Warning Human Populations of Technological Hazard

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ABSTRACT[1] Warning people of an impending hazard seeks to make them aware of the threat and to elicit actions that would minimize the dangers to life and property.[2] Because technological and natural hazards differ in important ways, the alerting and notification process for technological and natural hazards is also different. One of the differences rests in the ability of people to detect many natural hazards in a direct sensory manner; technological hazards often make such detection more difficult. For example, detection of radiological releases without instrumentation is nearly impossible, but even with tornadoes where warning is notoriously difficult, people are at least able to use their senses to detect the potential for hazard. Hence, warning for technological hazards is in some ways more problematic, generally representing a rather rapid shift from normalcy to emergency. This paper builds on the significant foundation of natural hazard warning research in developing a model of warning suitable for technological hazards. This model specifically examines immediate cascading, or networking, of the warning signal and message, so often reported in the natural hazard literature. The implications for technological and natural hazard warnings systems are examined.

I. INTRODUCTION

Warning people of an impending danger may be partitioned into two somewhat distinct aspects. The first deals with alerting the public that something is wrong, that some hazard is imminent. The second concerns the ability of emergency officials to communicate the warning message to prompt appropriate action. The primary issues of alerting revolve around the ability to make people aware of the threat. This alerting often involves the technical ability to develop, construct, maintain and use a warning system, which may consist of sirens, bells, whistles, television and radio broadcasts, telephone systems and even social organization. The primary notification issues center on the public's interpretation of the warning message. The interpretation of the warning message is fundamentally important in the selection of appropriate action in response to warning. The focus of this paper is on the social processes associated with alerting the public to potential danger.

Hazards are broadly cast as technological and natural. Technological hazards are generally characterized by the failure of a technological system(s). While technological hazards are generated by human interaction with the environment, natural hazards may be viewed as "acts of God." Hence, questions of culpability are often associated with technological hazards. The developers and operators of the technological system become legally responsible for the safety of its operation. Such culpability is seldom attributed to natural disasters. At least for some kinds of technological crises the potential impact area is predictable. While even the best meteorologist has difficulty determining the pathway(s) and point(s) of impact for an approaching tornado, hazardous facilities that are geographically fixed, thus there is the advantage of being able to establish emergency planning zones in proximity of the fixed facility. On the negative side, at least some technological hazards are less detectable than any natural hazard. Nuclear exposures, for example, are not detectable by any of the five human senses, some toxic chemical releases are similarly undetectable. However, other technological hazards make possible the use of many of the same detection criteria as natural disaster threats. For example, the danger of dam failures is often brought on by heavy rains and results in flooding that is detectable by the same mechanisms as other forms of flooding. This paper focuses on the social aspect of the alerting process, primarily for hazards of a fixed, or at least known geographic location. However, the social principles applied to these fixed geographic locations apply equally well to other technological hazards and even natural hazard alerting situations.

II. BACKGROUND

Warning messages pass through a variety of pathways which may color their meaning. Some of these pathways involve cognitive functions, others have to do with social structural considerations. An individual's interactions with others form social networks. Even though these networks have many forms, their routine and established nature has led to widely accepted empirical generalizations about how they function in society at large (e.g., Parsons 1951, Coleman et al. 1957, Granovetter 1973, Blau 1977) and in particular how they function during emergency warning. Two general propositions are strongly supported by the disaster literature (Williams 1964): First, that people respond to emergency warnings in a context of their prior experience, extant social and physical environment and existing conditions which interact with the warning message. And second, that the degree to which the warning message is received depends on the nature of the message, taken in the context of the social network, and the prior behaviors of all social actors in processing such information. Hence, people in social networks in specific locations have extant estimates of the threat presented by the environment in which they live. These estimates and their experience vector provide the data base from which the selection of behavior is derived--the decision to accept, ignore, disseminate, challenge, or confirm the warning message (Baker 1979).

