AN ADVANCED SYSTEM FOR QUANTIFYING THE EFFECTS OF RADIOLOGICAL RELEASES FOLLOWING A MAJOR NUCLEAR ACCIDENT

by

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(Abstract)

Although the use of nuclear power has several advantages over the burning of fossil fuels, it has several disadvantages also. The inherent danger of a nuclear accident at a power plant is one of these disadvantages. Although the probability of an accident is very low in comparison to other risks we normally encounter, the consequences are significant. Thousands of local citizens could be exposed to radiation levels more than the normal background levels. It is the responsibility of the State to make the necessary decisions regarding the evacuation of its citizens. To make the best decision possible, it is necessary to obtain a large amount of information regarding the concentration of radionuclides being released and to quickly make projections of the exposure to ionizing radiation of the neighbors of the plant.

An effort was made to design and develop a system to collect the necessary radiological data and to transmit these data to a remote facility that could process the data to allow the State to predict the exposures to the neighbors of the plant.

Several steps were necessary to design and develop this system. These steps included:

A. State personnel were contacted to learn their performance criteria,

B. a needs analysis was performed,

C. a functional analysis was performed,

D. a feasibility study was performed among several off site sampling, technologies,

E. the system's life cycle was defined,

F. a maintenance concept was developed,

G. the integration of the necessary disciplines was explored,

H. computerized control methods were explored and a method was, selected for the control device,

I. the type and number of detectors to be placed at the site boundary were optimized, and

J. four main subsystems were defined and the performance and effectiveness factors were allocated to these subsystems.

It was concluded that a viable automated system could be designed, produced, operated and decommissioned. The automated system would consist of four main subsystems: a computer, a remotely controlled land vehicle, fixed radiation detection monitors, and an airship. The hardware for three of the subsystems can be procured off the shelf. The hardware for the land vehicle utilizes current technology. No new technology is required for the software used for the collection and processing of data.

The automated system utilizes two remotely controlled vehicles. To ensure that the most accurate data are available to the State, it is necessary for these vehicles to move rapidly and efficiently to a specific location. The best available control mechanisms using digital technology would not provide the control necessary for an airship. It was, therefore, necessary to apply fuzzy logic for these control devices. Additional research is necessary in the area of fuzzy logic to enable the remote control of the airship. Figure A on the following page provides a pictorial view of the system.

