inhalation with some changes in parameters to reflect more recent data. All doses are adjusted for the age of the individual exposed to allow for different health effects and different per unit mass doses.

#### External Dosage

External dosage is computed for two exposure pathways: exposure from the passing cloud, and exposure from ground contamination. The external dose from the passing cloud (cloud "shine") is assumed to be short term, and is calculated as the product of cloud concentration, time exposed, and gamma ray conversion factors. Only radiation from gamma rays is considered for short-term external exposure.

Exposure from ground-deposited radionuclides is assumed to occur in both the short and long term. The short-term external dose from ground contamination in CRAC2 is the product of the ground contamination level, time exposed, a shielding factor, and a dose conversion factor. The long-term dose calculation is similar, but it also considers the time-dependent concentration changes due to weathering and decay. Two additional assumptions are contained in the long-term dose model: 1) the penetration of nuclides into the soil is not disturbed by man (no tilling, etc.); and 2) negligible runoff removal of radionuclides from soil is assumed. Ground contamination dosage also includes the buildup and decay of daughters.

Internal Dosage

Three exposure pathways are explored by the CRAC2 model to assess internal exposure to radionuclides: inhalation during cloud passage, inhalation of resuspended particles, and ingestion of contaminated food products.

Inhalation of radionulides during cloud passage is a short-term dose in CRAC2. The dose, calculated as the product of exposure time, breathing rate, and the dose conversion factor, considers the particle size distribution, the chemical state of the radionuclides and the age of the individual. The age distribution is assumed to be the same as the U.S. distribution. The breathing rate is assumed to be constant for adults, but is adjusted for children. The most significant internal dosage is the dosage received by inhalation during cloud passage.

The inhalation of resuspended radionuclides (e.g., wind-driven dust) is a long-term phenomenon and is assumed by CRAC2 to contribute relatively little to the total body dose. The assumed resuspension factor is based on average populations in relatively well-vegetated areas, and is assumed to decrease with a constant half-life until it reaches a low level when it becomes constant. The dose calculation is similar to the model for inhalation during cloud passage with the addition of the resuspension factor.

Ingestion Dosage

A behavioral assumption is made that all contaminated crops are ingested. The dose to humans from consuming contaminated foods depends upon the contamination of the food and dairy products. The CRAC2 code considers vegetation contamination levels both from direct contamination (dry deposition) and the incorporation of contaminants from soil into vegetation. For direct contamination of vegetation, half of the deposited material initially retained on the vegetation is assumed to be present at consumption, with adjustments for weathering and decay. Also considered are effects of the various transport mechanisms to man on the level of contamination remaining.

For indirect contamination from soil, calculation of dosage is similar to the above, with consideration of rate of root uptake by crops and the rate of decrease of availability to the plants.

### C.1.4 Evacuation

One of the factors that determines individual radiation dosage in the CRAC2 model is the duration of exposure. This time factor, and consequently dosage of radiation, may be reduced if the population is evacuated from contaminated areas. The CRAC2 code contains an evacuation model that impacts the dosimetry and early health effects and subsequent calculations.

#### Evacuation Model Inputs

To support the CRAC2 evacuation modeling, an input data base is used to specify the parameters for the model and to supply the constants for sheltering, shielding and evacuation. Up to seven evacuation strategies can be adopted to construct a weighted evacuation scenario by specifying the probability of each strategy in the weighted scenario, the warning time, the evacuation speed, the maximum evacuation distance for those within the downwind sectors, and the maximum sheltering distance. The evacuees can beassumed to travel at constant speed or can be tracked in more detail, which allows for delays, shelter, and rate of movement variability. Also included as an input to the evacuation model is the exposure duration for people in non-evacuating intervals.

The shielding data, breathing rate data, evacuation cost data, and duration of exposure data do not change among evacuation strategies; they are constant for any single-weighted evacuation scenario. Cloud shielding, ground shielding, and breathing rate data can be input for both stationary and moving evacuees and for cases of sheltering and of no emergency action. The evacuation area can be assumed to have a keyhole shape. In this case it is necessary to specify the measurements of the keyhole shaped evacuation path: the radius of the circular evacuated area near the reactor, the width of the evacuation arc for downwind sectors, and the length of the keyhole. Individuals outside the keyhole are assumed not to evacuate. Other evacuation shapes are discussed in the next section. Direct evacuation costs per evacuee and the maximum release duration for which the keyhole model can be applied are also included in the input data set EVACUATE.

#### Evacuation Modeling

The CRAC evacuation model was developed using descriptions of evacuations for hurricanes, floods, and transportation accidents. The size of the evacuation area is determined by the type of radioactive leakage, and the duration of its release. The user specifies the maximum release duration for which the keyhole evacuation strategy will hold. If the duration of the release is greater than this input value, all sectors will be evacuated to allow for possible changes in wind directon. Otherwise, the evacuation area will have a keyhole shape similar to Figure C.2 with dimensions determined by user input (EVACU subgroup).