[2]The former is the alerting function of warning systems, and the latter constitutes their notification function.
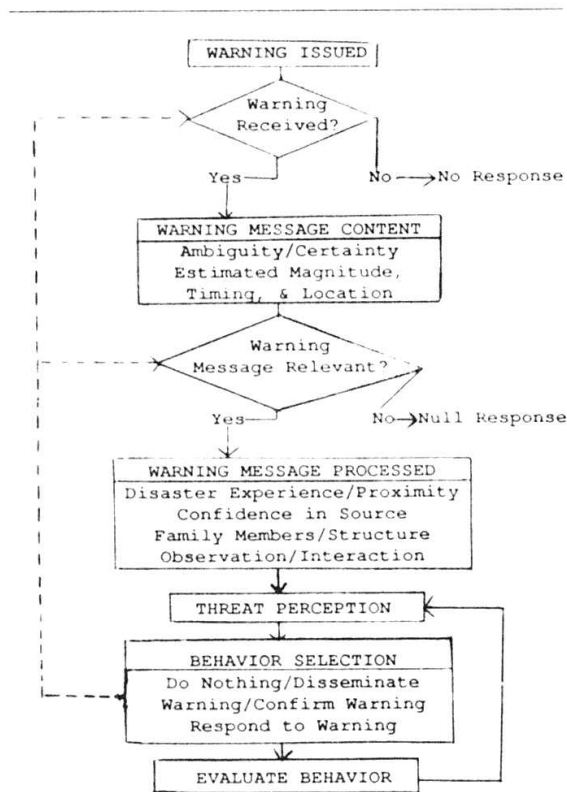
Figure 1 - Warning Process

Emergency warnings may result in the recognition of threat which creates a psychological discomfort. One important mechanism to alleviate this involves efforts to reduce uncertainty. The warning process (Figure 1) involves both factors affecting the message and characteristics of the receiver. Once the warning is received the content is evaluated in terms of the certainty and ambiguity of the estimated severity, timing and location of impact. Essentially, "Is it likely to effect me? When will it occur?" The evaluation of the warning message results in the determination of its relevance. If the message content is deemed irrelevant, no emergency response is likely. However, should the warning message be considered relevant, the message is further processed in the context of prior disaster experience, relative proximity, confidence in the source of warning, interpretation and discussion with members of the social network. The warning message is processed in the context of the existing social structure, which results in, at least, the initial perception of threat. The cumulative process provides the foundation for the selection and evaluation of emergency behavior.

The social process which is then triggered also serves to further disseminate the warning message. When an individual receives, recognizes, verifies and believes the warning message and deliberately disseminates it to others in the social network, a purposive warning dissemination takes place. An incidental warning takes place when the individual in the process of seeking confirmation of the warning message, inadvertently gets in touch with someone who has not been alerted yet. Warning confirmation and dissemination through the social network helps warn previously unwarned people, if indirectly, and confirms the meaning of the original warning for those having received it previously. "Instead of trying to stop people [from] calling one another ways ought to be found to take advantage of such calls

so as to improve the dissemination of warning messages " (Kendrick 1979 346) Furthermore it should be added that both confirmation and dissemination of warning through the social network improve response to emergency warnings (Quarantelli and Dynes 1976, Perry et al 1980. Drabek and Boggs 1968, Mileti and Beck 1975, and Rogers and Nehnevajsa 1984)

Effective warning messages have been described by Janis (1958) as requiring a balance between fear arousing and fear-reducing statements Fear-arousing statements describe the impending danger in sufficient detail as to evoke vivid mental images of the crisis, reducing the possibility for surprise as the disaster evolves Fear-reducing statements realistically present the mitigating factors of the impending situation, and provide information regarding realistic actions to be taken by authorities and individuals, both independently of one another and jointly The fear-arousing content of the warning message alerts the public to the potential for harm, while the fear-reducing statements consist of notification of appropriate mitigating action

III. THE ALERTING PROCESS

People are alerted to the potential for danger by a variety of sources. These sources of warning are broadly classifiable warning by authorities, from the mass media, and those transmitted through the social network. Drabek (1969) and Perry et al (1981) refer to warning from authority as those messages which are generated from and disseminated by emergency-services organizations (e.g., police or fire departments, civil defense organizations or the national guard), while mass media warnings usually come from radio and television, although in slowly-evolving disasters, the print media also play a crucial role. The social network provides warning through relatives, friend and neighbors. Perry et al (1981) report that 41.2% of first warnings for riverine floods in four communities came from authorities. While there was apparently no time for mass media warnings in two communities, the mass media accounted for 8.1% of warning alerts. Nearly half of the first warnings in these four communities stemmed from the social network--37.6% from friends and neighbors, and 13.0% from relatives. While the distinction between social network alerts that purposely disseminate the warning, and those that incidentally warn others is not possible on the basis of the present evidence, the receipt of first warning is often made through personal contacts with members of the social network (Perry 1981, and Mileti 1974).