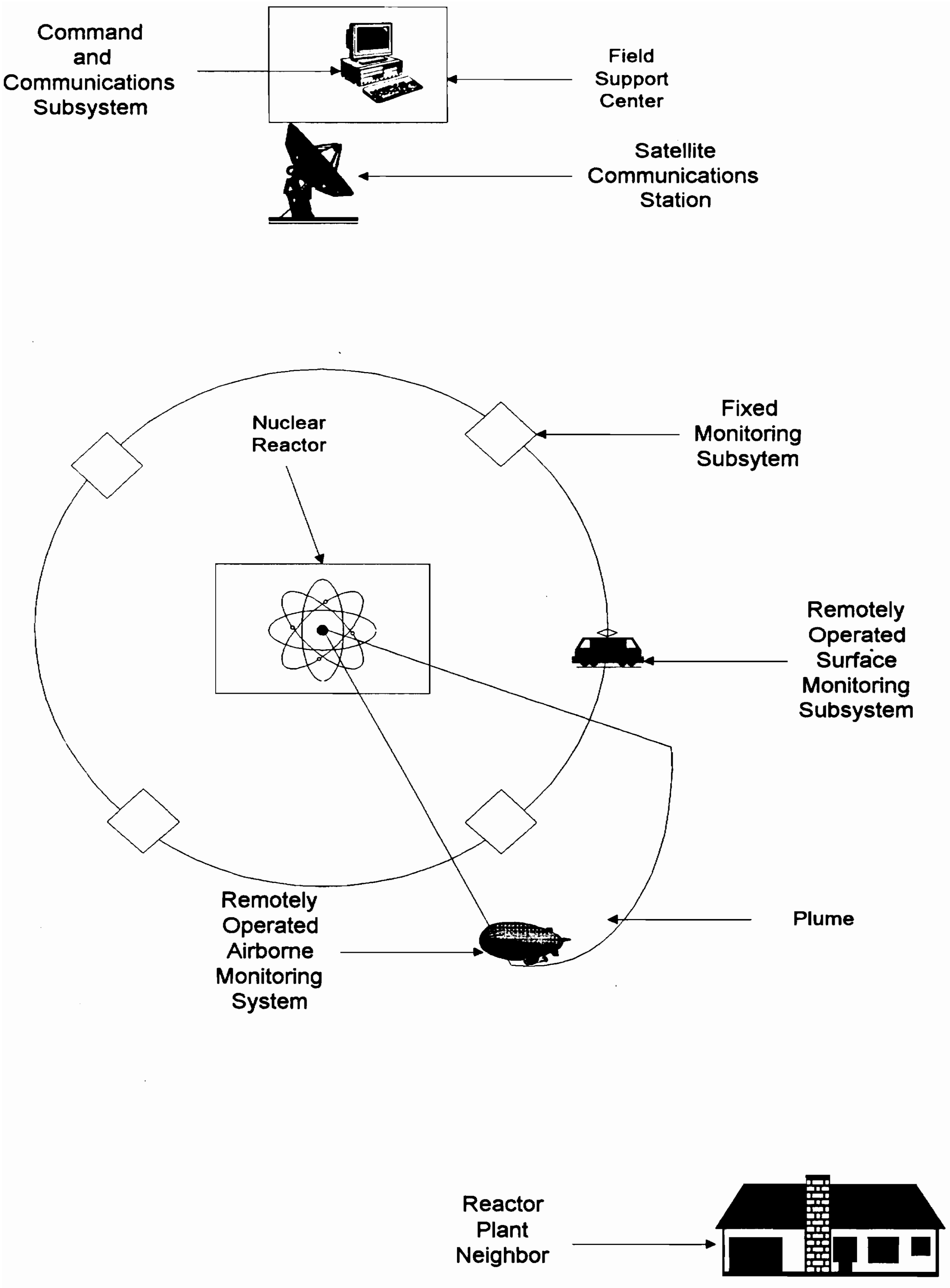

Figure A Pictorial representation of the system

Acknowledgments

I would like to acknowledge the efforts of Mr. James Troan, who assisted me in ensuring that the data on the standard detection package and the communications equipment were correct; the Thunder and Colt Company, who graciously provided the technical details for a usable Airship; the many employees of the State of Illinois, the NRC, the Westinghouse Electric Company Training Center at Zion, Illinois; the employees of Commonwealth Edison at the Zion plant and the City of Zion for their efforts in making this project one that was realistic and fun to complete.

Table of Contents

List of Figures

I. **Introduction and Statement of the Problem**: The State of Illinois, (the State) relies on nuclear power to generate most of its electric power. However, inherent in the use of nuclear power is the risk that an accident might result in an inadvertent release of radioactive isotopes to the atmosphere. If this release is great enough, local residents would be required to either take shelter in their homes or places of business, or to evacuate the effected area. In the more populated areas, the decision to take shelter or evacuate is a costly decision requiring millions of dollars of State and local funding to accomplish. The State is responsible for the protection of the health of its citizens and the good stewardship of their tax dollars. Therefore, the Atomic Energy Act of 1954 assigned to the State the responsibility for making the decision to take protective action for its citizens.

To make this decision, the State must have the information necessary to determine the residents' potential exposure to ionizing radiation. This exposure is typically from two sources, radioactive noble gases and radioactive iodine. These radioisotopes are created by the fission process, which is the basic process in a nuclear reactor.