In general, acute health effects appear within a year after large, acute doses of radionuclides; usually the effects are evident within days or weeks. The ACUTE data set specifies the affected body organs, the probabilities of dosage levels, and the mortality factors associated with the organ dosages.

Latent effects also result from early doses of radiation, but generally do not appear until years after the initial exposure. In radiation therapy experience, these effects, primarily latent cancers and thyroid nodules, are usually observed 2 to 30 years after exposure. The LATENT data set includes the specification of the affected organ, the number of time periods needed to calculate the latent effect, the name of the latent effect, dose effectiveness factors, and man-rem conversion factors.

Chronic health effects include health effects resulting from later, chronic radiation exposure and genetic effects that occur not in the irradiated individuals, but in their descendants. Data in the CHRONIC set takes into consideration six exposure mechanisms: 1) inhalation of resuspended particles; 2) ingestion of exposed crops; 3) ingestion of milk products; 4) ingestion of milk: 5) ingestion of crops contaminiated via root uptake; and 6) exposure to contaminated ground. With this data set, the CRAC2 user can input factors that allow for protection in the exposure mechanism, maximum allowable doses, weathering half-life for isotopes on each exposure pathway, dose conversion factors, and concentration factors relating ground contamination to intake of isotopes from crops and milk.

Health Effects Modeling

The CRAC health effects model considers three levels of health effects: acute effects; latent effects that are limited to latent cancers; and chronic effects. For each health effect level, mortality and morbidities are estimated. Thirteen body organs, listed in Table C.1, are specified to describe the body effects. Other body organs are not used to estimate health effects.

Table C.1. Organs Considered in the CRAC2 Model

| Subroutine Name | Description |
|---|---|
| 1. LUNG | Lungs |
| 2. T MARROW | Total bone marrow |
| 3. SKELETON | Skeletal bone |
| 4. T E C L | Total endosteal cells (interior bone surface) |
| 5. ST WALL | Stomach wall |
| 6. SI+CONT | Small intestine and contents |
| 7. ULI WALL | Upper large intestine wall |
| 8. LLI WALL | Lower large intestine wall |
| 9. THYROID | Thyroid |
| 10. OTHER | Tissues other than lungs, bone marrow, walls of G.I. track, and thyroid |
| 11. W BODY | Whole body |
| 12. TESTES | Testes |
| 13. OVARIES | Ovaries |

Different levels of medical treatment to mitigate the effects to the organ can be considered for acute, latent and chronic effects, but synergistic relationships between organs can not. All medical treatment must be contained in the user's input parameters. For example, for simulation of potassium iodine treatment, adjustments are made in dose conversion factors which result in a lower incidence of health effects for a given level of radiation. Alternatively, the user could change the dosage threshold values. These input values are the probability of death associated with a given level of radiation.

There are two problems with the way CRAC2 adjusts for different treatment levels. First, the simulation of treatment can currently only be performed by manipulation of the input parameters; the adjustment is through modification of the input health effects response functions. Secondly, the costs of the health treatment are not included in the economic costs of the accident; thus, the model underestimates the monetary costs of an accident.

Acute Effects Modeling

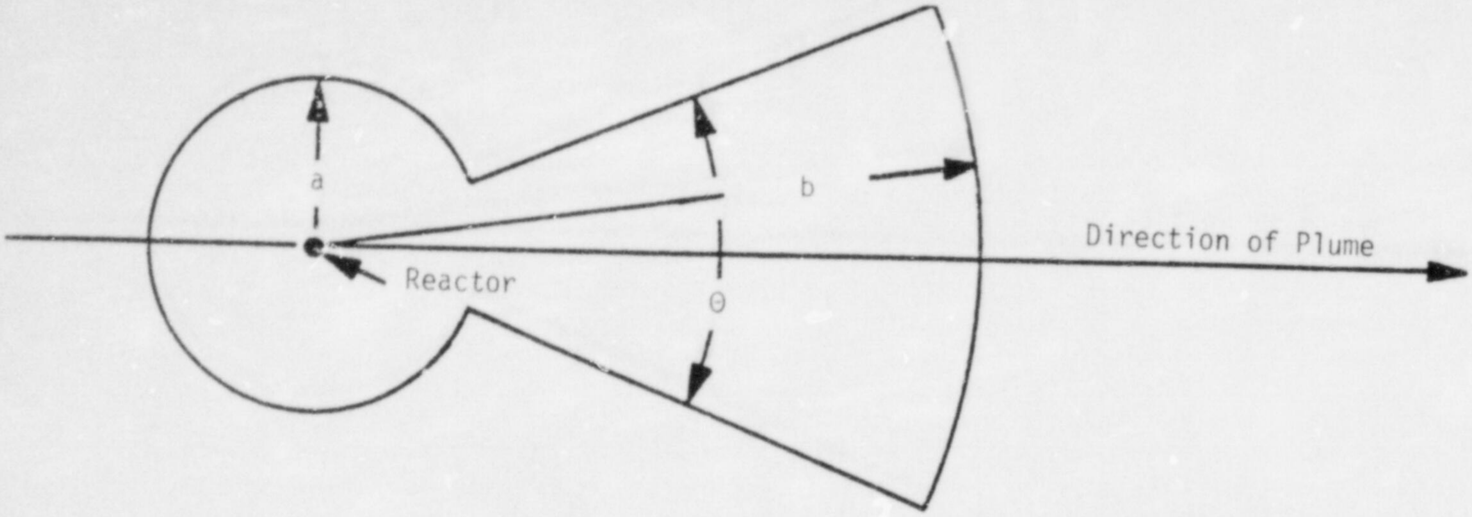
For every organ considered, the acute effects modeling accumulates the dose from each radionuclide. Three exposure paths--cloud shine, inhalation, and ground exposure--are calculated separately and summed together for the total dose to the organ.

