Vulnerability Analysis of Two Water Treatment Utilities to the Effects of Fallout Contamination

Richard R. Bell

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VULNERABILITY ANALYSIS OF TWO WATER TREATMENT UTILITIES TO THE EFFECTS OF FALLOUT CONTAMINATION

BY

RICHARD R. BELL

A thesis submitted in partial fulfillment of the requirements for the degree Master of Science, Major in Civil Engineering, South Dakota State University

1971
VULNERABILITY ANALYSIS OF TWO WATER TREATMENT UTILITIES TO THE EFFECTS OF FALLOUT CONTAMINATION

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser

Date

Head, Civil Engineering Department

Date
ACKNOWLEDGMENTS

The author wishes to extend his gratitude and thanks to Dr. James N. Dornbush and Dr. John R. Andersen for their guidance during this investigation.

Thanks are also extended to Professor Emory E. Johnson and Associate Professor Lorys Larson for their aid in accomplishing this research. Appreciation is also given to the water utility personnel of Brookings and Huron, South Dakota, who cooperated in this research.

As a recipient of an Office of Civil Defense Fellowship, the author acknowledges the financial assistance for this year.
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INTRODUCTION

During the course of the past twenty-five years since the Manhattan project ushered in the nuclear age, nations have expanded their arsenal of weapons in an effort to provide a symbolic deterrent to other nations that might impose on their nationalistic rights. The principal component of the larger arsenals is the nuclear weapon. As more and more countries obtain these weapons, the threat of a possible nuclear confrontation could increase. Should a confrontation occur, a comprehensive civil defense plan to combat the effects of a nuclear detonation would be desirable.

Today some Americans are apathetic whenever the topic of civil defense is involved. They feel that should something drastic actually occur, the world would not be worth living in. However, this exterior of calm does not present a true picture. Although the American people know some protection is probably available, they are not concerned because the event has not actually affected them personally. The Office of Civil Defense, in accepting its commission from the President of the United States, is responsible for the development of a comprehensive plan of civilian defense.

If a comprehensive plan is to be developed, some consideration should be given to the post-attack conditions that may result from a
nuclear detonation. Planning should be carried out to provide some direction during this post-attack period.

If plans have been developed to provide fallout protection for a two-week period following the detonation of a nuclear weapon, planning should be initiated to provide direction beyond this period where fallout contamination is the principal hazard until complete disaster recovery is obtained. Complete recovery may require some plan to limit the damaging effect that may alter the production of safe water from a municipal water utility system.

One method of planning for the recovery of a water utility is making an assessment of the effects that might result from a nuclear attack prior to the event. This assessment has been defined as a vulnerability analysis where the effects resulting from a nuclear detonation are assumed to occur, and various countermeasures are recommended to be instigated.

The vulnerability analysis involves not only fallout protection of the water utility operators, but it also involves the total realm of the operation of a water utility. Such facets as the source of supply, chemicals used in the production of safe water, and the back-up system of electrical power available to the water utility are included (1-11).

For this study two municipal water utilities were selected to provide representative examples for making a vulnerability analysis to determine the effects that a nuclear detonation would have on the
operation of typical water treatment systems in South Dakota. The water treatment plants of eastern South Dakota draw their untreated water from a groundwater aquifer, a surface water source, or possibly a combination of both. The water treatment plants at Brookings and Huron, South Dakota, were chosen for the investigation because one draws its untreated water solely from a groundwater aquifer and the other treatment plant draws its water solely from a surface water source.

The general objective of this study was to determine the vulnerability to the effects of nuclear detonation of two selected representative water treatment utilities in order to assess the overall preparedness of South Dakota Water utilities. Some specific questions of the investigation were these:

1) Is adequate protection from radioactivity available in the area of the treatment plant for the operators to function safely during a fallout period? Could the operators continue to operate the plant?

2) Will the source of water yield uncontaminated water during a fallout period?
   A. Can an adequate source of water be derived from a groundwater aquifer or will an additional surface water be required?
B. Would the treatment process as available be detrimental or beneficial in the supply of water with acceptable radiation content?

3) Is the system of distribution reliable under assumed fall-out conditions?

4) Is an adequate back-up power supply available to operate both the distribution system and the treatment plant under an assumed power failure following a nuclear attack?
LITERATURE REVIEW

History

Prior to 1961 the pros and cons of civil defense planning had approximated the pattern of political events, alternately being stimulated and forgotten as the pattern of events dictated (2). In the spring of 1961, President John F. Kennedy started to revive the civil defense program with a call for a new 207 million dollar nuclear shelter program (3). The purpose of the program was to identify sufficient shelter space for some 50 million Americans, or approximately one-fourth of the population. A portion of the initial expenditure, 93 million dollars, was earmarked for identifying community shelters in existing buildings. Areas which could be used as fallout shelters were identified in basements, subways, schools, and abandoned mines (3).

It was also assumed by civil defense personnel that more than one-half of the American population would survive the effects of a nuclear attack (3). If approximately 100 million Americans would survive the effects of a nuclear attack, it would seem fruitless for the survivors to die a few weeks later from typhoid fever or diphtheria because an adequate water utility was not in satisfactory operating condition (2).

