THREE MILE ISLAND NUCLEAR ACCIDENT AND ITS EFFECT ON THE SURROUNDING POPULATION

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January, 1984

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Introduction:

On the morning of March 28, 1979, a series of "unlikely events" at the Three Mile Island (TMI) nuclear plant led to a loss-of-coolant accident which became the most serious accident yet to occur in commercial nuclear power generation (1). For several hours after the reactor first tripped, the reactor core was allowed to overheat. Up to 10 million curies of radioactivity have been estimated to have escaped into the atmosphere during a tense week of worldwide concern over the fate of the nuclear plant and its surrounding population (2-3).

The maximum possible dose to a hypothetical person standing unprotected anywhere along the border of the plant site for the duration of the accident was estimated as no more than 100 millirems (4), the approximate equivalent of one year natural background radiation in the area. The average likely dose to persons living within 5 miles of the plant was estimated at 9 millirems (5). At these low doses of radiation, no major health effects on the exposed population can be expected. The long-term health effects from the TMI radiation exposure to the more than 2,164,000 persons living within 50 miles of the plant at that time was projected as one excess cancer death over the lifetimes of these residents. The total number of excess health effects from TMI radiation, including all cases of cancer (fatal and nonfatal) and genetic ill health to all future generations, was estimated as two (4).

Despite these radiation estimates and learned opinions of several technical groups, including those from government, industry, national laboratories and universities, substantial amount of anxiety was created and resultant apprehension remained in the area. The public questioned the validity of the estimated radiation dose to local residents and also the health risk

from that dose. The apprehension was due, in part, to the fact that radiation is invisible and its effects potentially pernicious. It was felt that even nonlethal doses are capable of causing immediate detrimental effects, especially on the unborn and the very young, as well as latent cancers and other chronic conditions. Many local residents actually believed that they received very high doses of radiation and some of them in fact developed a "radiation syndrome," a form of iatrogenic disease.

Health authorities in both the Commonwealth of Pennsylvania and the Federal government agreed that, because of the confusion and uncertainty surrounding the TMI accident from the beginning and because the nuclear accident was the first of its kind, the exposed population should be followed and studied for many years in order to monitor any possible changes in health status (6-7). Also, because of the high levels of psychological distress experienced by the local residents during the crisis period and the likelihood of distress continuing over the many years needed to clean up the damaged reactor, psychological health and its sequelae were perceived as important outcomes to monitor independently of the issue of radiation exposure.

Psychological Stress and Health:

Stress is an organismic state that can contribute, under the proper circumstances, to changes in body function, which, if intense or chronic, may lead to disease. In other words, stress can trigger a multiplicity of organismic reactions, some of which may contribute to illness, while others may result in normal adaptive responses.

Psychophysiological studies (8) indicate that life situations which threaten the security of the individual would evoke attempts at adaptive behavior and also evoke significant alterations in the function of most bodily tissues, organs and systems. These physiological changes, in turn, will lead to a lowering of the body's resistance to disease. It is assumed that certain

events require more intense and prolonged coping efforts than do others. The greater the strains on the coping mechanisms, the more likely that an inadequate or inappropriate response will be utilized, thus eliciting idiosyncratic or pathological physiological reactions.

It is also important to recognize that an understanding of a life event's impact must take into account the physical susceptibility of the individual, the meaning of an event, the person's ability to cope with a variety of stresses and the individual's social support network. With the exception of extreme and sudden life-threatening situations, no raw stimulus is a universal stressor. The true consequences of stress arise from the manner in which the organism responds to the presumed danger. It is the way in which the organism handles perceived stressors - the defenses it mobilizes and the alarm reactions ignited - that constitutes the true nature of the stress (9).

The psychosomatic approach (10), on the other hand, identifies certain personality type and life history that would make them more vulnerable to certain diseases. Whenever a stimulus is perceived to threaten a fundamental human need, the stress response also will be inititated. Imagination can produce its own stressors and prompt a neuroendocrine-autonomic response that itself poses a real threat to the organism.

Stress can cause disease by lowering or exaggerating the immune response (11), creating endocrine problems through either hypoactivity or hyperactivity (12), altering the balance of autonomic control, resulting in changes in the cardiovascular, respiratory, secretory, and visceral system (13), altering sleep patterns, with attendant impact on protein metabolism, hormone secretion and other vegetative functions (14), and by affecting the functions of the brain itself, which can have profound impact upon health through a variety of mechanisms, including changes in eating and health habits, such as exercise,

drug, alcohol or cigarette consumption (15). Numerous studies have shown that the pituitary-adrenal axis may be activated or inhibited by fear, anger, rage, pain or adverse environmental conditions.

The stress associated with the TMI nuclear accident cannot be considered as a single unique experience because the prolonged recovery period following the accident gives rise to numerous additional stressors. However, it is unlikely that any given psychological stressor will be etiologically specific for any given disease. The important point is that a range of health outcomes, both mental and physical, need to be assessed in studies of stress or disaster since certain individuals may be more susceptible to health sequelae than others.

There are a number of studies in humans which have found an association between prenatal anxiety/stress and gestational, perinatal, and developmental pathology including complications of pregnancy (16-17) and infant growth and development (18). These findings suggest a number of practical and scientific questions to be addressed within the context of the TMI Health Effects Research Program. The first is whether or not the local population, including pregnant women, as a whole experienced any detectable stress effects. The second question concerns factors which render individual pregnant women particularly vulnerable to stress effects. As reviewed earlier, stress may be associated with morbidity only in the absence of supportive interpersonal relations.

While the specific mechanism of stress induced morbidity is not yet fully understood, there may be several different explanations with respect to pregnancy outcome; e.g., stress-anxiety induced changes (a) in maternal behavior, such as increased smoking, drinking or medication while pregnant, (b) in obstetric practice, such as increased prescription of analgesics and psychotropic drugs or use of special diagnostic procedures, (c) in maternal-

infant bonding and child-rearing practices, and (d) in the hypothalamic-adrenocortical mechanism (19).

Subsequent to the TMI nuclear accident, the Pennsylvania Department of Health developed a comprehensive plan for a variety of epidemiologic and sociological studies designed to assess the impact, both immediate and long-term, of the accident upon the local population. Some of the short-term studies are still in progress while long-term followup studies are being planned. Investigators of other organizations and institutions have also conducted short-term studies. In this paper, findings from certain major studies are briefly summarized in three categories: (a) psycho-behavioral studies, (b) physical health studies, and (c) long-term epidemiologic surveillance.

Psycho-Behavioral Studies:

Although no immediate radiation health effects were recognized during the nuclear accident, and probably no delayed or late radiation health effects are to be expected, what emerged from this experience was that the major health effect of the accident appears to have been on the mental health of the people living in the region of TMI and of the workers at the nuclear power plant.

There was immediate mental distress produced by the accident among certain groups of the general population living within 20 miles of Three Mile Island (20). The highest levels of distress were found among adults living within 5 miles of TMI, or those with preschool children; and among teenagers living within 5 miles of TMI, those with preschool siblings, or whose families left the area. Workers at the TMI nuclear plant experienced more distress than workers at the Peach Bottom nuclear plant in Pennsylvania which was studied for comparison purposes. The level of distress was higher among the nonsupervisory employees and stress continued in the months following the

accident.

Health-related behavioral studies conducted by the Pennsylvania Department of Health in collaboration with the Hershey Medical Center (21) indicated that persons who are younger, more educated, married and female were especially distressed during the crisis. The greater responsiveness of younger, married persons was probably due to their concerns about the effects of radiation on their present and future children and, since radiation effects often have a long latency, concerns about their own future health. However, these demographic variables did not relate to changes in the level of distress over time. People who actively coped had high distress during the crisis and tended to maintain that distress over time. Persons with poor menta` or physical health tended to have high distress scores and to maintain their distress over time.

The number of persons with severe distress dropped shortly after the crisis, but between 10% and 20% of local residents residing close to TMI remained distressed nine months after the crisis. Persons residing close to TMI used more alcohol, tobacco, sleeping pills and tranquilizers during the two week period immediately following the crisis than before, but the use of these substances which were mediated through coping with the crisis situation did not persist beyond that time.

The October 1980 survey conducted by the Pennsylvania Department of Health in collaboration with the Hershey Medical Center indicated that the level of anxiety and stress declined more among residents within 5 miles of TMI than among those living more than 40 miles away. Thus, 18 months after the accident, the previously significant differences in stress-related symptoms, both behavioral and somatic which existed between the close and the far groups were no longer present. However, differences still persisted through October, 1980 as far as perceived threat of TMI and attribution of the recognized symptoms to TMI were concerned.

An in-depth epidemiologic study of psychological impact in a more psychiatric context was conducted by Bromet at the Western Psychiatric Institute (22). Her study covered three selected "high risk" groups in the TMI area, namely, (a) TMI employees, (b) mothers with preschool children, and (c) mental health clinic patients. People residing around the undamaged nuclear plant at Shippingport in western Pennsylvania were used as controls for comparison. One year after the accident, the condition of psychiatric outpatients near TMI did not differ significantly from that of counterpart in the control group. She also found that TMI workers experienced only slightly higher rates of clinical depression and anxiety as compared with Shippingport workers. But, mothers of preschool children living within 5 miles of TMI suffered far more anxiety and depression than did mothers living near Shippingport.

Bromet also found that mothers who evacuated in the height of the accident had more distress one year later than mothers who did not evacuate. Mothers living within 5 miles of TMI reported more distress symptoms than mothers living farther away from the plant. It was concluded that manifestations of clinical levels of mental health effects occurred primarily during the 2-month period after the accident, but sub-clinical levels of symptomatology were elevated as late as one year following the accident. There was evidence that social support bore an important relationship to these symptoms. Bromet's findings support a view that the burden of the stress was determined more by the actual experience, such as actual living in the vicinity of TMI, rather than by the perception of the stressful situation.