Mortality factors are applied to the cumulative dosages in different organs to compute the total number of fatalities and morbidities. The output for acute health effects includes statistical parameters for the following results:

- o Number of acute fatalities occurring within one year due to initial exposure to radioactive cloud
- o Number of acute injuries/illnesses occurring within one year due to initial exposure to radioactive cloud
- o Number of people with an acute bone marrow dose greater than 200 rems; includes people counted as acute fatalities
- o Probability of incurring a fatality within one year due to initial exposure to radioactive cloud at midpoint of interval specified
- o Greatest distance from the reactor at which acute fatalities occur
- o Probability of incurring an injury/illness within one year due to initial exposure to radioactive cloud at midpoint of interval specified
- o Greatest distance from reactor at which acute injuries occur.

Latent Effects Modeling

In the CRAC2 health effects model, latent effects modeling is limited to latent cancers and benign thyroid nodules. Latent effects are treated as phenomena where the probability of occurrence to an individual is some function of the dose received; they are measured as the increase in the incidence of post-accident latent cancers relative to pre-exposure incidence.




X-Radius of area near reactor to be evacuated (meters)
O-Angle of evacuation for downwind sector (degrees)
Y-Maximum evacuation distance

FIGURE C.2. Keyhole Evacuation Area

To calculate the doses to individuals in the evacuation area, people are postulated to move radially away from the reactor at a specified effective evacuation speed that is constant for all evacuees regardless of proximity to the accident site. Ten miles per hour is commonly used as the CRAC2 model evacuation speed. If the cloud should overtake the evacuees en route, it is assumed they will turn and travel circumferentially around the grid. CRAC2 makes no allowances for blocked evacuation paths from either site-specific topography or cloud contamination. To achieve an evacuation scenario with different evacuation delays, weights proportional to the percent of people leaving after specified delay times can be assigned to the evacuation strategies which assume these delay times. To allow for the percent of people who do not participate in the evacuation, a weight can be assigned to the evacuation scenario in which no evacuation takes place.

Evacuation Model Output

Output from the evacuation model includes an estimate of evacuation costs determined by the type of evacuation strategy used, the total area evacuated and the distance traveled by the evacuees. The model also determines where people are caught by the plume, and the total amount of radiation dose they receive.

### C.1.5 Property Contamination

In the CRAC2 model, levels of property contamination are assigned from the ground contamination levels computed by the dispersion model. Contaminated property raises the basic issue of protecting humans from contamination while maintaining as much of the value and productivity of the land as possible. According to standard acceptable radiation levels, property is not treated if radiation levels are sufficiently low. The property is decontaminated if radiation levels are too high for for the land to be used without decontamination and decontamination is economically feasible; otherwise, the property is interdicted.

The time period of land interdiction in the CRAC2 code depends upon the degree of contamination resulting from the accident in comparison with prespecified dose limits. In CRAC2, interdiction may involve all land and assets for more than 10 years, it may be limited to particular areas or assets for less than 10 years, or it may involve the impoundment and disposal of crops and/or milk.

The CRAC2 decontamination calculations involve a decontamination factor: this factor is equal to the contaminant density before decontamination divided by the contaminant density after decontamination. Maximum acceptable radiation levels are calculated by CRAC2 based on: 1) the per-person radiation limits, 2) the half-life of each isotope, and 3) the number of days of exposure necessary to reach (1). Each of these may be specified by the user. CRAC2 assumes that the actual decontamination factor attained is just sufficient to reduce ground contamination levels to the maximum acceptable level. The maximum decontamination factor considered practical is 20 in the CRAC documentation; the code assumes that it is economically feasible to decontaminate if the ratio is less than 20. Decontamination procedures are limited to roofs, paved surfaces, lawns and agricultural lands. These include replacement of roofing materials, sandblasting and resurfacing of pavements, vegetation removal and disposal, surface soil removal and burial, and deep plowing.