The Board of Directors of the American Water Works Association (AWWA), recognizing the dilemma of community shelters without an
adequate water utility supplying them and the mass confusion being created by this politically hot issue, authorized the formation of a Committee on Radioactivity and Civil Defense. This committee cooperated with the Office of Civil Defense in the United States Department of Defense in the development of a manual on radioactivity and civil defense for water utilities entitled *Civil Defense Aspects of Waterworks Operations* (1-1; 2).

Members of the AWWA committee were not the only people who recognized the need for water utilities to take an active role in the total civil defense picture. The editors of *Water Works Engineering* proposed the topic of "Water Supply Systems in Civil Defense" for a roundtable discussion by mail. Mailed replies that were received from around the country describing the status of specific water utilities as pertaining to civil defense were presented in four successive issues. The general consensus of most replies was that civil defense planning involving the water utilities was not occurring and that it was definitely needed (4, 5, 6, 7).

**Effects of Nuclear Explosions**

Before a system could be devised to adequately combat the effects of a nuclear attack, the investigators of the committee felt that the effects of a nuclear explosion should be somewhat understood. For instance, when a nuclear fission weapon is detonated, the energy of the
bomb is released as follows: 50 percent as blast and shock energy, 35 percent as thermal radiation, 10 percent as residual nuclear radiation, and 5 percent as initial nuclear radiation (8-8).

Although the energy distribution is heavily weighted towards the blast and thermal energy, the damage caused by these two types of energy is not extensive beyond the immediate area surrounding the point of detonation. The immediate area where the blast and thermal effects are prevalent is within a radius of 60 miles from the point of detonation, or ground zero, for a 20-megaton explosion (1-6). Even though residual radiation comprises only ten percent of the total energy released, the possible damage caused by it is more widespread. The residual radiation affects an area roughly 100 or more times greater than the area damaged by the effects of blast and thermal radiation (9).

The principal effect of the blast energy is the creation of a condition known as overpressure (2) which is defined as:

...the transient pressure usually expressed in pounds per square inch, exceeding the ambient pressure manifested in the shock (or blast) wave from an explosion (8-709).

A few seconds after the nuclear device is detonated the blast wave moves away from ground zero as an overpressure shock front at a speed slightly greater than the speed of sound. After a momentary elapse time, a negative pressure front follows the high pressure
front. The combined effect of these two pressure fronts is to squeeze and then expand the structures in their paths. If the structures expand too rapidly, they explode during the expansion (1-3, 4).

Safety of personnel in the path of the pressure fronts depends on the magnitude of the blast pressure that reaches them and the resistance of their protecting structure or shelter to the overpressure condition. Utility personnel caught in the open when the blast front passes are subject to damage from flying debris. The flying missiles consist of brick, pieces of masonry, glass, pieces of wood, metal, etc. They also could experience damage to their eardrums and lungs as a result of the overpressure condition. This type of internal damage is limited to a ten-mile radius from ground zero (1-3). The extent of the damage caused by the overpressure front is dependent upon the size of the detonation. Furthermore, the magnitude of the damage decreases as the distance from the point of detonation increases (10).

When a nuclear weapon is detonated, approximately 35 percent of the total energy dissipated is in the form of thermal radiation. For a one-megaton explosion, personnel standing in the open would experience second-degree burns on exposed skin up to a distance of nine miles from ground zero (10). Because thermal radiation travels in straight lines from the fireball source, any opaque material between a given object and the fireball acts as a shield and provides some degree of protection (1-2, 6). Like the blast effects, the severity
of the damage caused by the thermal energy is inversely proportional
to the distance from ground zero, but not in a linear relationship
(1-2).

The remaining 15 percent of the total energy from the detonation
is released in the form of nuclear radiation. The radioactivity is
divided into initial and residual radiation. The former consists of
approximately five percent of the total energy of the bomb (8-8). The
radiation emitted during the first minute after a nuclear device
detonates is defined as initial nuclear radiation. This type of radi-
ation consists of gamma rays, neutrons, alpha particles, and beta
particles. Of the four types of particles mentioned, the neutrons and
gamma rays are the significant health hazards. At close range these
two forms of radiation have an appreciable penetrating power and are
extremely difficult to protect against. But, as the distance increases
from the point of detonation, the intensity of radioactive fallout
decreases (10).

The long-term damaging effects of a nuclear explosion are asso-
ciated with the radioactivity present in the residual fallout (1-5).
Residual nuclear radiation is defined as that radiation emitted after
one minute has elapsed from the actual nuclear detonation. It is
comprised of the radiation stemming from the fission fragments and
bomb debris, a complex mixture of some 200 isotopes of 35 elements.
The majority of the unstable isotopes produced are radioactive and decay at varying rates (10).

The residual fallout and its accompanying radiation is the significant threat to life compared to the other types of energy released (10). It has the most significant effect because it is distributed over an area much larger than the areas where blast, heat, and initial radiation are significant. Therefore, it is possible for people to become casualties at locations far beyond the area where the blast and thermal damage are significant (1-5).

The accurate prediction of an early fallout pattern of the residual radioactivity is a highly complex topic with many variables to consider. But, in general, the pattern expands downwind from the point of detonation, following an elongated pear-shaped growth with the downwind portion expanding laterally. Therefore, the upwind residents will experience relatively small amounts of the early fallout radiation (2). Figure 1 is a diagram of an idealized early fallout pattern for a nuclear detonation showing the elongated pear-shaped characteristics (1-7).