Around Three Mile Island more people received their first warning (were alerted) via social networks than expected to receive such warnings. Flynn (1979) found that only 6% expected to be alerted by friends, neighbors and relatives, but Brunn et al. (1979) and Barnes et al. (1979) report 18% to 25% actually claimed to have received their first warning from social network sources. Of those people receiving warning on the first day of the accident, 22% were alerted through the social network, and for those with the highest saliency (living within 6 miles), 43% were alerted by people in their social network (Barnes et al. 1979). This is consistent with other research which suggests that "word-of-mouth" warnings are more likely among people most likely to be affected by the impending danger (e.g., closest to the threatened area (Diggory 1956). Hence, for fixed-site technological hazards, where the saliency for nearby residents is fairly clear, social networks may be more effective than in situations where the proximity of hazard is less clear. In natural disasters, in which the probable impact area can be ascertained reasonably well, significant proportions of people are also alerted through the social network. For example, Perry (1981) reports 31.7% and 38.6% of the people received their first warning from others in their social network in connection with the volcanic activity and floods respectively

The overall emergency alerting process can be considered as comprised of two basic processes. The <u>warning alert process</u> determines the capability of the warning technology (e.g., sirens, bells) to deliver the warning message to the public. The effectiveness, of course depends on factors of the physical environment and the system technology, both constrained by natural laws. Siren sound coverage, ambient noise levels, warning signal attenuation, biological hearing capability, acoustical properties of the alerting signal are among the salient considerations. To the extent that human activities alter such parameters, such as sleeping, operating equipment or listening to music, social behavior is clearly critical to the actualized initial receipt of the message. The <u>dissemination of the warning alert</u> takes place through the household and neighborhood alert processes. The household or "area" process involves the intra-household dissemination of the warning message, while the neighborhood process represents the inter-household dissemination of warning.

The warning alert process results in some households being completely alerted by the initial warning signal, others may have at least one person alerted, and in some households no one will be alerted by the initial warning signal (Figure 2). The household alerting process characterizes the distribution of the warning signal within a household that is partially alerted by the initial warning signal (i.e., at least one person). Households where everyone is alerted, either by the initial warning signal or through intra-household dissemination, become the potential warning message transmitters in the neighborhood process.
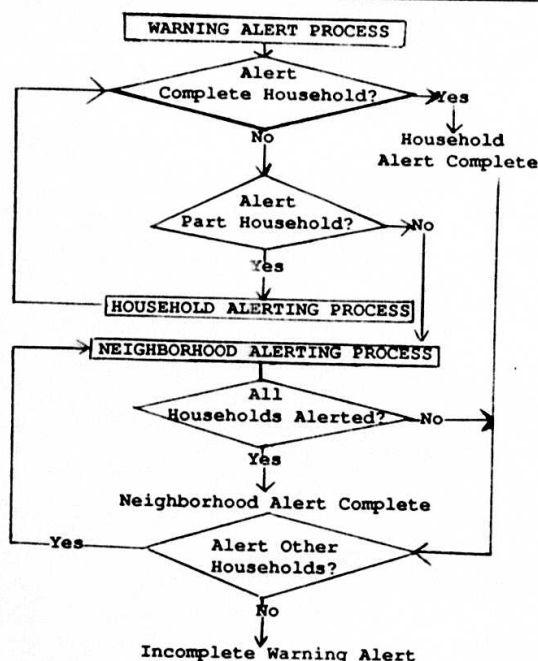

Figure 2 - Alerting Process

Households that initially remain unalerted may receive the warning through the neighborhood alerting process. The household alerting process is consistent with family re-unification for household emergency response (Rogers and Nehnevajsa 1984, Frazier 1979, and Drabek 1969), which finds that households prefer to respond to crises as a unit. Both the household and the neighborhood alerting processes provide consistent confirmation of warning that often takes place during emergency warnings (Rogers 1985).[3]