There are two basic nuclear power reactor types in use today in the United States, the boiling water reactor and the pressurized water reactor. In either type, the fuel in which the fission process occurs, is a series of pellets of ceramic uranium dioxide enriched in the ^{235}U isotope. This fuel is stacked in long zircaloy tubes that serve as cladding. These tubes, also called fuel elements, are then stacked together.

In a boiling water reactor these stacks of fuel elements are called a fuel channel because they form a channel to enable steam to rise through the reactor and become superheated. A typical arrangement for a boiling water fuel channel is depicted in Figure 1. This figure was provided by Dr. Charles Miller formerly with the State of Illinois.

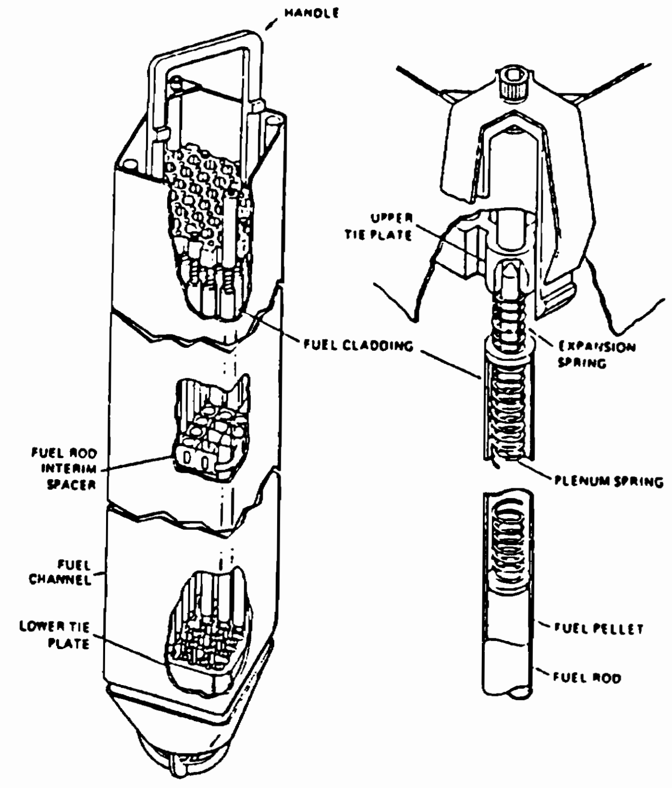

Figure 1 A typical boiling water reactor fuel channel

In a pressurized water reactor such as the reactors, at the Zion Nuclear Power Plant in Zion, Illinois, these clusters of fuel elements are designed slightly differently and are called fuel bundles. Several of these fuel bundles are arranged together to make the core of the reactor. This core is contained in a large steel pressure vessel. The pressure vessel, several major components (e.g., a pressurizer, steam generators, pumps, regenative heat exchangers, and valves for a pressurized water reactor), and the piping system are contained in a large reactor containment building. Figure 2, also provided by Dr. Miller, is a sketch of the arrangement of the Three Mile Island Nuclear Reactor Power Plant Number 2. A reactor accident, that resulted in a near total melt down of the core, occurred in this plant in April 1979.