The rate of radioactive decay of the 200 unstable isotopes created at the time of detonation starts instantly (10). Within any group of fallout particles, there is a wide variety of isotopes, each having a different decay rate. Initially for a mixture of fission products, the radiation level starts high but drops quickly as the short
half-life isotopes decay (1-7). The rate of decay of radioactivity in the combined fission fragments is expressed mathematically thus:

\[ \frac{R_t}{R_1} = t^{-1.2} \]

in which \( R_t \) is the intensity of radiation at time \( t \); \( R_1 \) is the intensity of radiation one hour after detonation; and \( t \) is the time in hours (10).
A simplified approximation for the above equation is that for every sevenfold increase in time after the detonation, the activity of the fallout decreases by a factor of ten. An example of this rule is that if after one hour from the time of detonation the radiation intensity is 1,000 roentgens/hr, seven hours later the intensity will be 100 roentgens/hr, and forty-nine hours later the intensity will be 10 roentgens/hr, etc. (10).

The effects on personnel to radiation hazards stem from the fallout particles themselves. The air through which they pass or the surfaces on which they settle are not radioactive. If the fallout particles are removed, the danger from radiation sickness is absent (1-7).

The contamination resulting from fallout is related to the radioactive dose, roentgens (1-11). The following is the definition of a roentgen:

... the quantity of X or gamma rays that will produce in air ions carrying an electrostatic unit of electricity of either sign per unit cubic centimeter at standard temperature and pressure (11-528).

According to the committee reports, the major hazard to life is the gamma radiation. This type of radiation is effective a great distance from the particle, and it has considerable penetrating power. Published articles using the example of a detector located three feet above the ground, report approximately 50 percent of the dose rate received in the center of a large, flat, uniformly contaminated area
came from a distance greater than 50 feet, and about 25 percent came from distances more than 200 feet away (1-7).

The intensity of the radiation dose varies from an almost insignificant dose at a location far removed from the point of detonation to rates in excess of 1,000 roentgens for individual exposures. The effects of the varying doses on the individual are summarized in the following table.

Table 1. Effects of Radioactive Exposure on Workers (9)

<table>
<thead>
<tr>
<th>Short term dose (roentgens)</th>
<th>Effects</th>
</tr>
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<tbody>
<tr>
<td>50</td>
<td>No visible effects, able to work.</td>
</tr>
<tr>
<td>75-100</td>
<td>On the day of exposure, brief periods of nausea for ten percent of those exposed, able to work.</td>
</tr>
<tr>
<td>200</td>
<td>As many as 50 percent may experience some symptoms of radiation sickness. Only five to ten percent will require medical attention. No deaths expected, able to work.</td>
</tr>
<tr>
<td>450</td>
<td>Serious radiation sickness for most followed by death to 50 percent within a two to four week period. Workers are unable to work.</td>
</tr>
<tr>
<td>600</td>
<td>Serious radiation sickness for all followed by death to most within a one to three week period. Unable to work.</td>
</tr>
</tbody>
</table>
**Vulnerability Analysis**

When the Board of Directors of the AWWA commissioned the Committee on Radioactivity and Civil Defense to prepare a guide manual for the water utilities, the initial table of contents contained various topics including disaster planning, emergency sources and supply procedures, post-attack assessment of plant operation, protective measures, and vulnerability analysis of the water utility (2). The last topic listed, vulnerability analysis, was a new concept recognized by the committee. It expanded the idea of protection beyond the scope of only radioactive protection to include the total area involved in the operation of a water utility.

Whitley (10), a member of the AWWA committee, published an article during an interim study in which he strongly advocated this concept of preattack assessment of the situation in which the utility was operating. Whitley felt that in order to fulfill the objectives of providing water for essential use following a nuclear attack, the officials of the water utilities had to be cognizant of the effects that such warfare had on the operation of a water utility and the key personnel operating the plant. He also felt that advance planning and preparation would make possible the implementation of countermeasures designed to minimize the damage and facilitate recovery (10).

When the idea of a vulnerability analysis was proposed, various concepts were presented as to what an investigation of this type should
encompass. The committee recommended that more than just fallout protection should be studied. Their definition (1-11) of the problem was this:

The vulnerability of a water system to a nuclear attack is the degree to which the service of an adequate supply of water would be adversely affected by the effects of an attack.

The committee also mentioned other areas for consideration, such as raw materials, equipment required for operation, and personnel protection, availability, and training (1-11).

To investigate the areas listed for consideration, the researchers of the committee made a more extensive list in which they set forth specific topics to be investigated. By investigating the topics listed, they felt that this action would provide a better guide by which they could assess the vulnerability of the treatment plants to the damaging effects of a nuclear detonation. Below is the more extensive list of the topics investigated (1-11):

1) Source of water
2) Treatment facilities and processes
3) Transmission facilities
4) Storage facilities
5) Distribution facilities
6) Structures
7) Power
8) Communication
9) Equipment
10) Material and supplies
11) Emergency procedures
As a result of the investigations made by the research committee, some of the items in the more extensive list could be deleted from the vulnerability assessment if the distance separating the plant from the point of detonation was above a prescribed distance. The committee noted that unless the water utility structures are located within a 60-mile radius of the point of detonation, the vulnerability to blast and to thermal damage of items two through five (treatment, transmission, storage, and distribution facilities) is extremely low. Beyond this distance from ground zero, the major hazard would be fallout radiation to human life (1-6; 9).