Related to the psychological stress caused by the TMI accident was crisis evacuation during the accident by local residents. Although the level of radiation exposure was minimal, a substantial number of residents in the

vicinity of the TMI plant left the area primarily because of their perception of imminent danger associated with radiation. The Governor of Pennsylvania advised pregnant women and small children to evacuate. Within hours of the Governor's advisory and with mounting media coverage of the accident, which was often confusing, mass evacuation occurred. Some 64% of the population in the 5-mile area left their homes some time during the nuclear crisis. It is important to document individual evacuation as it can be related to estimating radiation exposure and the future health effects studies.

A total cross-sectional population census conducted by the State Health Department supported by the Federal Center for Disease Control and Bureau of the Census shortly after the accident within five miles of the plant revealed that evacuation behavior was related to several demographic variables. Specifically, more younger people evacuated and for longer periods than older people. More females evacuated than males. The more educated and white collar workers evacuated somewhat more than the less educated and blue collar workers. The strongest predictor of evacuation was the presence of one or more preschool children in the household. Distance of residence from the damaged plant was inversely correlated with the decision to evacuate. There were no major differences in the pattern of evacuation between medical personnel and other residents in the same community, i.e., nurses and young women behaved similarly while physicians and middle-age men were alike in their evacuation behavior.

Radiation Exposure and Health Risks:

Nuclear accidents, such as the 1979 episode at TMI, are potentially harmful to health if the amount of ionizing radiation absorbed by humans is substantially high. However, whether health is affected by exposure at the low levels characteristic of natural background radiation is a matter of con-

jecture. Observations at higher radiation intensities have implied, but are difficult to measure, that the risk of certain health effects may be increased even at the lowest dose levels. These effects may include any one or combination of the following: (a) damage to genes and chromosomes, or mutagenic effects, (b) damage to the growth and development of the embryo and fetus, or teratogenic effects, and (c) damage to cells that increases the risk of their forming cancer, or carcinogenic effects (23-24).

However, since health effects of radiation at the levels of natural background cannot be distinguished individually from similar effects produced by other causes, the effects of low-level radiation are estimated only by extraporation from observations at higher radiation doses and dose rates, based on tentative assumptions about the relevant dose-effect relationships. In the present state of our knowledge, such estimates must be regarded as highly uncertain at best (25-26).

The accidental radiation received by people residing in the vicinity of Three Mile Island (TMI) came almost entirely from xenon-133 (half-life, 5.3 days), xenon-135 (half-life, 9.2 hours), and traces of radioactive iodine (principally iodine-131, half-life, 9.0 days), which escaped intermittently from the plant as gases (27-28). These radioactive gases followed prevailing winds and increased the level of ionizing radiation along their path. However, the increase was short-lived because xenon dispersed rapidly and because radioactive iodine was present only in barely detectable amounts. No release of long-lived fission products, such as strontium-90, cesium-137, and plutonium-239, was detected.

Based on the available measurements, it is estimated that the maximum cumulative whole-body gamma radiation dose to anyone off site was less than 100 mrem, that the average cumulative dose to those within 10 miles of the plant was approximately 8 mrem, and that the average cumulative dose to those

within 50 miles of the plant was about 1.5 mrem. Because these estimates make no allowances for shielding, they are generally considered to represent over-estimates (27-28). Additional exposure of the population came from the beta radiation dose to the skin and from the inhalation dose to the lung. It is estimated that the total dose to the skin could have been much larger than the whole-body gamma dose by a factor of 3 to 4 if the protective effects of shelter and clothing are neglected (27). The inhalation dose is estimated to have constituted no more than 3% to 7% of the dose to the whole body.

The risk of cancer is generally assumed to be increased by low-level radiation, but it is clear from observations at intermediate-to-high dose levels that the risk may vary depending on the type of cancer in question, age at the time of irradiation, the quality of radiation, and other factors. According to a linear, nonthreshold extrapolation model, with no allowance for biological repair at low doses and low dose rates, cancer risks are regarded by many experts as being likely to overestimate the risks of low-level radiation. For this reason, some experts prefer a linear-quadratic model, which yields risk estimates that tend to be 25%-50% smaller (29-30). If these risk coefficients are applied to the population of about 2.2 million people residing within 50 miles of Three Mile Island, they predict a lifetime risk of less than one extra fatal cancer and less than one extra nonfatal cancer.

It is generally assumed that irradiation can cause genetic damage in human germ cells that is transmissible to future generations in the form of various inherited diseases. It has been estimated that the incidence of genetic abnormalities in humans would be doubled by a dose of 20 rem - 200 rem (25-26) and, that the number of descendants of the population within 50 miles of TMI who are likely to be affected by genetic disorders resulting from

the TMI accident would be approximately one.

The risks of teratogenic effects of radiation on the human embryo and fetus are more difficult to estimate, owing to the paucity of relevant data. The evidence at hand implies, however, that the risks of such effects are smaller per unit dose than are the risks of carcinogenic and mutagenic effects (25-26). On this basis, it may be inferred that such effects are unlikely to result from the TMI accident in view of the small magnitude of the radiation dose.

Physical Health Studies:

Although increased risks of cancer, birth defects, and genetic abnormalities are potential long-term consequences of low-level irradiation, few if any such effects of the TMI accident are likely to be observed, because the collective dose of radiation received by the population within a 50-mile radius of the plant was so small.

In order to evaluate the potential effect of radiation and/or acute stress upon the reproductive process, an epidemiologic study was conducted to determine whether the incidence of spontaneous abortion was greater than expected near the Three Mile Island nuclear plant during the months following the March 28, 1979 accident. All persons including those who were pregnant living within five miles of TMI were registered shortly after the accident, and information on pregnancy at the time of the accident was collected. After one year, all pregnancy cases were followed up and outcomes ascertained. Using the life table method, it was found that, given pregnancies after four completed weeks of gestation counting from the first day of the last menstrual period, the estimated incidence of spontaneous abortion (miscarriage before completion of 16 weeks of gestation) was 15.1 percent for women pregnant at the time of the TMI accident. Combining spontaneous abortions and stillbirths (delivery of a dead fetus after 16 weeks of gestation), the estimated incidence

was 16.1 percent for pregnancies after four completed weeks of gestation. Both incidences are comparable to baseline studies of fetal loss, indicating that the effect of the TMI accident upon spontaneous abortion was negligible, if any.

The crisis at Three Mile Island presented a natural experiment in disaster response, although this disaster was substantively different from any before it. Not only was this the first to involve a nuclear plant, but no one was bodily hurt, no property outside the nuclear facility was physically damaged and, it is generally believed, no excess deaths or illness will be detected as a result of the accident. Nevertheless, a disaster situation was experienced psychologically and emotionally by the nearby population.

A study was conducted by the Pennsylvania Department of Health to determine the effect of the 1979 nuclear accident at Three Mile Island on residential mobility and subsequent population composition. The entire population living within five miles of TMI was registered shortly after the accident and traced one year later to identify movers. The results of this analysis showed that the rate at which people moved remained the same the year after the accident as before, and that approximately 15% of those who moved (changed address) gave TMI as the main reason for their decision to move. The study also found that those moving because of TMI had attributes highly associated with mobility in general. When those attributes were controlled in analysis, attitudes about TMI were virtually the same among movers and nonmovers. On the other hand, demographic characteristics of new people moving into the area were not different from those who had moved out. However, attitudes about TMI were significantly more positive among the newly moved-in people than among the moved-out people.

Probably the most important study developed shortly after the accident

was to determine if the TMI nuclear accident has had any measurable impacts upon pregnancy outcome and infant health in the vicinity of the damaged nuclear reactor. The embryo, the fetus and the infant are highly sensitive to environmental insults, such as ionizing radiation and maternal psychological stress, depending upon the severity or intensity of the insults, the mode of exposure, and the gestational/post-natal age at exposure.

A carefully designed retrospective cohort study of pregnancy outcome was initiated in August, 1979. This study covered all pregnant women residing within a 10-mile radius of the TMI plant, who gave births between March 28, 1979 and March 27, 1980. This study cohort consisting of some 4,000 deliveries was compared with a control cohort of another 4,000 deliveries which took place during the immediately following one year period for women who also resided in the same 10-mile area communities.

Measures of adverse pregnancy outcome investigated were: fetal deaths (stillbirths with 16-week or more gestation including abortions after 16-week gestation), neonatal deaths (deaths within 28 days postpartum), hebdomadal deaths (deaths within seven days postpartum), perinatal deaths (combined measure of fetal and neonatal deaths), prematurity (gestation less than 37 weeks), immaturity (birth weight 2,500 grams or less), congenital anomalies (one or more developmental defects observed at birth), and low Apgar score (less than seven at one minute of delivery).

Since there are numerous factors other than radiation and stress that are known or suspected to influence the course of pregnancy and fetal outcome, it is important that the influences of such factors be considered. Detailed data on these factors have been collected, inlcuding maternal characteristics (sociodemographic, behavioral, and medical-obstetric histories), health care provider characteristics, and prenatal care attributes. The influences of all these factors were taken into account when maternal stress and/or radiation

exposure were related to any of the various pregnancy outcome measures under study.

Maternal stress during and immediately following the TMI accident has been measured by overt personal statements of "anxiety-fear" as experienced and reported by individual pregnant women, and by actual stress-coping patterns described, such as taking extra medications (tranquilizers, sleeping pills, anti-hypertensive preparations, etc.) because of anxiety and fear.