## C.2 SOCIOECONOMIC COST ESTIMATES

The outputs of the CRAC2 modeling process are estimates of the damages to both people and property that result from the hypothetical reactor accident. These damages, or socioeconomic costs, are calculated by two submodels in the CRAC2 code: a health effects model is used to compute the damage to the population's health, and a property damage model computes the costs of interdiction, decontamination, evacuation, and relocation. For each result in the CRAC2 output, the mean, variance, nonzero probability, peak value, peak value probability, and complementary cumulative distributions are supplied.

### C.2.1 Health Effects Model

The CRAC2 health effects model translates doses of radiation into resultant effects on human health. The health effects model is based on clinical and experimental data of both the short- and long-run effects of radiation on the human body. These effects are grouped as acute, latent, and chronic depending upon the time relationship between exposure and manifestation of the effect. The health effects model requires the user to make assumptions about the level of health monitoring and treatment. However, dollar values are not attached to either the health treatment or the health effects in the CRAC2 code, only the incidence of particular health effects is calculated.

#### Health Effects Model Inputs

In the CRAC2 code, inputs to the health effects model are the dosages calculated by the dosimetry models and three input data sets: ACUTE, LATENT, and CHRONIC. Each of these data sets contains parameters specific to its class of health effects, identified by the response time of body organs to the exposure of radionuclides.

In general, acute health effects appear within a year after large, acute doses of radionuclides; usually the effects are evident within days or weeks. The ACUTE data set specifies the affected body organs, the probabilities of dosage levels, and the mortality factors associated with the organ dosages.

Latent effects also result from early doses of radiation, but generally do not appear until years after the initial exposure. In radiation therapy experience, these effects, primarily latent cancers and thyroid nodules, are usually observed 2 to 30 years after exposure. The LATENT data set includes the specification of the affected organ, the number of time periods needed to calculate the latent effect, the name of the latent effect, dose effectivencss factors, and man-rem conversion factors.

Chronic health effects include health effects resulting from later, chronic radiation exposure and genetic effects that occur not in the irradiated individuals, but in their descendants. Data in the CHRONIC set takes into consideration six exposure mechanisms: 1) inhalation of resuspended particles; 2) ingestion of exposed crops; 3) ingestion of milk products; 4) ingestion of milk: 5) ingestion of crops contaminiated via root uptake; and 6) exposure to contaminated ground. With this data set, the CRAC2 user can input factors that allow for protection in the exposure mechanism, maximum allowable doses, weathering half-life for isotopes on each exposure pathway, dose conversion factors, and concentration factors relating ground contamination to intake of isotopes from crops and milk.

Health Effects Modeling

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| 10. OTHER | Tissues other than lungs, bone marrow, walls of G.I. track, and thyroid |
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Different levels of medical treatment to mitigate the effects to the organ can be considered for acute, latent and chronic effects, but synergistic relationships between organs can not. All medical treatment must be contained in the user's input parameters. For example, for simulation of potassium iodine treatment, adjustments are made in dose conversion factors which result in a lower incidence of health effects for a given level of radiation. Alternatively, the user could change the dosage threshold values. These input values are the probability of death associated with a given level of radiation.

There are two problems with the way CRAC2 adjusts for different treatment levels. First, the simulation of treatment can currently only be performed by manipulation of the input parameters; the adjustment is through modification of the input health effects response functions. Secondly, the costs of the health treatment are not included in the economic costs of the accident; thus, the model underestimates the monetary costs of an accident.

## Acute Effects Modeling

For every organ considered, the acute effects modeling accumulates the dose from each radionuclide. Three exposure paths--cloud shine, inhalation, and ground exposure--are calculated separately and summed together for the total dose to the organ.

Mortality factors are applied to the cumulative dosages in different organs to compute the total number of fatalities and morbidities. The output for acute health effects includes statistical parameters for the following results:

- Number of acute fatalities occurring within one year due to initial exposure to radioactive cloud
- Number of acute injuries/illnesses occurring within one year due to initial exposure to radioactive cloud
- Number of people with an acute bone marrow dose greater than 200 rems; includes people counted as acute fatalities
- Probability of incurring a fatality within one year due to initial exposure to radioactive cloud at midpoint of interval specified
- Greatest distance from the reactor at which acute fatalities occur
- Probability of incurring an injury/illness within one year due to initial exposure to radioactive cloud at midpoint of interval specified
- Greatest distance from reactor at which acute injuries occur.

## Latent Effects Modeling

In the CRAC2 health effects model, latent effects modeling is limited to latent cancers and benign thyroid nodules. Latent effects are treated as phenomena where the probability of occurrence to an individual is some function of the dose received; they are measured as the increase in the incidence of post-accident latent cancers relative to pre-exposure incidence.