Source. Certainly the source from which the utility draws its water affects its vulnerability. If the source is a groundwater aquifer, the treatment process could generally be bypassed with only chlorine added for disinfection purposes (9). Harmon and Ludwig (9) proposed this concept of pumping directly into the mains thereby eliminating the need for operators to subject themselves to the fallout radiation.

For a water utility using a source that is vulnerable to fallout contamination, such as a river, problems were expected during the early period of fallout (2). Several technical papers on the subject of removing radioactivity from surface waters have been published. Table 2 summarizes the results of various purification methods contained in the literature on this subject. Even when the removal
Table 2. Removal of Fallout Radioactivity in Water

<table>
<thead>
<tr>
<th>Process</th>
<th>Removal or Decay</th>
</tr>
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<tbody>
<tr>
<td>Coagulation, sedimentation, filtration*</td>
<td>50-90 percent</td>
</tr>
<tr>
<td>Distillation*</td>
<td>99 percent</td>
</tr>
<tr>
<td>Ion exchange*</td>
<td>99+ percent</td>
</tr>
<tr>
<td>Boiling and chlorination</td>
<td>none</td>
</tr>
<tr>
<td>Dilution or storage</td>
<td>variable, depending on the specific nuclides in the solution</td>
</tr>
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*These processes will concentrate radioactivity in sludge or ion-exchange resins, and they may require special precautions by operating personnel.

efficiency is extremely high, Whitley felt that the initial amount of activity would be too high to be adequately removed by conventional water treatment practice (10).

**Structures.** As was mentioned previously, the most dangerous effect of a nuclear attack is the external radiation originating from the fallout particles. Furthermore, if the radiation dose received by an individual is above 200 roentgens, the individual cannot be expected to continue to work. To minimize the potential damage, the AWWA committee proposed shelter areas within the treatment plant structure. By having these designated areas, the operators would have
a haven to which they could return so that the radiation dose received might be kept below the prescribed maximum dose of 200 roentgens (10).

The Office of Civil Defense in its national shelter program has prescribed that the reduction in radiation dose received by a person in a shelter compared to the dose received by a person standing in an adjacent open area should be 0.025 for the shelter to protect adequately its occupants provided they did not intermittently expose themselves to the fallout radiation (12). Because the operational personnel of the water utility would have to expose themselves periodically to dangerous levels of radiation, it was thought desirable to obtain the best possible protection for the emergency operating personnel. The recommendation of the AWWA committee was a minimum protection factor of at least 100 (1-33). The protection factor is defined as the reciprocal of the radiation reduction factor. A radiation reduction factor of 0.01 was equivalent to only one percent of the fallout radiation reaching the individual in the shelter as compared to a person standing unprotected in an adjacent open field. Thus, a radiation reduction factor of 0.01 provides a protection factor of 100 and a radiation reduction factor of 0.025 provides a protection factor of 40.

With a protection factor of 100 being advocated by the research committee, the concept of a core protection area was also proposed. This concept consisted of a core shelter area which was relatively small, but which had a high protection factor, surrounded by a larger
area that had a lower protection factor. By using this concept, the committee felt that during the critical period, when the outside dose was lethal, the operators could stay within this limited area which had a minimum of space and ventilation. After the critical period had passed, the operating personnel could then use the larger shelter areas where better living conditions were available (1-33).

When the time comes to evaluate areas for fallout protection, adequate space should be provided so that the operating personnel can have his family with him during the emergency period. Contrary to what many authorities have advocated, a man should not have to choose between the obligation he has to his family and his duty to the community. Even though numerous problems may be encountered involving keeping a family together, the foresight to provide adequate space may insure that the operating personnel will accept their responsibilities in the water utility post-attack operation (1-61; 2).

**Power.** In the determination of the vulnerability of a water treatment plant, the source or system of power used would be a factor (2). If the generating source for the electrical power was located within the zone of destruction affected by the shock and thermal energy, some electrical power could be expected to be lost. Most water treatment plants, to comply with state requirements, are advised to have a dual system of power to the raw and finished pumps (13-335). But, if an adequate supply of power was not available to operate the
equipment within the plant, a bottleneck would be created which would deprive the needed water from the inhabitants of the community. Furthermore, if sufficient electrical power was not available, it was recommended that the treatment be by-passed in order to supply the required water (1-54).

For a vulnerability assessment of the power supply for a water treatment plant, various factors such as fuel supply, structures, transmission lines, distribution centers and cross ties with other systems were recommended for investigation. A water utility with safe water to deliver, but with no electric power for its pumps was classified as helpless, therefore this facet must be investigated (2).

Communication. Another factor that would not have a direct bearing on the vulnerability of a water utility, but would affect the community served by the utility was the mode of informing the general public as to the quality and quantity of water available to them. Statements issued by the water utility should be concise and presented in order to eliminate as much anxiety as possible. As a part of the vulnerability assessment, an advance survey should be made of all possible means of communication, and plans should be prepared for their coordination. With accurate information supplied to the public, much of the anxiety would be eliminated because a major portion of the post-attack survivors would have either covered distribution reservoirs or groundwater
water sources available, and this water, if properly handled, would be free of radioactive contamination (1-55).

**Equipment.** Because it is essential that the operators know the radiation intensity in their working environment, radiation survey and monitoring equipment is necessary. There are three potential needs: (a) a survey meter to measure high levels of radiation in the range of zero to 600 roentgens per hour, (b) a survey instrument to measure low levels of radiation in the range of zero to 20 milliroentgens per hour which could be used in the emergency measurements of radioactivity in food and water, and (c) radiation dosimeters with a range of zero to 200 roentgens to measure and record the total radiation to which operating personnel are exposed during attack and post-attack periods (10).