IV. WARNING ALERT MODELS

Considering a late-night (i.e., 12 midnight to 6 a.m.) warning, Nehnevajsa (1985a) incorporates three major factors in assessing warning alert: 1) The effect of non-sleeping activities, 2) the effect of intra-household networking, and 3) the effect of inter-household networking. Activity probabilities are based on a detailed study of time use conducted by the University of Michigan (Juster et al. 1983) which results in late-night probabilities of being awake of .092 and .058 between midnight and 2 a.m., and 2 a.m. and 6 a.m. respectively (Hummon et al. In Press). Intra-household networking is considered on the basis of household by size and composition, peak alerting signal levels as a function of distance from the warning signal source, attenuation rates for different types of houses and residential conditions. Somewhat conservatively assuming that about half of those alerted by the initial warning signal will make a single contact with another household (even though 87.5% of respondents in a recent University of Pittsburgh study expect their neighbors to contact others, even in the middle of the night, to warn them of impending danger), initial "acoustic" alerting of 69.0%, would be augmented to 79.3% of the residents, given these basic considerations. A second acoustic signal, resulting in 72.8% of the people alerted would be enhanced to 82.2% alerted.

Even an elementary model, which only accounts for arousal probabilities by household size significantly reduces the proportion of people left unwarned (Nehnevajsa 1985b). Assuming that only one in four people alerted by the initial signal would attempt to make contact with others in their social network the initial warning signal leaves 15.5% of the people unalerted. However, a single social network contact decreases the proportion of unalerted people to 11.6%, and a second networking attempt reduces the unalerted proportion to 8.6%.

One significant limitation of these models revolves around the timing of the networking process (Landry and Rogers 1982 and Nehnevajsa 1985b). The warning process that incorporates both the initial alerting system, which is technologically (e.g., sirens, bells, television, or radio) based, and diffusion of warning through the social network, involves initial alerting via a "broadcast" process,[4] and subsequent alerting via a "birth" process[5] (Lave and March 1975). Both processes are time oriented (t) and limited by the size of the population to be alerted (N). The broadcast and birth processes are represented respectively by

$$dn/dt = a_1(N-n), \text{ and } dn/dt = a_2 n(N-n),$$

where n, is the alerted population at the beginning of each period (t_0, t_1, t_2...), and a_1 and a_2, are proportions summarizing the diffusion properties of the respective processes. Combining these two processes into a single warning system

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[3]This paper does not examine the significant issues associated with the notification process, which involves the belief and interpretation of the warning message and the selection of behavior. The significant issues of behavioral contagion, will people take action independently or in conjunction with the behavior of friends, neighbors and relatives, and the effect of source of warning confirmation, or type of warning notification on behavior selection are excluded.

[4]This process rests on the broadcast of the warning message by technical mechanisms, such as television, radio, sirens, bells, whistles or a combination of these specific technologies in combination with organizational assistance. It is referred to as broadcast because the message is broadcast from a relatively centralized source to the public.

[5]This process rests on the dissemination of the message among people. It relies on a less centralized warning dissemination, where each recipient passes or at least attempts to pass the message to others in the network.

$$dn/dt = k\{a_1(N-n)\} + (1-k)\{a_2n(N-n)\}.$$

where k, is the proportion receiving the warning alert signal, and (1-k) represents the proportion not alerted by the broadcast signal.

Using this classical model of the dissemination of warning, the timing of warning over the initial period can be examined. Suppose the broadcast warning system only operates in the first three minutes of the warning period, even though no warning system that we are aware of operates only in the first few minutes without being reactivated in later periods. Further suppose that k is equal to the proportion of non-sleepers. This is equivalent to saying that arousal from sleep need not be considered for those that are not asleep. Finally consider a broadcast process efficiency (a_1) of only .5, and a birth process effectiveness (a_2) of .3. This broadcast efficiency is well below the acoustical warning rate reported by Nehnevajsa (1985a), and the contagion effect is substantially below people's expectations and reported incidents. Even assuming these conservative system parameters, the warning system alerts 76.2% in the dead-of-night (2 a.m. to 4 a.m.) in the first 15 minutes (Figure 3).[6] Given the drastically larger proportion of non-sleeping people between 8 a.m. and 10 a.m., and 8 p.m. and 10 p.m., the proportion warned exceeds 80% in the initial periods of warning, resulting in approximately 88% being alerted in the first fifteen minutes. Given quite different broadcast alerting probabilities, reflecting the period of the day differences, the results at the end of fifteen minutes are remarkably similar, but the trajectory within the period is very different. Hence for technological hazards with various onset times, the broadcast system requirements will be somewhat different. For technologies either with long onset times or where warning systems can be activated early, systems may place greater dependence on the birth process in emergency warning.
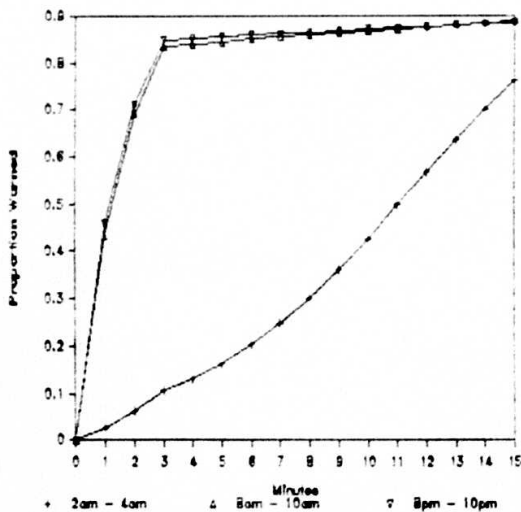