Maternal radiation exposure during the 10-day crisis following the nuclear accident has been estimated by the Department of Radiation Health, University of Pittsburgh. For this purpose, already documented, reliable thermoluminescent dosemetry (TLD) and other source data including time-dependent dose-rate distribution compiled by government and non-government agencies were used to estimate maximum possible and most likely doses, to each individual pregnant woman, of whole-body gamma, thyroid doses to the mother and the fetus as well as combined gamma and beta doses to the skin. For estimating maximum possible doses the evacuation factor was not considered, but for determining most likely doses this factor was taken into account, i.e., those who evacuated during the accident were assigned smaller doses depending upon when and how long evacuation took place on an individual basis.

When pregnancy outcome measures were compared between the exposed study cohort and the unexposed control cohort, no significant differences were noted for any of the various outcome measures under study indicating that the impact of the TMI nuclear accident upon pregnancy outcome was negligible, if any. After adjusting for the influences of the many maternal and provider characteristics described earlier, the incidences of fetal and neonatal mortalities, congenital anomalies, prematurity, immaturity, and of low Apgar score within the study cohort were not significantly different from those within the control cohort.

A separate analysis of the comprehensive data by multivariate logistic analysis indicated that neither radiation exposure nor psychological stress as such was significantly correlated to the incidence of fetal-neonatal mortality, congenital anomalies, prematurity, immaturity or low Apgar score within the exposed study cohort.

It should be noted, however, that the excess medication taken by those pregnant women who were severely stressed during and/or shortly after the accident was significantly correlated to the incidence of low Apgar score which was measured at one minute postpartum, and to the incidence of immaturity, i.e., the risk of low birth weight. This was interpreted to mean that the one-minute Apgar scores among newborns were significantly influenced by maternal excess medication of tranquilizers, sedatives, and anti-hypertensives which was mediated through the accident-caused stress and anxiety. Our data also indicated that the low Apgar score at 5 minutes postpartum was not significantly correlated to the same maternal excess medication while pregnant. This may suggest that the low Apgar score is a negative, but only a very short-term prognostic indicator with probably minimal clinical significance. However, the stress-mediated low birth weight can be a potentially significant long term health effect which requires special attention.

Apart from the above observations on pregnancy outcome, there was one other potentially important observation to be made particularly with respect to the effect of radioactive iodine upon thyroid function among newborn infants. Since State Health Department initiated a statewide screening program for congenital hypothyroidism in mid-1978, the available data were analyzed in relation to the March 28, 1979 nuclear accident.

During the March 28, 1979 - March 27, 1980 period, only one case of congenital hypothyroidism was identified within a ten-mile radius of TMI among approximately 4,000 newborn infants. This incidence rate is well within

a normal range of expectation.

An apparent clustering of seven cases of congenital hypothyroidism reported in Lancaster County during 1979 presented serious interests among epidemiologists and was subjected to a special in-depth analysis and investigation because of physical proximity of the county and timing of the TMI nuclear accident. From this investigation the following diagnostic and epidemiologic features emerged: (a) One of the seven cases identified was reported prior to the TMI accident, thus cannot be related to the nuclear accident. (b) One with severe multiple central nervous system anomalies was born three months after the accident; this case is unlikely to have been associated with the TMI accident because of the late gestation period of the fetus when exposed to the accident, and also of coexisting other developmental anomalies which are unlikely to be related to radiation. (c) One case was of dysgenesis, representing one of discordant Amish twins, thus, non-supportive of the etiology secondary to radiation exposure. (d) One case of dyshormonogenesis from an Amish family where the condition (lack of enzyme to synthesize thyroxine) was inherited from the parents. (e) Another case of dysgenesis in whom the thyroid glands were displaced from the normal position. (f) For the remaining two cases thyroid scan was not conducted, thus, exact diagnostic entity remains unknown.

Having completed detailed diagnostic analysis and epidemiologic assessment of all cases reported in Lancaster during 1979, it was concluded that reported cases of congenital hypothyroidism were not related to the TMI nuclear accident, i.e., these types of anomalies are not expected to have resulted from direct or indirect exposure of the fetus to radioiodine. This conclusion was also supported by an independent Hypothyroidism Investigative Committee organized by the State Health Department, which included expertise in the fields of epidemiology, pediatric endocrinology, obstetrics, medical genetics, biostatistics, and radiation physics.

Apart from the incidence analysis described above, there was also an important biological consideration with respect to radiation in relation to congenital hypothyroidism.

First, after March 28 through December 31, 1979, no single case of congenital hypothyroidism was reported in Dauphin, Cumberland, Perry, Northumberland, Juniata, Snyder, Mifflin, and Union Counties, the areas downwind (N, NW, NNW) from the Three Mile Island during the first 48 hours of the accident, when probably the largest amount of radioactive releases took place, thus the largest amount of contamination including I^{131}.

Second, the maximum combined (inhalation and ingestion) human thyroid dose of radioactive iodine in the vicinity of the TMI following the March 28, 1979 accident through April 1979 is estimated to be 7.5 mrad (Editorial: Annals of Internal Medicine, Vol. 91, No. 3, September 1979). At least 1,000 times greater thyroid doses (i.e., 7.5 rads) would be required to have significant acute damages to the thyroid glands; however, even at this dose level, many of the damaged cells may be repaired. Based on the experiences of the Marshallese exposed to fresh radioactive fallout and atomic bomb victims, it is considered likely that as much as 50 rads to 100 rads fetal thyroid doses would be necessary to cause irreversible tissue damages, such as congenital hypothyroidism and/or thyroid cancer. Acknowledging the fact that the fetal thyroid is much more sensitive to radioiodine than is the maternal thyroid (a conservative upper bound estimate is that the thyroid dose to a fetus may be as high as ten times the maternal thyroid dose), the maximum likely fetal thyroid dose of approximately 75 mrad and the maximum possible fetal thyroid dose of 190 mrad to 200 mrad in the vicinity of the damaged nuclear plant are still far too small to have caused congenital hypothyroidism.

In any epidemiological investigation of possible "cluster" of a disease or morbid condition, it is important to recognize the technical difficulty

and methodological limitations associated with such investigations. It is the overall consistent pattern of observations that provides useful clues for conclusion, rather than a single isolated change or difference, which in most cases occurs without substantive epidmeiologic significance. This is particularly true when relatively small populations are being studied. One may or may not find a "statistically significant" change, difference, or clustering in morbid rates in an area depending upon how such population is delineated geographically and/or temporally. It is equally important that investigators carefully examine the observed relationships and determine if such relationships are consistent with the known biological theory or orientation, which is based on the previous studies and experiences. Our conclusions regarding congenital hypothyroidism around the TMI nuclear plant have been based on both the overall pattern of epidemiologic observations and in reference to existing scientific knowledge.

Long-Term Epidemiologic Surveillance

TMI Population Registry:

Within three months after the March 1979 nuclear accident, a cross-sectional population census of some 36,000 persons living within 5 miles of the plant was undertaken jointly by state and federal governments (31). The information collected through the census provided baseline data for future epidemiologic studies of possible health effects of the TMI accident. The data base, known as the TMI Population Registry, is comprised of demographic characteristics on each resident and a brief medical history of cancer diagnoses, thyroid disorders, prior radiation therapy and exposure to ionizing radiation on the job. Smoking histories were also included for teenagers and adults. In addition, each person's daily travel in and out of the 5-mile area during the 10-days after the accident was recorded so that TMI-related radiation doses could be estimated from the already documented time-place

dependent radioactivity distribution in the area. After two months of data collection, the TMI Population Registry was considered to be 95 percent complete in coverage. For each resident included in the Registry, two radiation dose estimates (maximum possible and most likely) were given with respect to wholebody gamma and thyroid tissue respectively. Living status and whereabout of the registrants are updated annually for future contacts.

TMI Mother-Child Registry:

Within five months following the TMI accident, a carefully designed retrospective cohort study of pregnancy outcome was initiated (32). This study included two separate cohorts, the exposed study group and the unexposed control group, all residing within 10 miles from the damaged nuclear plant. In each group there were approximately 4,000 mother-child pairs which constitute the TMI Mother-Child Registry. For each registered pair, detailed information regarding maternal characteristics and perinatal characteristics of the index infant were recorded. For the exposed study pairs estimated radiation doses (wholebody gamma and thyroid tissue) and the proxy measure of maternal stress during and shortly after the accident were documented on an individual basis, which can and will be related later to the various measures of possible long-term health effects. The TMI Mother-Child Registry includes 94% of all eligible cases of pregnancy in the area and provides the necessary baseline data for long-term epidemiologic studies. Living status and whereabout of all registrants are updated annually in preparation for such studies.

Objectives of Long-Term Studies:

The aim of the TMI Health Effects Research Program is to provide factual information based on such studies which are epidemiologically sound and/or sociologically justified with respect to possible health effects of the TMI

accident upon local residence. Based on the available TMI radiation exposure data and from the previously reported epidemiologic studies of low dose radiation, major adverse health effects from the TMI accident are not expected. Although this may provide assurance to many people at potential risk, the assurance is only as good as the radiation data itself, which has become a subject of debate. There is also a possibility that psychological stress from the accident and its aftermath, which has been well documented, will cause some adverse health effects among the TMI residents.