If the personnel are expected to work under these conditions, an adequate number of personnel should be trained in the use of the appropriate survey equipment. Whitley also recommended that the operators be taught the effects of radiation and decay phenomena so that if they had to work during a radioactive fallout period, they could calculate their own exposure dose. Furthermore, the foreman of the water utility could stagger the work load between the operators in order to keep the total accumulated individual dose as low as possible (10).
Material and Supplies. Another facet of the water utility suggested for investigation was the topic of material and supplies.

The AWWA committee recommended that a minimum 30-day chemical supply should be maintained at the treatment plant (1-54;9). Other emergency mobile water treatment facilities recommended to be maintained were both chlorination and filtration units with coagulation facilities (1-54). In the National Water Emergency Plan, written by the Office of Emergency Planning, the authors stated that it was the responsibility of local water utility personnel to maintain or to have accessible reserve stocks of essential chemicals and other operating supplies, standby equipment, and spare parts in adequate numbers for at least ten days' requirements (14).

Planning to Reduce Vulnerability

The concept necessitating a preattack assessment of the vulnerability of the water utility is related to Babbit, Doland and Cleasby's definition of reliability:

Reliability of a waterworks is provided through the development of an inexhaustible source of supply or by supplementing an uncertain source with adequate storage, by the construction of adequate pumping where gravity cannot be used for conveyance and distribution; by the construction of substantial structures and equipment, by foresight in minimizing dangers from fire, flood, earthquake, sabotage, and other emergencies, and by the duplication of such structures, equipment, the breakdown of which might be disastrous to the supply of water (15-581).
Certainly, using the foresight to eliminate the damage of a nuclear attack by using a preattack vulnerability analysis would correspond to their reliability concept.

A few cities have used a vulnerability analysis to aid in their overall civil defense planning. The city of Lansing, Michigan, has coordinated its water utility expansion to follow its civil defense plan. The city has located and constructed additional units in the system in areas of less vulnerability as determined by the city engineer to insure post-attack operation (2).

The city of Milwaukee, Wisconsin, has constructed by-pass facilities, so that untreated but chlorinated raw water could be pumped directly into the distribution system. To insure that the pumps will be in operating condition, the city has also constructed blast resistant pumping stations (16).

These two examples show how two communities have sought to help themselves to survive the effects of a nuclear attack. This concept of self-help was defined by the Department of Defense in its initial publication as to be the fundamental principle of civil defense (17). The concept was also advocated as being essential by the AWWA committee if this country was to survive a nuclear attack.

The authors of the design text, Water Treatment Plant Design, have also recognized the problem of adequate fallout protection. They
have recommended that in future designs some provision be made for a fallout shelter for the operating staff in the event of a nuclear attack (13-335).
CRITERIA AND METHOD OF DETERMINING WATERWORKS VULNERABILITY

When a nuclear weapon is detonated, the effects of the weapon can be predicted to some degree. As stated previously the three effects are blast, thermal, and fallout radiation. During the course of this investigation, it was assumed that a nuclear weapon would not be detonated within a sixty-mile radius of the two water treatment plants that were selected for study. By making this assumption, the researcher eliminated from consideration the blast and thermal effects and used in the investigation only the fallout effect and the related facets.

Because the investigation was concerned with the status of water treatment utilities as pertaining to civil defense in eastern South Dakota, two water treatment plants, Huron and Brookings, were chosen for the investigation. Brookings draws its water from a groundwater aquifer located one mile north of the community along US Highway 77\(^1\) and the water treatment utility at Huron draws its water solely from the James River that flows through that community.\(^2\)

\(^1\)Obtained in a personal interview with Dwayne Kruse, Municipal Utility Building, Brookings, South Dakota.

\(^2\)Obtained in a personal interview with Glenn Housiaux, city engineer, and Harold Root, chief waterworks operator at Huron, South Dakota.
A fallout shelter survey was conducted at the Brookings and Huron water treatment plants to determine if adequate fallout protection was available. According to an Office of Civil Defense Publication, protection of the operators from fallout should be provided within the treatment plants. It also recommends a protection factor of 100 be the minimum standard because of the periodic exposures to which waterworks operators would be subjected. Information was obtained by extracting the building dimensions and physical characteristics from the plans furnished by each respective water utility system. An on-site inspection was also made to determine the physical layout of the area surrounding the water treatment plants. Information obtained from the survey was used as input data (See Appendix) for a computer program developed by the Direct Mail Shelter Survey Development System within the Office of Civil Defense for the identification of community shelters (21-6). The results from this computer operation were used to determine whether adequate fallout protection was available at the sites of the water treatment plants.

Another facet of the water utility operation that was investigated was the amount of chemical supplies that would be available in the event of a nuclear attack. As previously mentioned, the AWWA committee recommended a 30-day minimum supply of chemicals used in the water treatment operation. Information concerning the status of the water treatment plants was obtained by personal interview with knowledgeable
personnel such as the chief water works operator or the city engineer.

An interview was also used as the method of obtaining information concerning back-up power generation equipment, source and location of primary and alternative supplies of raw water, quantity of the raw water, and amount of elevated storage available for the treated water, all of which were considered in the vulnerability analysis.