Figure 3 - Timing of Warning

[6]Minutes is perhaps better described as steps, inasmuch as we remain uncertain about the exact duration required for message passing. While given adequate saliency household contagion probably take less than a minute, message passing in the neighborhood process is less certain. Hence, what we label as minutes, reflects steps that probably range in duration from somewhere near 15 seconds upwards to 3 to 5 minutes. The actual duration of these time intervals is almost certainly dependent on the nature of the hazard, its saliency, timing and action requirement.

V. POLICY IMPLICATIONS AND CONCLUSIONS

Social network alerting deserves full recognition as a valid aspect of the overall emergency warning process. It cannot be assumed that everyone, especially younger children, is able to properly interpret the meaning of the warning signal, even if it is "heard," and thereby recognize the impending threat. Therefore, the cascading effects of networking become an integral part of the system. The dissemination of warning provided by the cascading of the warning message through the social network significantly enhances coverage of the warning alert. Hence, emergency warning systems can effectively alert residents in adjacent areas by taking advantage of the social network dissemination of warning. This is particularly true for fixed-location technological hazards, such as nuclear power plants. However, it is incumbent upon risk managers of such facilities to increase public awareness of the potential for hazard, ability to recognize and interpret the alerting signal, and awareness of what actions to take.

All emergency warning systems take advantage of both an alert signal and a further dissemination of the warning through the social network. The trade-off between the two processes rests on considerations of cost and timing of adequate coverage. Because the birth process depends on alerted people to disseminate the warning message, the more expensive broadcast of emergency warning is inherently faster. For hazards with onset trajectories similar to hurricanes, the warning system can place more reliance on the networking process. Relatively slowly evolving emergencies not only provide time for the social networking process to be highly effective, but these hazards also allow people to become attuned to the impending hazard, which "pre-charges" the network for further alerting and notification as information about the hazard gets to be more intensive, and the danger becomes more acute. On the other end of the hazard spectrum, rapidly evolving hazards require greater reliance on a broadcast system, even though such a system can never be completely effective on its own. Hence, one key factor in determining the extent to which the less costly social network dissemination of warning can be employed concerns the technologies which permit an early detection of particular hazards. Can the hazard be detected with sufficient lead time to alert the public? Another factor in the selection of an efficient emergency warning system (i.e., obtaining coverage with an optimum mix of the broadcast and social network processes) is the reliability of early warning, and appropriate policy decisions to warn at early stages of a possible disaster. This involves another trade-off between the issuance of early warning and the probability of a false alarm.

To the extent that there is actable time, any warning system can be improved, in the sense of alerting more people with less time, both through improvements in the broadcast system and by enhancing the social network process. The broadcast system can alert more people by enhanced coverage (e.g., louder signals, or more complete distribution of warning devices among the population). While these system improvements are desirable, the social network process can also be enhanced by encouraging people to contact others when they are alerted. By encouraging people to become involved in the emergency warning process, emergency preparedness beyond better warning is improved, because people are more likely to develop an understanding of the potential hazards, the nature of potential threats, the kinds of available protective actions needed, and take an active role in assuring their own safety, and in enhancing the safety of their relatives, friends and neighbors.

VI. REFERENCES

Baker, E. (1979) "Predicting Response to Hurricane Warnings: A Preanalysis of data from Four Studies," Mass Emergencies, 4, 9-24.