Although the effect of psychological stress is difficult to predict, these public health concerns should be addressed. We are taking a precautionary route by carefully documenting both the exposed population and its health experiences after the nuclear accident. The already established TMI Population Registry and the TMI Mother-Child Registry will provide reliable data bases for long-term followup studies of the health effects (physical, psychological and behavioral), if any, from the TMI nuclear accident for both the general population and for the special cohort of pregnant women and their in-utero exposed children. Causes of death and cancer diagnoses will be routinely ascertained by linkage to the State mortality and cancer incidence files. Data for other physical, psychological and behavioral health indices will be collected every five years, on the basis of a random sample through prospective followup surveys for both cohorts.

Regardless of the results of a variety of short-term and long-term studies undertaken, the primary mission of the TMI Health Research Program is to fullfill the need to respond to the much publicised, potentially important public health concerns. Because of the uniqueness of the TMI nuclear accident, thus its historical significance, as well as the scientific need to document health effects of very low dose radiation in humans, the rare opportunity presented by the TMI nuclear accident should not be lost in the pursuit of these important epidemiologic studies.

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Socio-Econ. Plan. Sci. Vol. 18, No. 3, pp. 183–193, 1984
Printed in the U.S.A.

0038-0121/84 $3.00 + .00
Pergamon Press Ltd.

HEALTH-RELATED ECONOMIC COSTS OF THE THREE-MILE ISLAND ACCIDENT†

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(*Received* 26 *April* 1983)

Abstract—On 28 March 1979, a nuclear power station at Three-Mile Island (TMI) near Harrisburg, Pennsylvania, had a major breakdown. During the two-week period of the accident, about 150,000 residents were evacuated for reasons associated with safety and health. Many residents during and after the accident, regardless of whether they left or stayed, made mental and physical adjustments due to this accident. This paper is to estimate the economic costs incurred by individuals or communities as a result of a change in physical or mental health status and/or a change in health care services due to the TMI accident. The findings indicate that stress symptoms caused by the accident did affect the health-related behaviors of area residents. Of the costs examined, the economic costs of work days lost and physician visits are the largest cost items. There were some increases in consumption of alcohol, cigarettes, and tranquilizers immediately following the accident.

1. INTRODUCTION

On 28 March 1979, a nuclear power station at Three-Mile Island (TMI) near Harrisburg, Pennsylvania, had a major breakdown. A meltdown and subsequent radioactive discharge from the nuclear plant would have had catastrophic consequences on the lives and properties of individuals in the surrounding area. During the two-week period of the accident, many residents were vacated for safety and health reasons. Many industrial and business establishments were also closed. This accident had various effects on local communities, as well as the country as a whole. The nationwide impact on the energy industry has been widely publicized and is well known; however, perhaps the most important effects of the accident were on the residents of the area surrounding TMI. Possible effects included an escalation in the cost of electricity, changes in agricultural production, business activities, the housing market, the tourism industry, and the physical and mental health status of the people in the area.

The Governor's Office of the Commonwealth of Pennsylvania has issued a report which examines the socioeconomic impact of the accident [1]. This report estimated a monetary loss of $7.7 m in the value of production in manufacturing industries, $74.2 m in business sales in non-manufacturing industries, and $0.25–$0.50 m in the agricultural sector for a total monetary loss to industry of about $82 m. The effect on the housing market were negligible [2]. The household economic costs of evacuation were estimated at $6 m, excluding the $1.2 m insurance reimbursement [3]. These cost estimates do not include the possible costs relating to changes in the physical and mental health status of the people in the TMI area. The focus of the current study is to estimate the health-related economic costs of the accident. All these costs are estimated from survey data sources.

In this study, health-related economic costs are defined as the economic costs incurred by individuals or communities as a result of a change in physical or mental health status and/or change in health care services due to the TMI accident. Although changes in agricultural production, business activities, the housing market, and tourism may have direct economic consequences in the area, changes in the physical and mental health status of the local populations will also produce economic consequences to their communities. These latter economic consequences are: (1) the possible increase in demand for health care services which may increase health care expenditures and utilization of health care resources, (2) the possible increase in morbidity which may increase a worker's absenteeism or other forms of loss of worker's productivity, and (3) the possible increase in consumption of alcohol, cigarettes, sleeping pills, and other tranquilizers during and after the accident. Estimation of these costs will provide policymakers with needed information regarding household responses and the related economic costs of these adjustments in the local communities.

In Section 2, the data sources used in the study will be described. Section 2 will provide an analysis of the effects of the TMI accident on physician visits, work days lost, and alcohol and cigarette consumption. Concluding remarks are contained in Section 4.

2. DATA DESCRIPTION

Two separate data collections were made in July 1979 by the Chilton Research Services of Radnor, Pennsylvania, under separate contracts from The Pennsylvania State University and the Nuclear Regulatory Commission. A telephone survey using random digit dialing was employed, with no overlapping of respondents between the two surveys.

†This study was funded by the Division of Epidemiological Research, Pennsylvania Department of Health, under service contract 641996.

The Pennsylvania State University (PSU) data contained 691 households; 5% of households within the 5-mile radius of TMI were randomly selected (there are 14,300 households in the 5-mile ring). Obviously, this was the most intensely affected area within the TMI region. The data included responses to extensive questions about the social and psychological effects of the accident, the costs of evacuation, and health care utilization patterns during the two-week period of the accident and a two-week period of the accident and a two-week period in July 1979. The data contain respondents' files as well as information on the individuals within the respondents' households. A follow-up survey of 400 households within the PSU data set was conducted in January 1980.

The Nuclear Regulatory Commission (NRC) data contain 1503 households covering an area 0–55 miles from TMI, with heavier sampling within the 15-mile ring than beyond the 15-mile ring. These data include responses concerning the evacuation decision, evacuation costs, views on nuclear power plant installation, social and psychological effects of the accident, but no information on health care utilization. The importance of these data is the cross-sectional information (variations in distance away from TMI) which allows comparisons to be made in terms of the evacuation decision, costs of evacuation, and the effects of the TMI accident on mental and psychological behaviors. A detailed discussion of the sampling design and weighting procedures is presented in a report prepared by the Social Impact Research, Inc. [4].

In order to understand the sociodemographic characteristics of the samples in these two data sources, they are briefly discussed and compared in this section. Table 1 provides sociodemographic information on the total sample of both data sets. As shown in Table 1, these two data sources are comparable, since they are both randomly selected from the area. The average household size is about three persons. During the two-week TMI accident period, a little over 4% of the households in the area included pregnant women. The mean education of the heads of households is about high school level.

In these two samples, about 20% of the households have an income of less than $10,000. About 40% of the household have an income between 10,000 and $20,000, while about 20–25% of the households have an income between 20,000 and $30,000. The characteristics of marital status and age of the heads of households are also very similar in these two samples.

Table 1 shows that according to the PSU data, 60% of households within the 5-mile ring evacuated during the two-week TMI period. The NRC data show 16% of households evacuated within the 55-mile ring; however, a detailed breakdown indicates that the evacuation rate was 63% within 0–5 miles, and declined to 49, 32 and 5% for 5–10 miles, 11–15 miles, and beyond 15-miles, respectively [3]. Table 2 provides summary information about the size of population and the percent of evacuation within the 15-mile ring.

3. HOUSEHOLD ECONOMIC COSTS OF HEALTH-RELATED BEHAVIOR

Regardless of whether a household decided to evacuate or not to evacuate during the TMI accident, household members in the TMI area may have felt tension, confusion, or stress due to the TMI accident. Not all households experienced these mental phenomena, and even if they did, the stresses may not have led to physical or behavioral responses. However, some household members may have experienced physical symptoms or behaved differently as a result of the TMI accident. Physical symptoms included stomach trouble, headache, abdominal pain, diarrhea, etc. Behavioral symptoms included insomnia, excessive sweating, loss of appetite, irritability, etc.

The basic analytical framework for estimating the health-related economic costs of the TMI accident is illustrated in Fig. 1. As shown in Fig. 1, the TMI accident as well as a set of socioeconomic and demographic factors may have affected the stress level of individuals in the TMI area. The change in stress level

Table 1. Selected sociodemographic characteristics of households. The Pennsylvania State University data (within the 5-mile ring) and the Nuclear Regulatory Commission Data (within the 55-mile ring)

Variables	PSU Sample	NRC Sample
Size of household (no. of persons)	3.1	3.2
Pregnant woman in the household (in percent)	4.5	4.3
Mean education of the heads of households (in years)	11.8	12.4
Occupation: (in percent)		
White collar	18.1	32.1
Blue collar	57.7	37.6
Other	24.2	30.2
Family income before taxes (in percent)		
less than $10,000	20.2	23.3
$10,000 - $19,999	41.8	42.7
$20,000 - $29,999	23.8	21.2
$30,000 and above	7.9	10.6
No answer	6.3	2.4
Male as the head of household (in percent)	83.9	82.1
Mean age of the heads of households (in years)	42.4	43.5
Marital status:		
Married	74.3	71.2
Divorced, Separated, or Widowed	14.7	14.8
Single	11.0	14.0
Left the area during two-week TMI (in percent)	60.0	16.0
Sample Size	691	1503

Table 2. Estimated number of households and population evacuated during the two-week period of TMI accident within the 15-mile ring, 28 March–10 April 10

	Households			Population	
Miles	Percent[1] Evacuated	Universe[2]	Estimated No.[3] of Evacuations	Universe	Estimated No.[4] of Evacuations
0-5	63	14,300	9,000	41,470	26,100
6-10	49	40,161	19,700	124,500	61,000
11-15	32	72,262	72,262	209,560	67,000
Total	--	--	51,800	--	154,100

Notes: [1]Obtained from the NRC data.
[2]This figure was supplied by the Pennsylvania Department of Health, based on their TMI census.
[3]This figure is obtained from the product of the percent of evacuation and the universe in the area. Estimated figures are rounded to hundreds.
[4]This figure is obtained from the product of the household size and the number of evacuated households.