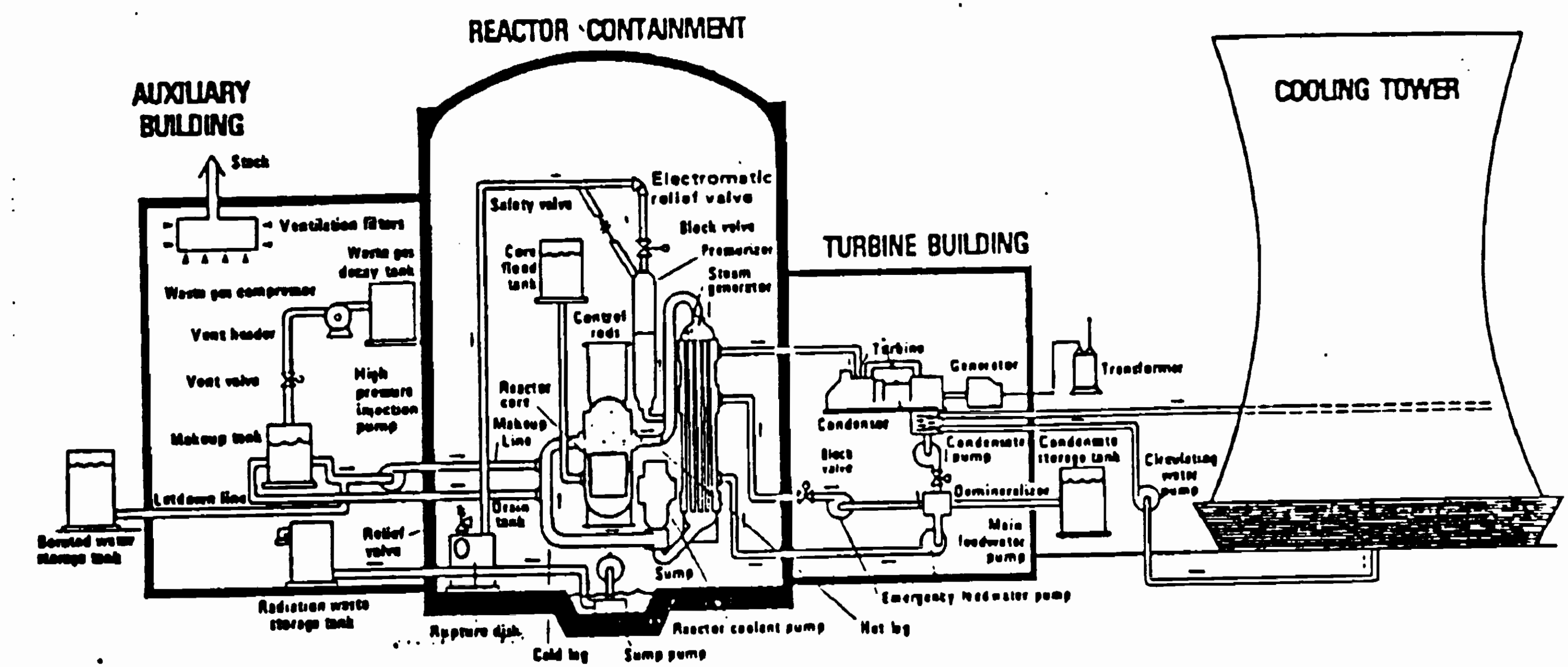

Figure 2 A Sketch of the arrangement of the Three Mile Island Nuclear Power Plant

A typical, although simplified, release scenario might be similar to the following:

1) a problem occurs in the plant in which the water covering the highly radioactive nuclear core is drained from the piping system,

2) the water is eventually flushed from the reactor pressure vessel that contains the core,

3) the core becomes uncovered,

4) without the cooling water the core will melt,

5) the melting of the core and the loss of coolant water releases radioactive isotopes to the reactor containment building. The water that was drained from the piping systems is initially a compressed fluid at approximately 600°F and 2000 psi.,

6) the release of the water from the piping system raises the pressure in the containment building,

7) through the failure of several redundant systems this increase in pressure could result in the containment building becoming breached,

8) the high energy steam from the cooling water would carry the radioactive isotopes from the core into the atmosphere in a plume,

9) most of the particulate matter settles out very rapidly, before it has a possibility of significantly affecting the public. The plume is, therefore, composed of primarily two fission products, radioactive noble gases and compounds of radioactive iodine. Figure 3, also provided by Dr. Miller, depicts the damage to the core that might be expected following an accident of this magnitude.