CRAC2 makes three estimates of the number of latent cancers: an upper bound, based on a National Academy of Sciences study (NAS 1980); a central estimate, adjusted with dose-effectiveness factors; and a lower bound obtained by applying a dose threshold value below which no effects are presumed to occur. The upper bound is based on a linear, no-threshold model that assumes all risks of somatic effects are proportional to the dose received. This upper bound model also contains adjustments for age and duration of exposure. The central estimates consider dose effectiveness factors and are calculated based on the initial dose rate (dose rate of first 30 days); the whole dose is assumed to be received at the initial dose rate.

Thyroid nodules and cancers are treated separately in the CRAC2 health effects modeling. A 10 percent mortality rate is assumed for thyroid cancers. The average latency period is 10 years and the plateau period averages 30 years. No mortality is assumed to occur more than 30 years after the accident. Results from the latent effects modeling include:

- total latent effects occurring due to initial exposure to the radioactive cloud
- total latent effects occurring due to both initial and chronic exposure
- whole body population dose
- risk of incurring cancer due to initial exposure to the radioactive cloud at the midpoint of the interval specified
- number of specified "latent effects" incurred due to initial exposure to the radioactive cloud
- number of specified "latent effects" incurred due to both initial and chronic exposure.

#### Chronic Effects Modeling

Chronic doses are calculated from exposure to contaminated ground, from inhalation of resuspended particles, and from the ingestion of radionuclides. The chronic effects modeling takes into account the nature of the population exposed and the amounts and distribution of the exposure. In the modeling of genetic effects, only major genetic disorders are considered. At present, genetic effects are not specified in the output results.

### C.2.2 Economic Model

The CRAC2 economic model estimates the direct costs of: 1) evacuation and relocation for the evacuees, 2) the value of goods condemned, 3) decreased value of interdicted property, and 4) decontaminating property. These costs depend upon the extent to which evacuation, interdiction, and decontamination are applied, which depends upon the nature of the contamination, the amount of human exposure, and the standards for acceptable exposure levels. The socioeconomic costs associated with the above activities are estimated in dollar terms by CRAC2.

Economic Model Inputs

The CRAC2 economic model uses the ground-level contamination levels as a measure of radiation damages to property. Other inputs are supplied through the input data subgroup ECONOMIC, found in the group data set of site description parameters. The site description inputs are at the area element level (see Figure C.1). The ECONOMIC data set must include the following inputs: decontamination costs for farm areas and for residential, business and public areas; compensation rate per year for and value of residential, business and public areas; relocation costs; and the costs of milk and nondairy products consumption. Other input parameters are the seeding and harvesting months, the fraction of land devoted to farming, the fraction of farm sales, and the average farmland value. These values are also at the area element level, but the user is limited to 54 sets of values. The sets of values were originally conceived to be state values (the 54 values included several Canadian provinces and Mexican states), thus limiting the input values to statewide averages. The sets are still referred to as "states." However, the inputs can be any collection of 54 sets of values. The user can specify at most one state for each element. For example, the user can specify State 1 for an area element. That element uses the seeding and harvesting months, the fraction of land devoted to farming, the fraction of farm sales, and the average farmland values associated with State 1. The next element can be assigned input values from State 2. Except for the decontamination of farm land and the compensation rates, which are in dollars per acre, all costs are in dollars per person.

Economic Effects Modeling

The CRAC2 economic modeling process divides the costs of decontamination, interdiction, evacuation and relocation into two groups, according to the exposure time frame. In the early exposure phase, the contaminated area is assumed to be keyhole shaped, and crops and milk in contaminated areas are condemned for the local growing season. Total costs for this phase are the costs of evacuation plus the value of the crops and milk condemned. In the chronic exposure phase, interdiction and decontamination choices are made, resulting in costs equal to the lost value of public and private property plus lost income. The costs in the chronic exposure phase also include the costs of relocating displaced members of the affected population.

Costs of Acute Exposure Phase

In the CRAC2 code, the direct costs of the early exposure phase are equal to the costs of evacuation and condemned crops. Evacuation costs include the management of the evacuation, transportation costs, temporary food and shelter, and the costs of securing property prior to the actual evacuation.

In measuring the value of crops in contaminated areas, CRAC2 considers both the original deposition and the diminishing strength of the deposit between the time of the accident and harvest. If contamination levels are within the prescribed standards, or if deposition of radionuclides occurs during the dormant season, crops and milk are not counted as lost. If crops are lost, costs are generated using current price data.

Costs of the Chronic Exposure Phase

Three basic cost categories are summed to compute total costs for the chronic exposure phase: decontamination costs, interdiction costs and relocation costs. Costs of decontamination are computed separately for farmland and developed land, with the developed land category including housing and commercial, industrial and public property. Different decontamination techniques may be utilized, depending upon the level of contamination; these techniques are usually limited to the roofs of buildings, when buildings are involved. To determine the costs of decontamination, the user must specify the level of decontamination to be achieved, and the cost per acre for farmland along with the cost per person for residential, business and public areas necessary to reach that level of decontamination.