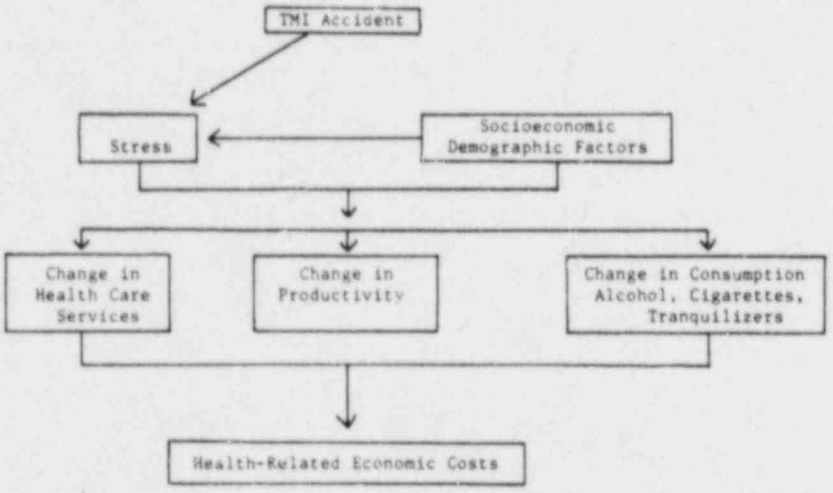

Fig. 1. Framework for estimating health-related economic costs of the TMI accident.

together with a set of socioeconomic and demographic factors may, in turn, have influenced (1) the demand for health care services (number of physician visits), (2) the change in productivity (work days lost and slower pace of work), and (3) the changes in consumption of alcohol, cigarettes, and tranquilizers. The resources expended for these three types of effects constitute the health-related economic costs of the TMI accident.

3.1 *Relationships between TMI and stress*

To measure and test these possible effects of the TMI accident, one has to first establish the linkage between the effects of the TMI accident and the stress level of area residents. Once the effects of TMI on stress is certain, a statistical model will be used to examine the resultant stress on three types of health-related behavior. A much detailed analysis on the relationship between the TMI accident and the psychological effects on the area residents has been examined by another study [5]. This section is simply to quantify the relationships between TMI and stress.

As discussed earlier, the NRC data cover an area 0–55 miles from the TMI facility. Distance from TMI is used as a control variable to test whether the accident increased the tension and stress of the TMI area residents. Two forms of dependent variables are measured—the number of psychosomatic symptoms a respondent reported having during the two-week interview period and a dummy variable for those who had any one of the behavioral symptoms. Three time-periods are used:(1) the two-week period after the accident (28 March 1979); (2) a two-week period four months after the accident (July 1979); and (3) a two week period ten months after the accident (January 1980). In addition to the TMI accident itself, the independent variables that may affect a person's psychosomatic and behavioral symptoms are: age, sex, education, marital status, occupation, income, and pregnancy status. Few non-white residents are in the sample so the race variable is not included.

Since the dependent variables are expressed in either discrete numbers or dichotomous (0–1) form, tobit and probit techniques should be used to obtain

the maximum likelihood estimation. This study used the ordinary least squares for it is easy to estimate and the coefficient is easy to interpret. The drawbacks of the ordinary least-squares technique are minimized because of the relatively large sample size and sufficient non-zeros in the dependent variable.

Table 3 shows that during the TMI period the distance variable had the most statistically significant effect on residents' psychosomatic and behavioral symptoms. The deleted distance category is 15-miles beyond the TMI area. Residents within the 15-mile ring were about 20% more likely to have behavioral symptoms than those beyond the 15-mile ring. The effects on psychosomatic symptoms are very similar. The effects of TMI were still apparent during the July period but to a lesser degree. Residents within the 5-mile ring and those in the 10–15 mile ring showed stronger stress symptoms than the residents in the 5–10 mile ring. Examination of other socio-demographic variables suggest that the higher the level of education, the less the degree of stress, that males felt less stress than females, and that pregnant women had higher levels of stress.

To examine the duration of these stress effects, January 1980 survey data are used to examine the effects of stress level in March on stress level in July, and the effects of stress levels in March and July on stress level in January. Table 4 presents the regression results based on the PSU data within the 5-mile ring, since only this data set has the longitudinal information on stress level. The results indicate that the earlier stress level has a significant effect on later stress level, with the magnitude of these effects about 0.30–0.50. In other words, one stress symptom in an early period would contribute to about 0.30–0.50 symptoms in the later period. The numerical magnitudes in Tables 3 and 4 are used to calculate the effect of stress level on health-related behaviors. Based on these findings, the analysis of the effects of stress on the health care services and health-related behaviors can be linked to the TMI accident.

3.2 *Relationships between stress and physician visits*

The NRC survey data did not collect physician visit information. Therefore, the analysis of the effect

Table 3. Relationships between TMI accident and stress levels

Variables	March		July	
	Psychosomatic	Behavioral	Psychosomatic	Behavioral
intercept	.284*** (.115)	.148*** (.064)	.965*** (.169)	.354*** (.065)
age	.013 (.017)	-.013 (.009)	-.018 (.024)	-.013 (.009)
0-5 miles	.225*** (.061)	.185*** (.034)	.218*** (.089)	.115*** (.034)
6-10 miles	.179*** (.055)	.201*** (.031)	.099 (.080)	.036 (.030)
11-15 miles	.270*** (.054)	.197*** (.030)	.248*** (.080)	.068*** (.030)
married	-.010 (.074)	.060 (.041)	.012 (.109)	.012 (.042)
divorced, separated, widowed	-.021 (.085)	.032 (.048)	.009 (.126)	-.0006 (.048)
blue collar	-.081 (.060)	.037 (.034)	.080 (.089)	-.014 (.034)
white collar	-.013 (.053)	.031 (.029)	-.017 (.078)	-.015 (.030)
education	-.016 (.028)	.014 (.015)	-.080** (.041)	-.013 (.015)
family size	-.0007 (.016)	.004 (.009)	-.045** (.024)	-.005 (.009)
income	-.021 (.015)	-.020*** (.008)	-.018 (.021)	-.018*** (.008)
pregnant	.158* (.099)	.005 (.055)	.441*** (.145)	.063 (.055)
male	-.0111*** (.043)	-.110*** (.025)	-.225*** (.066)	-.065*** (.025)
sample size	1356	1356	1356	1356
R^2	.038	.066	.038	.031
F statistic	4.06	7.31	4.07	3.34

Note: Values in the parentheses are standard errors of coefficients
*** Indicates the 1% level of significance (one-tailed test)
** Indicates the 5% level of significance (one-tailed test)
* Indicates the 10% level of significance (one-tailed test)

Table 4. Relationships between stress level and physician visits March and July 1979

	March	July
intercept	-.052 (.051)	-.062 (.063)
male	-.024 (.019)	-.032 (.024)
age	.007 (.007)	.012 (.009)
pregnant	.541*** (.074)	.253*** (.092)
married	.034 (.032)	.039 (.040)
separated, divorced, widowed	-.026 (.038)	.104 (.047)
chronic ailments	.068*** (.020)	.012 (.025)
family size	-.008 (.007)	-.004 (.009)
education	.020 (.013)	.013 (.016)
income	.0044 (.011)	-.0003 (.014)
behavioral symptoms	.015 (.025)	.069** (.029)
# of psychosomatic symptoms in March	.031*** (.013)	-.036** (.017)
# of psychosomatic symptoms in July	--	.056*** (.013)
work in the market	.016 (.023)	.049* (.028)
sample size	639	639
R^2	.132	.0911
F statistic	7.96	4.82

Note: Values in the parentheses are standard errors of coefficients
*** Indicates the 1% level of significance (one-tailed test)
** Indicates the 5% level of significance (one-tailed test)
* Indicates the 10% level of significance (one-tailed test)

of stress of physician visits rely solely on the PSU data.

Residents in the TMI area may have sought medical help during the TMI accident for two possible reasons. (1) Psychological and emotional tension may have led people to consult with a doctor or health professional in order to reduce their anxiety or to gain medical opinions about the possible effects of radiation. In the PSU survey, 73 out of 692 respondents indicated that they did consult with doctors and health professionals to make them less tense during the two-week period of the accident. (2) Physical discomfort resulting from psychological and emotional disturbances during the TMI accident may have prompted a physician visit. It is difficult to make accurate judgments as to which visits to physicians were due to the TMI accident even from the patient's point of view. Therefore, a model of the demand for physician services is used to measure the effects of stress on physician visits. The dependent variable is the number of physician visits during the two-week period of the accident, the two-week period in July, and total number of physician visits between TMI accident and January 1980. Since few respondents in the survey were admitted to the hospital, only the physician visits will be used as dependent variables. In reality, people who are under mental stress are rarely admitted to the hospital; more often they seek help from a physician. A demand function for physician visits usually includes income, price of a visit, insurance coverage, and a set of sociodemographic variables. In this study, information on the price of physician visits was not available. However, this is a relatively small geographic area and there are only a few physicians in the area. A separate physician fee survey indicated that in this area fees for a routine visit range from 12 to $14, a rather narrow variation. Insurance coverage is approximated by the occupation of the respondent. In addition to age, sex, educational level, and marital status, both psychosomatic and behavioral symptoms are included in the equation. A self-valued health status of the respondent and the existence of chronic ailments are included as state of health variables. In the survey, a question was asked about whether a respondent will usually consult with a physician when discomfort

occurs. This variable is included to reflect the preference for a doctor visit.