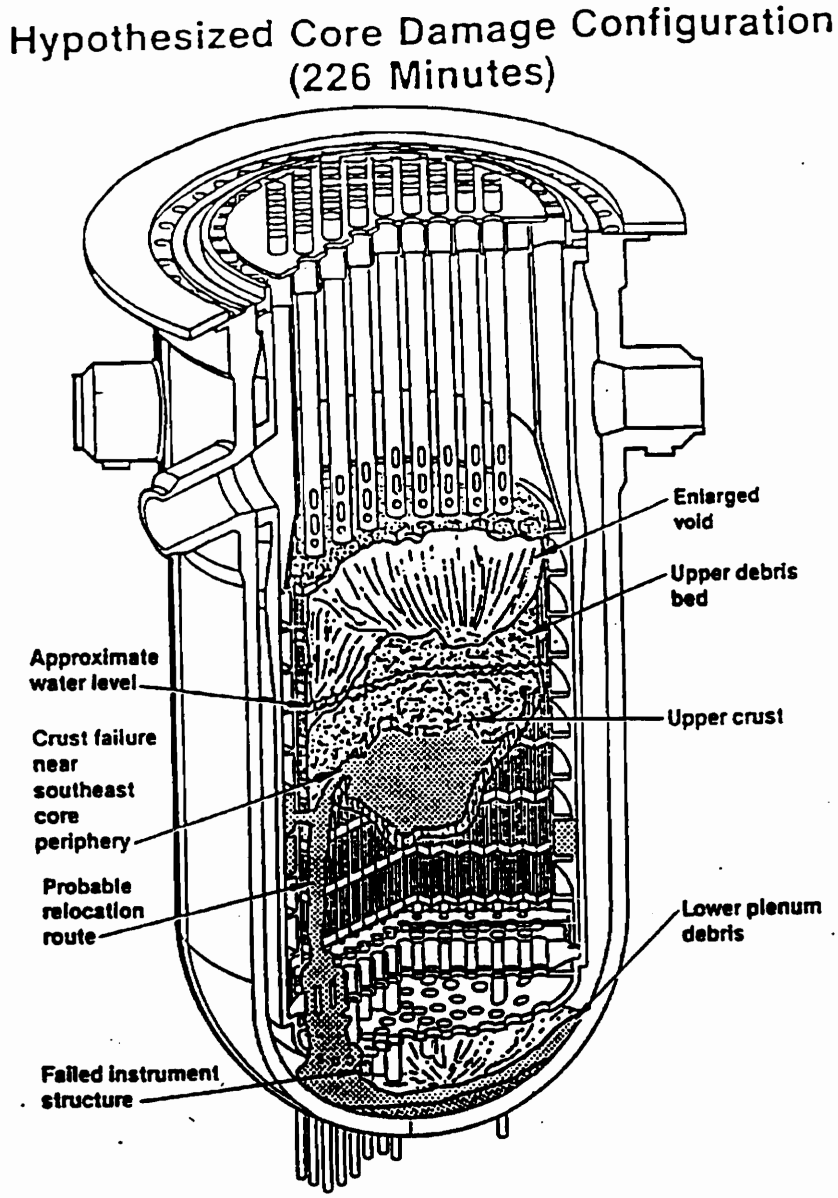

Figure 3 The expected damage from a nuclear accident after 226 minutes of leaving the core uncovered

The radioactive noble gases are a risk to the public since they emit gamma radiation and beta particles that would result in direct exposure as the plume contacts the body. The resultant risk is an increase in deaths from cancer at the rate of approximately $5x10^{-4}$ additional deaths per lifetime per rem. A rem is the unit of measure of radiation exposure to the human body. This unit is explained in more detail in the glossary at the end of this report.

The radioactive iodine compounds are an additional problem because as they settle out from the plume centerline they come into contact with vegetation. The radioactive iodine has two primary pathways into the body: it can be digested directly if it falls on consumable fruits and vegetables; or it can be digested by cattle, whose milk is then ingested by the local population. As the iodine enters the body, it concentrates in the thyroid gland. The radiation from this concentrated iodine results in an increased risk of thyroid cancer. Although thyroid cancer is not often fatal, it strikes primarily small children and, therefore, the dose to the public from radioactive iodine was incorporated into the constraints of the State's decision making process. In reality, the analysis of the exposure pathways is very complex and involves many different possible entries for radionuclides beyond the primary pathways. Figure 4 shows a typical complex pathway analysis. This figure was also provided by Dr. Miller. The important aspects of this figure are that many pathways are available. The specific pathways represented by the small circles are not important for this project.