The costs of interdiction are calculated by the CRAC2 model as the market value of the property before interdiction, including the value of both the land and any improvements. Also included are the costs of holding the property estimated by a discount rate, and the costs of taxes paid. The model assumes land will regain its pre-accident value, adjusted for inflation, once the interdiction period is over, but allows for the depreciation of improvements at a rate supplied by the user.

In the economic model, the cost of relocating displaced members of the affected population is input, and is assumed to equal lost income plus moving expenses for both the residential and business sectors. The Reactor Safety Study (WASH 1400) includes a methodology for estimating these costs. In WASH 1400, income lost is usually based on a six-month relocation period. Moving costs for the residential sector are based on 10,000 pounds of personal property moved 50-100 miles; moving costs for the commercial and public sectors are based on 10 percent of the value of equipment and inventory. However, the user may supply any value for the cost of relocating.

TABLE C.2. Economic Input Parameters Required for CRAC2

| Parameter Name | Unit of Measure |
|---|---|
| Decontamination Cost for Farms | $/acre |
| Decontamination Cost for Residential, Business, and Public Areas | $/person |
| Compensation Rate | % of value |
| Value of Residential, Business, and Public Areas | $/person |
| Relocation Costs | $/person |
| Cost of Milk Consumption | $/person |
| Cost of Non-Dairy Products Consumed | $/person |

The specific results produced by the CRAC2 economic model are as follows:

- number of people formerly occupying permanently interdicted land
- cost of permanent land interdiction (sum of land interdiction cost and relocation cost, assuming cost-effective decontamination measures are undertaken)
- total land area from which people are permanently interdicted
- maximum distance from reactor at which land is permanently interdicted
- number of people occupying the area which may be decontaminated within a period of 30 years
- cost of recovery of land contaminated above limits for occupancy but below limits for permanent interdiction
- total land area from which people are temporarily interdicted
- maximum distance from the reactor at which land is temporarily interdicted
- cost of disposal of contaminated crops
- total land area in which only crops are interdicted
- probability of interdicting crops at the midpoint of the interval specified
- cost of disposal of contaminated milk
- total land area for the interdiction of milk only
- maximum distance from the reactor at which milk is interdicted
- cost of relocating people occupying the permanently interdicted area
- cost of evacuating people according to last evacuation scheme specified in data subgroup EVACUATE
- total accident cost with no decontamination
- total accident cost with decontamination.

# APPENDIX D

# DEVELOPMENT OF INPUT VALUES FOR CRAC2

# APPENDIX D

## DEVELOPMENT OF INPUT VALUES FOR CRAC2

To date, results from CRAC2 have been derived primarily from inputs based on generic or national average information. It seems likely that CRAC2's accuracy could be significantly improved by using site-specific input values. In this appendix, we describe how the Site Analysis Branch (SAB) of the Division of Engineering in the NRC's Office of Nuclear Regulation has obtained site-specific information for use with CRAC2. For the variables shown in Table D.1, the user has the option of including site-specific information or relying on statewide averages.

TABLE D.1. CRAC2 Economic Input Parameters

| PARAMETER | UNIT |
|---|---|
| Value of Developed Property | \$/person |
| Depreciation Rate | fraction |
| Relocation Costs | \$/person |
| Decontamination Costs for Developed Property | \$/person |
| Decontamination Costs for Farmland | \$/acre |
| Evacuation Costs | \$/person/week |
| Annual Expenditure for Dairy Products | \$/person/year |
| Annual Expenditure for Nondairy Food Products | \$/person/year |
| Fraction of Land in Farmland | fraction |
| Fraction of Dairy Products | fraction |
| Sales of Farm Products | \$/acre |
| Value of Farmland | \$/acre |

## Value of Developed Property [1]

The per capita value of developed property is an important parameter used in CRAC2 to estimate the costs of interdicting property. The estimate includes the value of residential, industrial, business and public property. Since accurate data on the value of all these property types, especially public property, are rarely published, we rely on several sources of data to obtain estimates for specific sites. The steps in estimating a per capita value of developed property are outlined below.

Step 1: Determine the Appropriate Counties

Since interdiction would normally affect only areas fairly close to the plant, we have based our property value estimates on counties within 10 miles of each site. Typically, there are only a few counties having most of their population within 10 miles of the reactor site.

Step 2: Obtain Estimates of the Market Value of Taxable Property

Several sources, including state and local governments, collect this type of information. We have used a U.S. Census publication, 1977 Census of Governments, Volume 2, Taxable Property Values and Assessment/Sales Price Ratios. This is a survey of total assessed valuation of property and the results of a sample indicating ratios of assessed to market values. Unfortunately, the Census of Governments does not contain property values for all counties. If, for a specific plant, some counties were not included, we used only the included counties to calculate our input parameter. In cases where none of the counties within 10 miles are included in the Census of Governments, we recommend using the closest available county with income patterns resembling those in the counties surrounding the reactor.