Table 5 presents the regression results for total number of physician visits between the TMI accident and January 1980. This equation includes more information about the respondents' health status and preference for physician visits. The results show that both behavioral symptoms and psychosomatic symptoms have statistically significant positive effects on physician visits. One additional behavioral symptom in the study period increases physician visits by 0.13, while one additional psychosomatic symptom increases physician visits by 0.07.

Table 5 also indicates that an obviously healthier person makes less physician visits, that individuals with chronic ailments prefer to consult with physicians and make more physician visits. Pregnant women made four more visits than non-pregnant women during the period. Males made less physician visits, and older persons made more physician visits. Neither income nor education shows significant effect on physician visits. It also appears that people with any one or more of the chronic aliments have a greater demand for physician visits. Also, as expected, pregnant women and older persons visit physicians more often than everyone else.

3.3 *Relationship between stress and work days lost*

In the January 1980 survey, respondents were asked about the number of work days lost for health reasons for the period from Labor Day 1979 to January 1980. On the average, individuals lost 3.2 work days.

The factors that affect the number of work days lost include the status of health of the respondent, age, education, sex, marital status, pregnancy status, preference for doctor visits, and status of labor market participation. For the purpose of this investigation, behavioral and psychosomatic symptoms were also included in the analysis. The regression analysis will be able to introduce these confounding variables as well as the stress variables, measured during and after the TMI accident. Thus, indirectly, the effect of stress may measure the effect of the TMI accident on work days lost, holding other socio-demographic variables the same.

Table 5. Relationship between stress and physician visits since TMI accident

intercept	2.454***
	(.836)
health	-.567***
	(.140)
preference for physician visits	.908***
	(.122)
male	-.350*
	(.207)
age	.196***
	(.079)
married	-.286
	(.385)
separated, divorced, widowed	-.609
	(.440)
family size	-.099
	(.068)
education	-.090
	(.137)
income	.047
	(.123)
chronic ailments	.512***
	(.206)
pregnant	4.259***
	(.711)
behavioral symptoms	.801***
	(.215)
total # of psychosomatic symptoms since TMI	.092**
	(.041)
farmer, homemaker, unemployed, retired, other	.156
	(.236)
sample size	379
R^2	.411
F statistic	18.15

Note: Values in the parentheses are standard errors of coefficients
*** Indicates the 1% level of significance (one-tailed test)
** Indicates the 5% level of significance (one-tailed test)
* Indicates the 10% level of significance (one-tailed test)

Table 6 shows the regression results for the number of work days lost. As in the demand for physician visits, stress has a statistically significant positive effect on the number of work days lost. Additionally, the pregnancy variable had a greater effect on the number of work days lost.

An interesting result of this analysis is that people who have a preference for visiting a physician when they are ill also have a larger demand for time off work. This suggests that time off work and physician visits are complements in the production of health. The alternative explanation would be that physician visits and time must be combined in fixed proportions in order to produce health. Thus, a certain amount of time must be used in conjunction with a physician visit to produce health.

Finally, individuals who work in the labor market have more work days lost than individuals who do not work in the labor market. There are two possible explanations. One is that individuals who do not work in the labor market may always report zero days lost from work for health reasons. Alternatively, individuals who work in the market may have fringe benefits that compensate them for their work days lost so that there is an incentive to take time off for health reasons.

Another aspect of the change in the productivity of labor is the possible change in work habits in relation to the TMI accident. According to the January 1980 follow-up survey, 10 out of 404 respondents indicated having difficulty concentrating in the work place and five reported working at a slower pace, for a total of about 3.7% of the respondents. Table 7 presents the regression estimates for the relationship between the behavioral and psychosomatic symptoms and change of work habits. Both variables suggest statistically significant effects on work habits.

3.4 *Relationship between stress and alcohol and cigarette consumption*

There is a tendency for people under stress or anxiety to increase their consumption of alcohol or cigarettes or to take tranquilizers or sleeping pills. According to the PSU survey, 63 respondents indi-

Table 6. Relationships between stress and work days lost, September 1979–January 1980

intercept	-2.317 (5.972)
preference for doctor visits	2.177*** (.871)
market workers	5.443*** (1.686)
health	-1.433 (1.004)
chronic ailments	.778 (1.471)
age	.178 (.567)
education	.110 (.979)
income	.613 (.881)
male	-2.050 (1.480)
married	1.319 (2.753)
divorced, separated, widowed	-1.524 (3.140)
family size	-.229 (.485)
pregnant	21.090*** (5.084)
behavioral symptoms	1.215 (1.535)
# of psychosomatic symptoms (March, July, January)	.951*** (.290)
sample size	379
R^2	.1501
F Statistic	4.59

Note: Values in the parentheses are standard errors of coefficients
*** Indicates the 1% level of significance (one-tailed test)
** Indicates the 5% level of significance (one-tailed test)
* Indicates the 10% level of significance (one-tailed test)

cated they drank more alcoholic beverages than usual during the accident period. This represents about 13.4% of the 469 regular consumers of alcoholic beverages. On the average, the regulars had four additional servings a day in any one day during the period. In general, 55% of the people drank beer, 15% drank wine, and 30% drank liquor. In the January 1980 follow-up interview, however, only 7 out of 404 respondents indicated that they increased their consumption of alcoholic beverages in relation to the TMI accident.

Within the 5-mile radius, 43% of the respondents were regular smokers, consuming about one pack (20 cigarettes) a day. Thirty-two percent of regular smokers indicated that they increased their smoking during the two-week TMI accident. These respondents smoked an additional ten cigarettes each day during the accident period. In the January 1980 follow-up interview, 32 out of 404 respondents indicated that they increased smoking in relation to the TMI accident.

During the two-week period of the TMI accident, 51 respondents took sleeping pills compared to 24 respondents who took sleeping pills during the questionnaire interview time (July). Similarly, there were 60 respondents who took tranquilizers during the TMI accident compared to 32 respondents who took them during the questionnaire interview period. These figures indicate that about twice as many people took sleeping pills or tranquilizers during the TMI accident as at other times. The consumption of sleeping pills and tranquilizers in January 1980 was about 22 and 31 out of 404 respondents, respectively.

Tables 8 and 9 provide the regression for the relationship between the consumption of sleeping pills, tranquilizers, alcohol, and cigarettes and the stress levels of the TMI residents, during March 1979 and January 1980. Other sociodemographic variables are also included in the three equations. Table 8 indicates that both psychosomatic and behavioral symptoms have statistically significant positive effects on the taking of sleeping pills and smoking cigarettes during the two weeks after the accident. In addition the psychosomatic symptoms have significant positive effects on the taking of tranquilizers and the behavioral symptoms have effects on drinking. These

Table 7. Relationships between stress and work habits, January 1980

Variables	Trouble Concentrating at Work	Work Slower
intercept	-.045 (.054)	.040 (.036)
sex	-.0004 (.017)	-.019 (.011)
age	.009 (.007)	.004 (.004)
income	.012 (.010)	-.012* (.007)
married	-.002 (.032)	.009 (.021)
divorced, separated, widowed	-.015 (.037)	-.018 (.075)
family size	.014*** (.006)	.002 (.004)
education	-.004 (.071)	-.009 (.008)
pregnant	-.012 (.060)	-.0006 (.04)
white collar	-.026 (.027)	.04*** (.018)
blue collar	.002 (.021)	.004 (.014)
see the TMI plant from work	-.016 (.016)	-.004 (.010)
behavioral symptoms	-.013 (.018)	.021* (.012)
psychosomatic symptoms	.009 (.003)***	-.001 (.002)
sample size	380	380
R^2	.06	.05
F Statistic	1.82	1.63

Note: Values in the parentheses are standard errors of coefficients
*** Indicates the 1% level of significance (one-tailed test)
** Indicates the 5% level of significance (one-tailed test)
* Indicates the 10% level of significance (one-tailed test)

Table 8. Relationship between stress and consumption of sleeping pills, tranquilizers, alcohol and cigarettes, March 1979

Variables	Sleeping Pills (Dummy Variable)	Tranquilizers (Dummy Variable)	Alcohol (# of Servings)	Cigarettes (in number)
intercept	-.012	-.016	.416	4.63
	(.05)	(.05)	(.240)	(2.34)
male	-.016	-.039*	.144	.518
	(.02)	(.022)	(.107)	(1.05)
age	.013	.012*	-.148***	-1.5***
	(.008)	(.008)	(.040)	(.39)
income	.00005	-.06	.008	-0.35
	(.013)	(.013)	(.06)	(.61)
married	.0002	.014	.046	2.62
	(.04)	(.036)	(.173)	(1.69)
divorced, separated, widowed	.03	.075*	-.067	2.32
	(.04)	(.044)	(.206)	(2.02)
family size	.009	.016**	.003	.23
	(.008)	(.008)	(.037)	(.36)
pregnant	.01	-.122	-.46	-8.60**
	(.064)	(.086)	(.40)	(3.93)
white collar	.018	-.016	.226	-1.67
	(.033)	(.034)	(.161)	(1.57)
blue collar	-.001	-.006	.084	-.877
	(.026)	(.027)	(.129)	(1.26)
psychosomatic symptoms (March)	.032**	.086***	.060	4.07***
	(.014)	(.013)	(.07)	(.69)
behavioral symptoms (March)	.072***	.040	.256**	3.68***
	(.028)	(.029)	(.134)	(1.30)
sample size	633	633	633	633
R^2	.046	.111	.056	.176
F statistic	2.70	7.13	3.21	8.13

Note: Values in the parentheses are standard errors of coefficients
*** Indicates the 1% level of significance (one-tailed test)
** Indicates the 5% level of significance (one-tailed test)
* Indicates the 10% level of significance (one-tailed test)

same patterns of significance exist for the January period as well, except that the alcohol consumption was not significantly affected by the stress level (see Table 9).