Barnes, K. et al. (1979) "Responses of Impacted Population to the Three Mile Island Nuclear Reactor Accident," Rutgers Univ., Dept. of Geography.

Blau, P. M., (1977) Inequality and Heterogeneity: A Primitive Theory of Social Structure, The Free Press, New York.

Brunn, S. D. et al. (1979) "Social Survey of Three Mile Island Area Residents," Michigan State Univ., Dept. of Geography.

Coleman, J., et al. (1957) "The Diffusion of Innovation Among Physicians" Amer. Sociology Review, 20, 253-270.

Diggory, J. C. (1956) "Some Consequences of Proximity to a Disaster Threat," Amer. Sociology Review, XIX, 47-53.

Drabek, T. (1969) "Social Processes in Disaster: Family Evacuation," Social Problems, 16, 336-346.

Drabek, T. and K. Boggs (1968) "Families in Disaster: Reactions and Relatives," J. of Marriage and the Family, 30, 443-451.

Flynn, C.B. (1979) "Three Mile Island Telephone Survey," Mountain West Research, Tempe, AZ.

Frazier, K. (1979) The Violent Face of Nature, William Morrow & Co., New York.

Granovetter, M. S., (1973) "The Strength of Weak Ties," Amer. J. of Sociology, 78, 1360-80.

Hummon, N. P. et al. (In Press) "Time Budget Analysis and Risk Management: Estimating the Probabilities of Event Schedules of American Adults," Enhancing Risk Management and Decision Making, R. Waller et al. (eds), Plenum, New York.

Janis, I. L., (1958) Psychological Stress, John Wiley and Sons, New York.

Juster, F. T., et al. (1983), "1975 - 1981 Time Use Longitudinal Panel Study", The University of Michigan, Institute for Social Research, Survey Research Center, Ann Arbor.

Kendrick, F., (1979) The Violent Face of Nature: Severe Phenomena and Natural Disasters, William Morrow and Co., New York.

Landry, T., and G. Rogers, (1982) "Warning Confirmation and Dissemination," Univ. of Pittsburgh, Univ. Center for Social and Urban Research.

Lave, C. A. and J. G. March (1975) An Introduction to Models in the Social Sciences, Harper & Row, New York.

Mileti, D. (1974) A Normal Causal Model Analysis of Warning Response, Univ. of Colorado, Dept. of Sociology (Ph.D. dissertation).

Mileti, D. and E. M. Beck (1975) "Communication in Crisis," Communications Research, 2, 24-49.

Nehnevajsa, J. (1985a) "Testimony of Jiri Nehnevajsa," Hearing before the U. S. Nuclear Regulatory Commission, Atomic Safety and Licensing Board, in the matter of Carolina Power and Light Co. et al. (The Shearon Harris Nuclear Power Plant, Unit 1), November 4 and 5.

Nehnevajsa, J. (1985b) "Some Effects of Social Networking on Warning Message Delivery," for International Energy Associates, Washington, D.C.

Parsons, T., (1951) The Social System, The Free Press, New York.

Perry, R. (1981) "Citizen-Evacuation in Response to Nuclear and Non-Nuclear Threats," Fed. Emergency Management Agency, Washington, D. C.

Perry, R. et al. (1980) The Implications of Natural Hazard Evacuation Warning Studies for Crisis Relocation Planning, Battelle, Human Affairs Research Centers, Seattle, WA.

Perry, R. W. et al. (1981) Evacuation Planning in Emergency Management, Lexington Books, Lexington, MA.

Quarantelli, E. L., and R. R. Dynes (1976) "The Family and Community, Context of Individual Reactions to Disaster," Emergency and Disaster Management, H. Parad et al. (eds), Charles Press Pub., p. 231-244, Bowie, MD.

Rogers, G. O. (1985) "Human Components of Emergency Warning," Univ. of Pittsburgh, Univ. Center for Social and Urban Research.

Rogers, G. O., and J. Nehnevajsa (1984) Behavior and Attitudes Under Crisis Conditions: Selected Issues and Findings, U.S. Government Printing Office, Washington D. C.

Williams, H. (1964) "Human Factors in Warning-and-Response Systems," The Threat of Impending Disaster, G.H. Grossin et al. (eds), MIT Press, Cambridge, MA.