In order that a water utility may be reliable, adequate electrical power has to be available at all times. The recommendation of the AWWA committee was that a dual source of power should be maintained (1-59). In addition, the AWWA committee also endorsed the concept that portable water pumps with fuel operated units be made available for emergency use by the water utility system.

Information concerning the source of raw water supply was used to determine whether the treatment process could possibly be by-passed, thereby eliminating the need for water utility personnel to subject themselves to possible dangerous levels of radiation. Several authors have stated that if adequate pumping capacity was available, the treatment processes could be by-passed provided the source of raw water came from a non-radioactive, groundwater aquifer. If the source of raw water was a surface impoundment or river, the treatment processes would be required to remove the radioactive particles in order that the raw water be improved to potable quality.
The following questions were used as a basis of determining the vulnerability of the two selected water utilities:

A. Three questions pertaining to the raw water source were asked:
   1. What was the gallonage pumped in 1969?
   2. What is the location of your raw water source?
   3. What is the quality of the raw water?

B. Would there be a 30-day minimum supply of chemicals available at the water treatment plant in the event of a nuclear attack?

C. Is there a satisfactory system of back-up power available to the water utility if the main source of electrical power is lost? Can the treated water be pumped from the clear wells to the distribution mains if the main source of electrical power is lost?

D. How much elevated storage is available for the treated water?

E. Has there been any contact from the civil defense personnel on the status of your water treatment utility as pertaining to continued operation during a nuclear disaster?

The answers to these questions and the results of the fallout shelter survey analysis were used as a basis of determining whether or not the water utility would be vulnerable to the effects of a nuclear attack.

The answers to these questions also provided a foundation by which recommendations could be made concerning the water utility systems
and by which the various measures could be taken to counteract the damaging effects of a nuclear disaster.

The various plans were then drawn up and developed as

The various plans were then drawn up and developed as
Fallout Protection

The Direct Shelter Survey Development System has developed a computer program which takes the data furnished by various analysts from various areas in the country and analyzes the information for fallout protection. The calculation of protection factors rests on the gross characteristics of the buildings, i.e., the physical dimensions of the building, interior partitions, aperture openings, etc. The computer takes the information fed into it and computes the protection factors present within the building.

After the results of the computer analysis were returned for this study, another on-site inspection was made of each treatment plant. Areas identified by the computer were inspected to determine if shelter space actually existed. The area was also inspected to observe if any object or obstruction was occupying the area as defined by the computer. The information received from the computer operation was more extensive than the information obtained from manually calculating the protection factors. The computer program that was used also delineated multiple protection areas within the treatment plant.

Information pertaining to the two water treatment utilities that were investigated showed that some fallout protection was available. However, in the case of Brookings the areas identified by the computer as possible protection areas did not have a protection factor above
the minimum value, 100, recommended by the AWWA committee. Furthermore, some of the areas that were identified were not acceptable because of the usage made of the area by the treatment process. For instance, an area that was identified in the center of the Brookings treatment plant as an area of shelter that had a protection factor equaling 74; however, this location would not be normally used. The coagulation basins are located in the area identified and consequently the area would be unavailable. Another area identified as an area of protection was the lavatory facilities of the Brookings treatment plant. This area, if the need arose, could be used as an area of fallout protection. The protection afforded by this area was only 48. A protection factor of this level would provide protection to the operators amounting to $\frac{1}{48}$ or 0.0208 of the radiation dose that would be received by a person standing in an outside adjacent area unprotected by any physical barrier or construction. However, a protection factor of 48 is below the minimum recommended by the AWWA committee.

The protection factors were not larger at the two areas previously mentioned because of the physical characteristics of the building. The mass of walls per square foot was not larger because the area occupied by the windows and doors had essentially a zero mass thickness. To account for these areas, the researcher smeared the walls in order to obtain an average wall mass (12-631). If the initial mass of the walls
had been larger, or the percentage of the aperture openings had been smaller, the protection available would have increased proportionately.

At the Huron water treatment plant, fallout protection was also available. In Huron, the water treatment plant is located on a side hill which provides some fallout protection by its orientation to the surrounding area. Figure 2 is a diagram of the dimensions used for the calculation of fallout protection at the Huron water treatment plant.

In order to use the SAND analysis forms for the fallout shelter survey, as was done at Brookings, the building at Huron had to be divided into portions because the building dimensions were not uniform. The building was divided as shown in Figure 2. Part 1 of the Huron
water treatment plant had two stories. In Part I the first story had
the overall dimensions of 142 feet by 115 feet. The second story of
this part was set back 56 feet from sides A, B, and D as shown by the
shaded area in Figure 2. The protection factors identified in Part I
were ten and seven for the first and second story center detector
locations, respectively. The low protection factors stem from the
aperture percentage averaging 20 for the four sides of the building,
and the low initial mass of the walls, 90 lbs/ft², for the walls in
this part of the building.