3.5 *Estimates of health-related economic costs*

Empirical estimations of the effects of the TMI accident on stress and the effects of stress on healt-related behaviors have been established in the previous four sections. The estimation of economic costs of these behaviors will rely on the magnitude of these changes. The procedure used to estimate these costs is as follows:

(Δ Stress level due to TMI) × (Δ Health-related behavior due to stress) × (size of the population in a given area) × (unit cost of the health-related behavior).

Changes in stress level due to the TMI accident can be obtained from regression coefficients in Tables 3 and 4. Changes in health-related behavior due to stress can be obtained from regression coefficients in Tables 5–9. Size of the population of the 0–5 mile ring is presented in Table 2. Unit costs of the health-related behaviors are obtained from prevailing fees in the local market. Costs can be estimated for the period from April 1979 to January 1980, based on the three interval time period. Table 10 provides the cost estimates of the changes in health-related behavior due to the TMI accident within the 5-mile ring, since data on the health-related behaviors are limited to within the 5-mile ring.

Based on the results in Table 4, about 50% of the stress symptoms existing in January 1980 may have been affected by the symptoms which existed in March or July 1979. Therefore, if one takes 50% of the stress level in March, 0.112 (0.255 2) for psychosomatic symptoms, and 0.240 (0.481 2) for behavioral symptoms, and multiplies by the coefficients for psychosomatic and behavioral symptoms in Table 5, the results indicate that the additional amount of stress level due to the TMI accident increases physician visits by 0.4 [0.1125 × 0.084) + 0.240 × 0.128)] for an average individual living 0–5 miles from TMI during the ten-month period. With 14,300 households in the 0–5 miles, the total number of additional physician visits becomes 5720 (14,300 × 0.4) for the ten-month period. Given a cost of $15 per physician visit, the total cost for the entire period would be $85,800.

Similarly, the effects of psychosomatic stress on the

Table 9. Relationship between stress and consumption of sleeping pills, tranquilizers, alcohol and cigarettes, January 1980

Variables	Sleeping Pills (Dummy Variable)	Tranquilizers (Dummy Variable)	Alcohol (# of Servings)	Cigarettes (# Packs)
intercept	-.114*	-.114	-.024	.132
	(.069)	(.08)	(.037)	(.084)
male	-.014	-.034	.019	-.016
	(.024)	(.029)	(.013)	(.03)
age	.026***	.014	-.006	-.032***
	(.009)	(.01)	(.005)	(.01)
income	.012	.016	-.0008	.047***
	(.015)	(.017)	(.008)	(.018)
married	-.03	.028	.019	-.057
	(.05)	(.054)	(.024)	(.056)
divorced, separated, widowed	-.01	.077	.031	.026
	(.05)	(.061)	(.028)	(.065)
family size	.008	.016*	-.001	.007
	(.008)	(.009)	(.004)	(.01)
education	.004	-.001	.009	-.044***
	(.016)	(.01)	(.009)	(.02)
pregnant	-.008	-.068	-.01	-.09
	(.09)	(.099)	(.05)	(.11)
white collar	-.005	-.026	.003	-.039
	(.04)	(.044)	(.02)	(.047)
blue collar	.029	.001	-.001	-.026
	(.029)	(.034)	(.015)	(.036)
behavioral symptoms	.051***	.037	.01	.079***
	(.026)	(.029)	(.013)	(.031)
psychosomatic symptoms	.017***	.019***	.003	.014***
	(.005)	(.005)	(.003)	(.006)
sample size	379	379	379	379
R^2	.112	.094	.024	.112
F statistic	3.85	3.15	0.76	3.86

Note: Values in the parentheses are standard errors of coefficients
*** Indicates the 1% level of significance (one-tailed test)
** Indicates the 5% level of significance (one-tailed test)
* Indicates the 10% level of significance (one-tailed test)

Table 10. Changes in health-related behavior due to TMI, 0–5 mile ring two weeks after the TMI accident and two weeks between July 1979—January 1980 (additional quantities)

	April 1979		July 1979–January 1980	
	Quantity[a]	Costs[b]	Quantity[a]	Costs[b]
physician visits	290	$ 4,350	235	$ 3,525
work days lost (days)	8,870	266,100	8,597	257,100
sleeping pills (tablets)	298	36	153	18
tranquilizers (tablets)	802	96	171	12
alcohol (servings)	560	336	--	--
cigarettes (pack)	1,900	950	1,753	876
Total		$271,868		$261,531

Notes: [a]The quantities are derived from the product of the three distance regression coefficient in Table 3 (March) in relation to psychosomatic stress and the regression coefficients in Tables 4, 6, and 8.

[b]The unit costs were $15 for each physician visit, $30 for each work day lost, $.12 for each sleeping pill or tranquilizer, and $.70 for one alcoholic beverage serving, and $.50 for one pack of cigarettes.

work days lost during the September 1979–January 1980 period was the 1.34. Statistical results indicate that about 32% of the stress level in March could affect the stress status during the last quarter of the year, as shown in Table 4. Table 3 also shows that there were 0.22 additional stress symptoms for 0–5 mile residents due to the TMI accident. Thus, the resultant number of work days lost for 14,300 households becomes 1349 days ($1.34 \times 0.32 \times 0.22 \times 14{,}300$). If one extends this estimate for the period of April 1979 to August 1979 (an additional 5 months), it would become about 2698 (1349×2) for the entire ten-month period after the accident. At $30 for each work day lost, the total amount would be $80,940.

Similar estimation techniques are used for estimating the additional consumption of sleeping pills, tranquilizers, alcohol, and cigarettes. Actual quantities are also shown in Table 10. The total cost of sleeping pills, tranquilizers, alcohol, and cigarettes are about $11,679.

The monetary valuation of the health-related economic costs of the TMI accident indicates that the increase in physician visits and work days lost are the two largest health-related cost items. The total monetary costs for residents within the 5-mile ring are about $178,419 for the ten-month period. Compared to the economic costs of evacuation and the costs to the industrial and utility sector, the health-related economic costs appear rather trivial. However, from the survey data, it was obvious that the TMI-related stress was real and did exist. Thus, these monetary cost estimates of the health-related behaviors provided in this study may be conservative figures.

4. CONCLUDING REMARKS

This study has hypothesized that the accident at TMI affected area residents' mental status, if not their physical status. Mental status refers to increased stress and psychosomatic symptoms of people in the area. This study examines three types of health-related economic costs of the TMI accident: (1) the increase in health care services, (2) the increase in work days lost, and (3) the increase in consumption of sleeping pills, tranquilizers, alcohol, and cigarettes. Two data sets are used to examine these effects—the NRC data and the study survey (PSU data).

The findings indicate that stress symptoms caused by the TMI accident did affect the health-related behaviors of area residents. Based on regression analysis, it is estimated that the cost of the changes in health-related behaviours was about $178,419 for a period of 10 months within a 5-mile ring of TMI. Of the costs examined, the economic costs of work days lost and physician visits are the largest cost items. The results also show that there are significant effects of the stress on the increased consumption of cigarettes, alcohol, and tranquilizers after the accident.

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AMERICAN JOURNAL OF Public Health reprint

Utilization of Medical Care following the Three Mile Island Crisis

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Abstract. Four studies are reported on how utilization of primary health care was affected by the Three Mile Island (TMI) crisis and subsequent distress experienced by persons living in the vicinity of the plant. The studies concerned: 1) Blue Cross-Blue Shield records of claims by primary care physicians in the vicinity of TMI; 2) utilization rates in a family practice located near the facility; 3) interviews with persons living within five miles of TMI following the crisis; and 4) responses to a questionnaire by primary care physicians practicing within 25 miles of TMI. All four studies indicated only slight increases in utilization rates during the year following the crisis. One study found that persons who were upset during the crisis tended to be high practice utilizers both before and after the crisis. These results suggest that, while patterns of physician utilization prior to the TMI crisis predicted emotional response during the crisis, the impact of the TMI crisis on subsequent physician utilization was small. (*Am J Public Health* 1984; 74:140–142.)

Introduction

There is substantial evidence that psychological distress is related to physician utilization.[1] However, less is known about the conditions that affect that relationship, such as whether there is a threshold level of distress which must be reached before utilization is affected, and whether certain kinds of stress situations are more likely to lead to increased utilization than others. The crisis at Three Mile Island (TMI) in March and April of 1979* and related events during the following year provide an opportunity to study such questions. Four studies of physician utilization in the vicinity of TMI during the year following the crisis are summarized in this article.

Two facts about the TMI crisis provide context for the studies reported here. First, the releases of radiation during the crisis were quite small** and, therefore, very unlikely to have any measurable physical health impact on the population. Second, levels of distress, as evidenced by both attitudinal concern and symptom reporting, were reported among persons living in the immediate vicinity of TMI for at least a year following the crisis.[3–5] These long-term distress levels near TMI were in the "high normal" rather than "pathological" range as indicated by Symptom Check List 90 scores.[4,5] The question addressed in the studies reported here was whether these persistent, low levels of psychological distress resulted in increased utilization of primary care physicians (family practitioners, pediatricians, obstetricians, and internists) by persons in the immediate vicinity of TMI.