Step 3: Estimate Market Value of All Property

To obtain an estimate of the market value of all property--including non-taxed property--we multiply the market value of taxable property (Step 2) by the U.S. ratio of the value of all property to the market value of all taxed property. This ratio is based on data reported in U.S. Department of Commerce 1980b (Table 790), and U.S. Department of Commerce 1977; the ratio, which is estimated to be 1.95, can be computed only for the entire U.S. Thus, we multiply our estimate from Step 2 by 1.95 to obtain an estimate of the market value of all property.

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[1] The following sections on CRAC2 input parameters assume basic understanding and knowledge of how CRAC2 estimates the economic consequences of an accident. This background is contained in USNRC 1975 (Appendices J and K).

Step 4: Convert to a Per-Capita Estimate in 1980 Dollars

We first multiply our estimate from Step 3 by the ratio of home purchase prices in 1980 to prices in 1977 (Economic Report of the President 1983; Table B-53). We then divide by the 1980 county population estimates from the U.S. Census.

Depreciation Rate on Improvements

A severe accident might require interdiction of property for several years. During this time, the property and any improvements would likely receive minimal maintenance. For that reason, the Reactor Safety Study used a value of 20 percent as the depreciation rate on improvements. The Study states that 20 percent might be too high for short periods, but could be offset by other costs not directly included (USNRC 1975, Appendix VI, pp. 12-7). We have followed the Reactor Safety Study and have used the 20 percent rate.

Relocation Costs

Relocation costs, as defined and used in the Reactor Safety Study, include two factors: loss of income and moving costs. Each of these can be subdivided into other factors to estimate site-specific relocation costs. For example, loss of income includes lost "local" income and lost corporate income. Moving costs include the costs of relocating residences, businesses and public facilities. Our estimation procedure for loss of income and moving costs is described below.

We define "local" personal income to include earnings and proprietors' and rental income, but to exclude dividends and interest income. We have used a BEA publication, Local Area Personal Income: 1975-80, for estimating lost local personal income by county, including the rental income component. Total labor and proprietors' income by place of work for each county within 10 miles of the plant is used as well as an estimate of lost rental income. We multiply the sum of rental, dividend and interest income by the national ratio of rental income to the total of rental, dividend, and interest income. This ratio is 0.1056 (Economic Report of the President 1982, Table B-22). We divide this figure by the county population from the 1980 Census. This rental income would be lost only during the period of resettlement.

We use the average duration of unemployment to approximate the length of the resettlement period. Since the average length of unemployment from 1970 to 1980 was about 12 weeks (Economic Report of the President 1982, Table B-34), we multiply the annual per capita figure by 12/52. For example, if the sum of per capita labor and proprietors' income is $8000 and the rental estimate is $800, we would multiply 8800 by 12/52 (= $2031) to obtain an estimate of per capita local personal income losses.

Lost corporate income is added to the lost local personal income. Lost corporate income is estimated using national figures since local estimates of corporate profits are not available. The RSS assumes lost corporate income is the sum of lost income plus depreciation (a noncash-flow item) and interest paid. Table D.2 shows the items and relevant sources.

TABLE D.2. Sources for Lost Corporate Income

| Item | Source |
|---|---|
| Corporate Income | Economic Report of the President 1982, Table B-21 |
| Depreciation | Economic Report of the President 1982, Table B-12 |
| Interest Paid | Statistical Abstract - 1980, Table 948. (Escalated to 1980 level) |

Using these sources, we estimate the 1980 value for per-capita corporate income at $2720 per person. We follow the RSS methodology of assuming this income is lost for six months. Thus, we use $1360 in our calculations for relocation costs.[2]

In addition to lost local personal and corporate income, relocation costs also include moving costs for residences, corporations and the public sector. Estimates for these moving costs are in the RSS although they are in 1975 dollars. We have followed the RSS and estimated a single value for relocation costs that can be applied to any plant site. Our re-estimate in 1980 dollars of the RSS moving costs, using the original assumptions, is about $1285 per person. This is composed of separate estimates of $400 for residential moves, $730 for business moves, and $155 for public-sector moves.

As described above, we estimate only lost local personal income on a county (or site-specific) basis. To obtain relocation costs, we add lost corporate income ($1360 per person) and moving costs ($1285 per person). In retrospect, some improvement could be made by scaling the moving costs by a ratio of local labor costs to a national average labor cost. However, we did not attempt this because resources were not available for determining what fraction of moving expenses might be sensitive to local labor conditions.

## Decontamination Costs

Two decontamination cost estimates are used as inputs to CRAC2. First, a value expressed in dollars-per-person is required for developed property. This includes residential, public and commercial property. The second decontamination cost is a value, expressed in dollars-per-acre, for farmland and undeveloped property.