In Part 2 of the Huron water treatment plant, the protection
factor in the center location of the basement was 138. This value
exceeded the recommendation of the AWWA committee, which endorsed a
protection factor of 100 for a portion of the water utility structure.
The high protection factor stemmed from the orientation of this por-
tion of the building to the surrounding area. In addition, the base-
ment and first story of Part 2 were below grade line when compared to
Part 1 of the total building. By being below the grade line, the
basement area was protected by a twelve-foot earth embankment on the
west and south sides. In addition, the thickness of the overhead mass
comprising the floors above the basement location was large. The
radiation that would reach this area would also be attenuated by a
genometric factor of 39 feet. The thickness of the overhead floors had
an initial mass of 100 lbs/ft². The floor of the first story of Part
2 had a mass weight of 20 lbs/ft\(^2\). The low mass weight of the floor stemmed from an extremely large opening in the center of the floor. If this opening had been absent, the protection factor would have been greater.

The area in the Huron water treatment plant that was identified as a high protection area was a large open area which had been used for a storage area. At the time of the second shelter survey, the area was completely clear of all obstructions. Therefore, sufficient space would be available for the operators to have their families with them during the post-attack operating period. According to the results of the computer operation, sufficient space was available for 236 persons within this area; however, forced ventilation might be required. This large area and the high degree of protection given by this area would help to insure that the operators, as well as their families, could safely assume their positions in the post-attack operation of a water utility once a plan was devised.

**Chemical Supply**

At both the Brookings and Huron water treatment plants, the supply of chemicals required in the water treatment operation exceeded the recommended 30-day minimum supply endorsed by the AWWA committee. At Huron, which employs a lime-soda ash softening process, the supply of chemicals available to operate the treatment system included activated
carbon, one year; lime, 45 days; soda ash, 60 to 90 days; chlorine, 45 to 60 days; and coagulant aids, 40 days. During the course of the personal interview, the chief waterworks operator stated that these were minimum values and that he expected to be restocked with chemicals within a short period of time.

The picture at Brookings as pertaining to the supply of chemicals was similar to that of Huron. The treatment process at Brookings, which is essentially a lime addition for the removal of iron, had available the following supply chemicals for use: lime, 60 days; alum and fluoride, 35 days; and chlorine, 60 to 90 days.²

As is evident by the list of chemicals available at both water treatment plants, the criterion of a minimum 30-day supply would have been more than satisfied when the vulnerability was assessed.

**Power System**

When the question was asked concerning what system of back-up power was available for the utilities in the event that the main source of electrical power was lost, the replies from the water utility spokesman of Brookings were more encouraging than those from the Huron counterpart. Brookings does have a back-up system of power generation ¹

¹ Obtained in a personal interview with Glenn Housiaux, city engineer and Harold Root, chief waterworks operator at Huron, South Dakota.

² Obtained in a personal interview with Dwayne Kruse, Municipal Utility Building, Brookings, South Dakota.
for both its treatment system and its distribution system. It has two gasoline engine-driven pumps to pump from the clear well to the elevated storage tanks, which have a capacity of 900,000 gallons. Each pump is driven by a high-lift gasoline motor, one pump having a capacity of 1000 gal/min and the other, a capacity of 500 gal/min.

Brookings also has a back-up system to pump raw water from the aquifer to the treatment plant. At one well, the city has installed a gasoline engine to drive a pump with a capacity of 650 gal/min; furthermore, Brookings has the ability on short notice to install two portable generators at other well sites to furnish sufficient power to drive pumps with capacities of 1,500 and 1,000 gal/min. With Brookings having an adequate back-up system of power, the utility is in a favorable position in this regard when the effects stemming from a nuclear detonation are considered.

The municipal water utility at Huron was not in the same favorable situation as was Brookings. Should its main system of electrical power fail, the water treatment plant would be essentially useless. Huron has no separate back-up system of power to operate its treatment facility. Because Huron draws its water solely from the James River, and because treatment would be required to reduce the radioactive content of the water to acceptable levels, a power failure would represent a severe hazard.
Even if the criteria of determining the vulnerability of the water utility were not based solely on the effects of nuclear contamination, the situation at Huron would be classified as critical. What would be the effect on the Huron water treatment system in the event of an ice storm of sufficient magnitude to break electrical distribution lines? As in the case of a nuclear disaster, the water treatment facility would be helpless. This condition of no electrical power would certainly be classified as a critical factor when the vulnerability of the water utility system was considered.

The water treatment plant at Huron has a back-up system of power by which it could pump from its three million gallon clear well to the elevated storage portion of its distribution system. The city has one high-speed Fairbanks diesel pump with a rated capacity of 2,000 gal/min to pump treated water from its clear wells to the distribution system. The capacity of the elevated storage within the distribution system is 1.5 million gallons. With the daily consumption in the calendar year, 1969, averaging 2,155,704 gallons, it is evident that Huron does not have an adequate supply of water should its treatment facility cease to function properly. Granted that the daily water consumption would be lower than the value stated under fallout conditions, the point still remains that the supply of potable water would probably not be sufficient.
After all facets have been considered pertaining to a system of power for the two treatment plants, the Brookings water treatment facility would not be considered to be adversely affected for an extended period should the main source of electrical power be lost, whereas the water utility at Huron would certainly be classified as vulnerable to the effects of a power outage.

**Treatment By-pass**

It was determined by personal interview that the water treatment plants at Huron and Brookings could both be by-passed if the need arose. However, the circumstances surrounding the source of raw water would not deem this alternative to be desirable in both cases.

Brookings draws its water from a groundwater aquifer of potable quality. Concentrations of certain chemical characteristics, particularly iron and manganese, exceed the limits in the drinking water standards recommended by the United States Public Health Service, but the water would still be considered as potable (18,19).