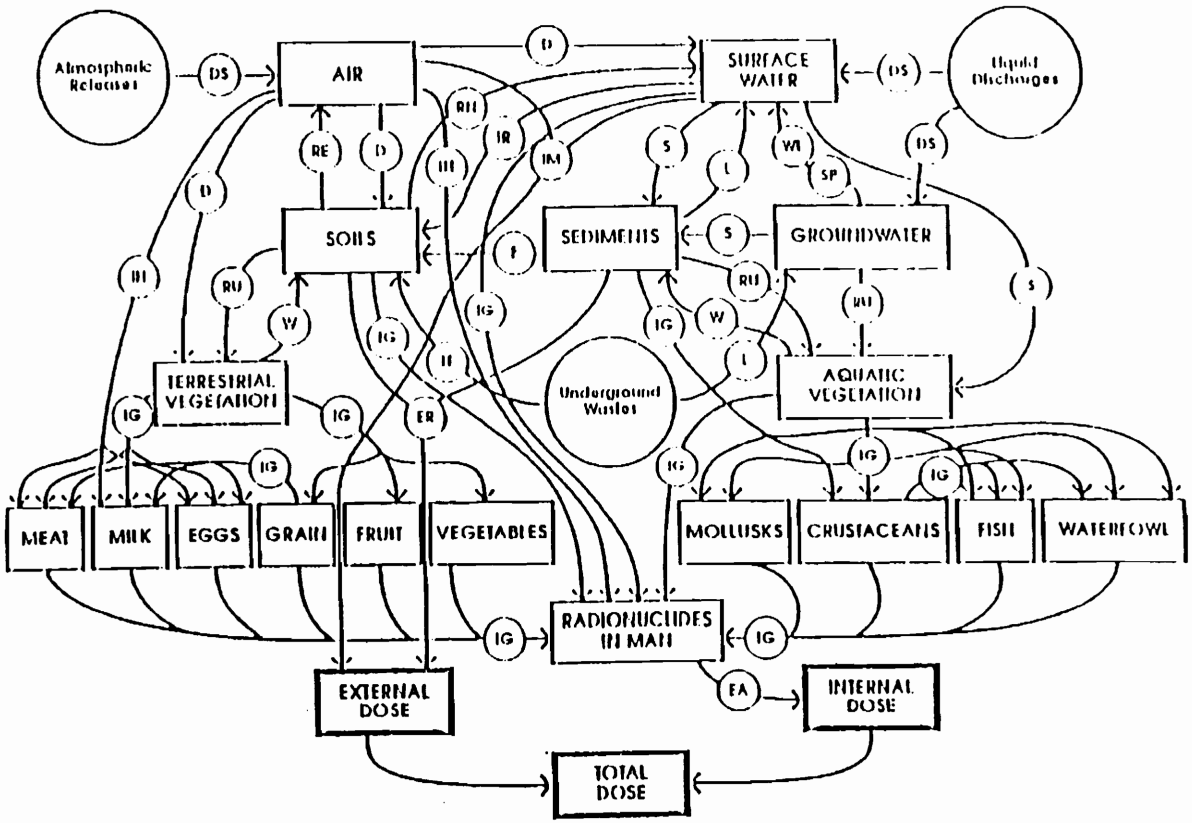

Figure 4 Typical complex pathway analysis

Although the State maintains the responsibility to make decisions regarding the protection of its citizens, it was realized early in the development of nuclear power that the federal government and the utilities would typically have more expertise in the field of nuclear engineering and health physics. Therefore, it was decided that in case of an accident, the utility and the federal government would review all data that were available and process these data into useful information that would be available to the State. This information is in the form of exposure to the public to direct radiation and radioactive iodine. The branch of the federal government that is responsible for regulating the utilities and for processing these data are the Nuclear Regulatory Commission (NRC).