Estimates of these costs are available from CRAC2 documentation. To date we have used these estimates, adjusted to 1980 dollars, using a cost index for construction costs (U.S. Department of Commerce 1982, Composite Index). These values are $4705 per person for developed property and $535 per acre for

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[2] Review the testimony of Ronald J. Nesse on Site-Specific Economic Input Parameters (Indian Point), Docket Nos. 50-247-SP and 50-286-SP

undeveloped land and farmland. Again, as with relocation costs, these values could be made site-specific by using relative wage rates to adjust the national estimates. However, this would entail a major effort to determine which costs might vary across sites.

## Evacuation Costs

Estimates in the RSS of per capita evacuation costs are based on estimates of the large number of expenses and costs likely to occur during an evacuation. The description of what is assumed to take place during an evacuation is contained in Appendix VI of the RSS and is not repeated in this report. Using essentially the same set of assumptions, we "built up" estimates of evacuation costs based on an assumed seven-day evacuation period. Our estimates, in 1980 dollars, are $225 per person.

## Annual Expenditures on Dairy and Nondairy Food Products

CRAC2 uses expenditures on dairy and nondairy food products to estimate health effects from ingesting contaminated foods. These values are not used in estimating any of the economic effects. The figures of $165 per person and $1025 per person for dairy and nondairy products, respectively, were obtained from U.S. Department of Commerce 1980b (Table 1236 and Table 2) by dividing total civilian expenditures on each category by total civilian population.

## Agricultural Impacts

CRAC2 utilizes 1) fraction of land in farmland, 2) fraction of dairy products, 3) sales of farm products, and 4) value of farmland in evaluating the loss of agricultural products due to a nuclear power plant accident. The RSS and, until recently, most users of CRAC2 have used statewide averages as the values for these variables. Since agricultural production and land values can vary greatly within the same state, using county averages can greatly improve the accuracy of the CRAC2 results. Unfortunately, CRAC2 can accept data from only a total of approximately 55 political subdivisions. Thus, we recommend using county data out to around 60 or 70 miles (depending on the size of the counties), and statewide averages out to 350 or 500 miles. This procedure will usually result in a total of around 40-50 political subdivisions.

The source for calculating the agricultural input parameters is the 1978 Census of Agriculture. There are individual volumes for each state, and county totals are provided in a section entitled "County Summary Data." The Census contains a wealth of county-level agricultural information. Most values for CRAC2 are obtainable either directly from the Census or require relatively simple calculations with the Census values.

The percent of land area devoted to farming is available by county in U.S. Department of Commerce 1980a (Table 1). Statistics are given for all farms and for farms with sales of $2500 or more. We have used the estimate based on all farms.

The average value (per acre) of all farmland and buildings can also be read directly from Table 1 (U.S. Department of Commerce 1980a). The value is in 1978 dollars and, therefore, must be escalated to 1980 dollars. The procedure for adjusting to 1980 dollars is described later in this section.

The per-acre market value of agricultural products sold is obtained by making the simple calculation of dividing the total market value of agricultural products by the total number of acres. The total value of agricultural products is found in U.S. Department of Commerce 1980a (Table 10). The total acres is found in Table 1. Again, we use total acres for all farms and not just those with over $2500 in agricultural sales.

The ratio of dairy sales to total agricultural sales is obtained by dividing the value of dairy products by the total value of agricultural products. The value of dairy products, by county, is in U.S Department of Commerce 1980a (Table 16, part 6). The total value of agricultural products is obtained for the per-acre value of agricultural products (Table 10).

Since the values in the Census of Agriculture are in 1978 dollars, the agricultural values described above need to be adjusted to 1980 dollars. The average per acre farm values are adjusted to 1980 dollars by multiplying by the ratio of farm real estate prices in 1980 to the corresponding value for 1978 (Economic Report of the President 1982, Table B-97). Similarly, multiplying the annual per acre sales of farm products by the ratio of cash marketing receipts in 1980 to the same value for 1978 (Economic Report of the President 1982, Table B-94) yields the proper adjustment to 1980 dollars.

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This report identifies and characterizes the off-site socioeconomic consequences that would likely result from a severe radiological accident at a nuclear power plant. The types of impacts that are addressed include economic impacts, health impacts, social/psychological impacts and institutional impacts. These impacts are identified for each of several phases of a reactor accident--from the warning phase through the post-resettlement phase. The relative importance of the impact during each accident phase and the degree to which the impact can be predicted are indicated. The report also examines the methods that are currently used for assessing nuclear reactor accidents, including development of accident scenarios and the estimating of socioeconomic accident consequences with various models. Finally, a critical evaluation is made regarding the use of impact analyses in estimating the contribution of socioeconomic consequences to nuclear accident reactor accident risk.

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