Huron presently draws its water solely from the James River which flows through that community. At one time, Huron also had a well field located west of that community. At the present time, however, the collection system used to convey the raw water from the well field to the distribution system is reported to be in deplorable condition. According to a personal interview with Huron's city engineer, this
source of raw water would not be available on short notice without extensive repairs to the collection system.

Furthermore, even though the Huron community were without a supply of water, it would not be advisable to by-pass the treatment plant with the surface water source. The James River above Huron and its tributaries are known to receive wastewaters from numerous cities and industries (20). As a result, the James River would likely be polluted with harmful bacteriological organisms. Therefore, because of the organic pollution emptied into the river system, it would not be advisable for the Huron waterworks operators to by-pass the treatment plant and pump raw water directly into the distribution system.

Civil Defense Planning

Another question asked of both water utility spokesmen pertained to civil defense planning involving each water utility system. Neither of them stated that he had any previous contact from civil defense personnel. Furthermore, their knowledge of the various types of radiation detection equipment that would be required if they had to operate the water treatment plant during a fallout period was nil.

If, in the future, the civil defense personnel do formulate a plan of a post-attack operation of the water utilities, an on-site educational process would have to be initiated to inform the water utility personnel of the various facets involved in fallout protection.
SUMMARY

The following table is a summary of the results of the various questions used in the vulnerability analysis of the two water treatment plants investigated.

The answers to these questions provide a foundation by which the conclusions could be drawn from this study.
<table>
<thead>
<tr>
<th>Question</th>
<th>Brookings</th>
<th>Huron</th>
</tr>
</thead>
<tbody>
<tr>
<td>What was daily gallonage pumped in 1969?</td>
<td>1,174,432</td>
<td>2,155,704</td>
</tr>
<tr>
<td>What is the raw water source?</td>
<td>Groundwater--7 wells located north of Brookings</td>
<td>Surfacewater--James River</td>
</tr>
<tr>
<td>Is the raw water potable?</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>How large is your clearwell?</td>
<td>1,500,000 gallons</td>
<td>3,000,000 gallons</td>
</tr>
<tr>
<td>How large is your elevated storage?</td>
<td>900,000 gallons</td>
<td>1,500,000 gallons</td>
</tr>
<tr>
<td>Is there available a 30-day supply of all chemicals used in the water utility department?</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Is there a back-up system of power for:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. the treatment plant?</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>b. the distribution system?</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Would it be possible to by-pass the treatment plant?</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>What degree of fallout protection is available?</td>
<td>fallout protection factor--48</td>
<td>fallout protection factor--138</td>
</tr>
<tr>
<td>Has there been any contact from civil defense personnel pertaining to post-attack operations?</td>
<td>no</td>
<td>no</td>
</tr>
</tbody>
</table>
CONCLUSIONS

Analysis of the information obtained during this investigation led to the following conclusions:

1. Both water treatment utilities that were investigated had fallout protection available within the existing plant for their personnel to operate the plant under fallout conditions. Protection at the Huron plant exceeded the minimum standard recommended by the AWWA committee; the protection afforded by the water treatment structure at Brookings fell short of the value.

2. Both water utility systems exceeded the recommendation of the AWWA committee on the amount of chemicals available for use in the event of a nuclear disaster.

3. In the event of a nuclear disaster, the treatment plant at Brookings may be by-passed because a potable, non-radioactive source of water is available; i.e., the community could be supplied with potable water without the need for the operators to subject themselves to possible dangerous levels of radiation intensities.

4. Because of the quality of the James River, which is the source of supply at Huron, the treatment plant should not be by-passed.
5. A system of back-up power is available at Brookings to run both the treatment plant and the pumps of the distribution system should the main source of electrical power fail; however, the water treatment system at Huron would be severely affected if its main source of electrical power was lost.

6. The Huron water facility should consider the installation of a back-up system of power to operate the treatment plant in the event of a power failure either from a nuclear disaster or otherwise.

7. Based on the results of the evaluation of the Brookings and Huron water systems, it would appear that most water systems in South Dakota probably are ill informed of, and vulnerable in some respect to, the effects of a nuclear attack.
LITERATURE CITED


Figure 3. Input data for the calculation of fallout protection factors in Part 1 of the Huron water treatment plant.
Figure 3. (continued)
Figure 4. Input data for the calculation of fallout protection factors in Part 2 of the Huron water treatment plant.
<table>
<thead>
<tr>
<th>Detector Location</th>
<th>Protection Factor</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>10.0</td>
</tr>
<tr>
<td>2</td>
<td>6.6</td>
</tr>
<tr>
<td>3</td>
<td>11.9</td>
</tr>
<tr>
<td>4</td>
<td>12.3</td>
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<tr>
<td>5</td>
<td>6.9</td>
</tr>
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<td>7</td>
<td>8.4</td>
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<tr>
<td>8</td>
<td>13.8</td>
</tr>
<tr>
<td>9</td>
<td>7.4</td>
</tr>
<tr>
<td>10</td>
<td>138.0</td>
</tr>
</tbody>
</table>

Part 1 - Ground Floor

Part 2 - Basement

Figure 3. Results of the fallout analysis delineating the protection factors at various locations in the Huron water treatment plant.
Figure 6. Input data for the calculation of fallout protection factors of the Brookings water treatment plant.
Figure 6. (continued)
Figure 7. Results of the fallout analysis delineating the protection factors at various locations in the Brookings water treatment plant.