Blue Cross/Blue Shield Study

The first study[6] analyzed procedure claims submitted to the Pennsylvania Blue Cross/Blue Shield from April through December 1978 and April through December 1979 from the 556 primary care physicians practicing in the five counties surrounding TMI. The sample included 287 family practitioners, 152 internists, 78 gynecologists, and 39 pediatricians. Distance from TMI was used as a proxy measure for stress, based on the finding that both symptom reporting and attitudinal concern about TMI for nine months following the crisis were elevated within a 15-mile radius of the facility but dropped sharply beyond that distance.[7] The limitation of these data is that visits due to stress are likely to be underrepresented in Blue Cross/Blue Shield claims, since they may not result in procedures that are chargeable to Blue Cross or Blue Shield.

Table 1 shows a drop in the number of procedure claims from 1978 to 1979 for physicians practicing both within and beyond 15 miles from TMI, but the drop, although not statistically significant, was smaller within 15 miles of TMI than beyond. Additional analyses were conducted to determine if an effect of TMI would be evident for the different types of primary care physicians. The results were consistent with those reported here with no statistically significant effects that could be attributed to the TMI crisis noted.

Family and Community Medicine Study

The second study concerns frequency of visits to physicians by a sample of patients of the Department of Family and Community Medicine at the M.S. Hershey Medical Center (8½ miles from TMI) during the year before and the year following the crisis. The 498 subjects in this study had been patients in the practice for at least a year prior to the TMI crisis, had visited the practice two to six weeks after the crisis and had filled out a brief questionnaire in which they reported their age, sex, education level, and rated how upset they were during the TMI crisis on a six-point scale ranging from "not upset" to "extremely upset." This rating scale was subsequently used in surveys conducted by the Pennsylvania Department of Health where it was shown to be correlated with concerns about the safety of TMI, with attributing of symptoms to TMI, and with distance from TMI (higher ratings of upset close to TMI). It was also shown in these studies to correlate with Langner scale scores.[7]

Results of the Hershey study are shown in Table 2. The comparison of post-TMI utilization rates of high and low distressed patients, controlling for utilization rates prior to TMI, age, sex and education of the respondents, is not statistically significant. However, an examination of the

*The "accident" began on March 28, 1979 at 4:00 a.m.

**Maximum possible off-site dose that an individual could have received was less than 100 millirems.[2]

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TABLE 1—Mean Number of Blue Cross Claimed Procedures per Physician per Month Pre- and Post-TMI Crisis for Primary Care Physicians‡ Practicing in the Five Counties Surrounding TMI

	Mean Number of Claimed Procedures per Month	
	April–December 1978	April–December 1979
Physicians practicing within 15 miles of TMI (N = 295)	112.5	110.7
Physicians practicing beyond 15 miles of TMI (N = 261)	93.2	89.8
Difference**	19.3	20.9*
Difference controlling for number of claims April–December 1978‡‡		4.5

*P < .05.
‡Includes family practice, internal medicine, OB-GYN and pediatrics.
**Differences in physician monthly rates tested utilizing t-test.
‡‡1979 physician monthly rates tested controlling for 1978 monthly rates utilizing analysis of covariance.

TABLE 2—Mean Number of Practice Visits before and after the TMI Crisis, Family and Community Medicine Practice, M.S. Hershey Medical Center

Patient Ratings of Upset during TMI Crisis	N	12 months before TMI	12 months after TMI
Extremely, very or somewhat upset	344	4.10	4.63
A little or not upset	154	3.55	3.91
Difference‡		.55*	.72*
Difference controlling for a number of visits before TMI, age, sex and education‡‡			.65

*p < .05.
‡Differences in patient utilization rates tested utilizing t-test.
‡‡Differences in patient utilization rates post-TMI controlling for patient utilization pre-TMI, age, sex, and education of the respondent utilizing analysis of covariance.

means shows a trend in the predicted direction with greater utilization by the upset as compared to non-upset groups post-TMI, controlling for pre-TMI utilization rates. It can also be noted that both high and low distressed groups showed an increase in utilization after TMI, but this is difficult to interpret since the sample was taken from patients waiting to see physicians which would normally include many patients who were increasing their utilization. There were, however, two interesting statistically significant findings indicating that patients who were high utilizers of the practice both before as well as after the crisis period tended to rate themselves as upset during the crisis. This suggests that persons with a pattern of high practice utilization responded emotionally to the crisis to a greater degree than did those who were low practice utilizers.

Sample bias is an important limitation of this study and should be considered in interpreting its findings. The sample included only patients who had been in the practice over one year, who used the practice during the period immediately following the crisis, and who agreed to fill out the questionnaire. Because the sample was of consecutive users, it is likely to include a disproportionate number of high practice utilizers which is indicated by the fact that the study group averaged over four visits to the practice per year while the average number of visits to family practices nationally is estimated to be 2.55.[8] Since the sample included only patients who used the practice for at least a year before the study period, it is also biased toward long-term utilizers. Other biases are indicated by comparing the age and education levels of persons in this sample with those of the adult population within 25 miles of TMI as estimated from randomized telephone surveys conducted by the Nuclear Regulatory Commission shortly after the crisis.[9] The mean ages of sample members was 43.4 as compared to 44.9 for the NRC sample, and the mean years of schooling was 13.5 as compared to 12.5 for the NRC group. Therefore, this sample is probably slightly younger and more educated than the population as a whole. The strengths of this study, on the other hand, are that objective records of utilization were used and that pre-TMI baseline rates were included in the analyses. Additional analyses of patient records were carried out to determine whether visits for certain types of problems or of certain types of patients may have been affected by the crisis and, as with the results reported here, no statistically significant effects of the crisis could be detected.

Population and Physician Surveys

In this section, results of three interview surveys will be discussed. Two of these were telephone surveys of persons living within five miles of TMI, conducted by the Pennsylvania Department of Health in July 1979 and January 1980.[7] In these surveys, adult heads of households were asked if they had visited physicians since the TMI crisis and, if so, if the visit was because of Three Mile Island? The third survey was a questionnaire mailed to primary care physicians in the five-county area surrounding Three Mile Island.[6] Physicians were asked questions about how their practices had been affected by the TMI crisis. The strength of these studies is that they report the perceptions of the persons who receive and provide medical care. In the case of the two telephone surveys, a high response rate (82 per cent) was achieved. The limitations of these studies include the possibility of distorted recall, the fact that data were obtained only for adults in the telephone surveys, and that the return rate was only 32 per cent in the physician survey. Therefore, both response bias and sample bias are possible.

In the July 1979 survey, fewer than 1 per cent of respondents (two out of 692) said they had visited physicians during the two-week period of the crisis because of symptoms associated with TMI. However, in January 1980, 9 months after the crisis, 8 per cent of respondents said they had visited physicians at some time because of the crisis.

Results of the physician survey indicated that primary care physicians were aware of only a small effect of the TMI crisis on their patients' visiting patterns. As shown in Table 3, within the 25-mile radius, primary care physicians reported an average of only 4.9 patients each who believed that their visits were due to TMI. Furthermore, the physicians felt that only one of those patients (23.6 per cent) were caused by TMI-related stress. The most frequently cited symptoms which the physicians felt may have been due to TMI included stomach trouble, headaches, difficulty in sleeping, and loss of appetite. These are among the symptoms that were found, in telephone surveys, to be elevated near TMI.[7]

TABLE 3—Perceptions of 223 Primary Care Physicians Practicing within 25 Miles of TMI of How Their Patients Were Affected by the TMI Crisis

Average number of patients (per physician) who *believed* visit is due to stress from TMI	4.9
Average per cent of these patients' visits that *physicians* think is due to stress from TMI	23.6
Selected symptoms physicians noticed may be due to TMI (per cent of physicians reporting each symptom)	
Stomach trouble	12
Headache	5
Trouble sleeping	5
Loss of appetite	3

Discussion

Despite the limitations of the studies presented here, the results are strikingly consistent: all indicate only small, if any, increases in utilization of primary physician services following the TMI accident. Since magnitude of the effects observed were small, the lack of statistical significance may be the result of type II error. In view of this, the consistency of findings across the studies is especially important. Patient self-reports yielded the largest estimates of utilization due to TMI (8 per cent). Two other investigators have reported similar self-report findings for physician utilization in the vicinity of TMI. Kasl *et al*,[10] reported that approximately 7 per cent of nuclear workers at TMI said they had seen a physician because of the accident, and Dunn[11] reported that 8 per cent of her sample of mothers of young children living within 10 miles of TMI said they had visited a primary care physician because of TMI. However, attributing a physician visit to TMI does not necessarily mean that the visit would not have occurred in the absence of an accident. This was suggested by the results of the physician survey where less than one-fourth of the visits which patients attributed to TMI were felt by physicians to be due to TMI.

The low levels of long-term distress near TMI were below the range characteristic of mental patients.[3–5] It may be that distress must be in the mental patient range for a considerable period of time in order to have a marked effect on physician utilization. Furthermore, as Gortmaker[12] has pointed out, the linkage between stress and health care utilization depends on the measures and time periods involved. For example, the length of the time periods studied may have obscured short-term effects of the crisis on health care utilization.

The one statistically significant finding was in the Family and Community Medicine study indicating that persons with a pattern of high practice utilization tended to be more upset during the crisis than low practice utilizers. This finding suggests that high utilizers of medical services may be especially sensitive to stressful situations. Such sensitivity may be one factor in the reported relationship between psychological distress and physician utilization.[1]

A practical implication of these findings is for planning services that may be needed in dealing with similar events in the future. The findings presented here suggest that there will be only small increases in demand for medical services following a crisis where there is little direct physical harm to persons and where long-term distress is well below the level characteristic of mental patients.[12]

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ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of Robert Miller, PhD, Marilyn Goldhaber, MPH, and Robert Crist, PhD, in both data analysis and editorial assistance.