In order for the State to take the necessary protective actions, it is highly critical that the information be provided to the State in a timely manner. Many citizens lives may depend on this information.

Because of problems explained in detail in later portion of this report, the State of Illinois has determined that a decision making system is needed for radiological events that might be expected to occur at nuclear power stations or processing facilities. The complete system must be able to collect applicable radiological data, transmit the data to the State, integrate these data with data provided by the NRC and the facility, process these data into useful information, display the information in a format that is usable by the State, and aid in the process to decide the actions the State should take to protect the people residing near the facility. The purpose of this report is to explore the requirements for the emergency environmental data collection portion of the total State system. These data collection system is needed to collect and process data from positions outside the boundaries of the facility following a major release of radioactivity. The general requirements for the remainder of the system (including the data communications link, the data processing computer network, the display terminals and, the software utilized at the remote facility and the voice communications systems) are outside the scope of this report.

As required by the State personnel, the goal for the system is to enable the State to take protective action before anyone in the general public receives a dose of one rem, Total Effective Dose Equivalent (TEDE) or five rem to the thyroid, and enable that action to preclude anyone from receiving greater than five rem TEDE or twenty-five rem to the thyroid for releases that occur in twenty-four hours or less.

II. **Description of the Current State Monitoring System:** Currently, the State relies on the nuclear facility to collect all environmental and emergency data. The facility has installed a system composed of sixty-four fixed environmental monitors at the fence line, a stack monitor, an equipment performance monitor, and plant radiological monitors.

- The fixed environmental monitors collect airborne and surface water data from many positions located on the fence line. These data typically represents very low concentrations of radioactive carbon-14 and tritium and also background radiation. Some of this equipment requires an attendant to manually collect and analyze samples. In case of an accident, each of these monitors has the ability to collect the gamma radiation levels from the noble gases in the plume and it directly to the utility's control room via a land line. In addition, collection devices are collocated with these monitors to collect radioiodine deposition. Samples drawn from these devices must be manually collected and analyzed. In case of an accident where large quantities of radionuclides are released, the manual collection and analysis of these samples pose an increased risk to the worker. The inherent time delay in the processing of the data could delay the decision making process.

- The stack monitor is an automatic monitor that collects data for airborne emissions near the source of the emissions. Typically these data are composed of very low concentrations of radioactive noble gases, carbon-14, and tritium. Data on gamma radiation from the noble gases, and to a certain extent from particulate matter and radioactive iodine samples, are collected by these monitors. Data are fed directly to the utility's control room via a land line. In the event of an accident, these monitors may be of little value since the breach in the containment would not result in a release of radionuclides through the stack.

- The equipment performance monitors utilize automated detectors to determine when some facet of facility operation has degraded to the point that a radiological incident is likely to occur. For example, these monitors are often used to detect changes in system temperature and pressure at critical locations in the facility. These data are also provided to the utility's control room.

- The plant radiological monitors are used to detect changes in the radiological conditions inside the plant containment. This information provides an early warning of conditions leading to a radiological release.

In the State of Illinois, the data from the environmental monitors and the stack monitor are transmitted directly to the State's system via a satellite based data communication's network. These data, as well as the station performance and radiological data, are fed to the NRC via a satellite based data network that in turn is processed by the NRC. The information gained from the processed data are then transmitted to the State for their analysis. Figure 5 provides a functional description of the system. currently in use by the State. Beyond this on-site data, the facility provides off-site teams which attempt to retrieve data from predetermined locations and to track the plume. Further off-site data are provided by the Department of Energy who provides an aircraft with applicable data collection equipment within twenty-four hours following the accident.

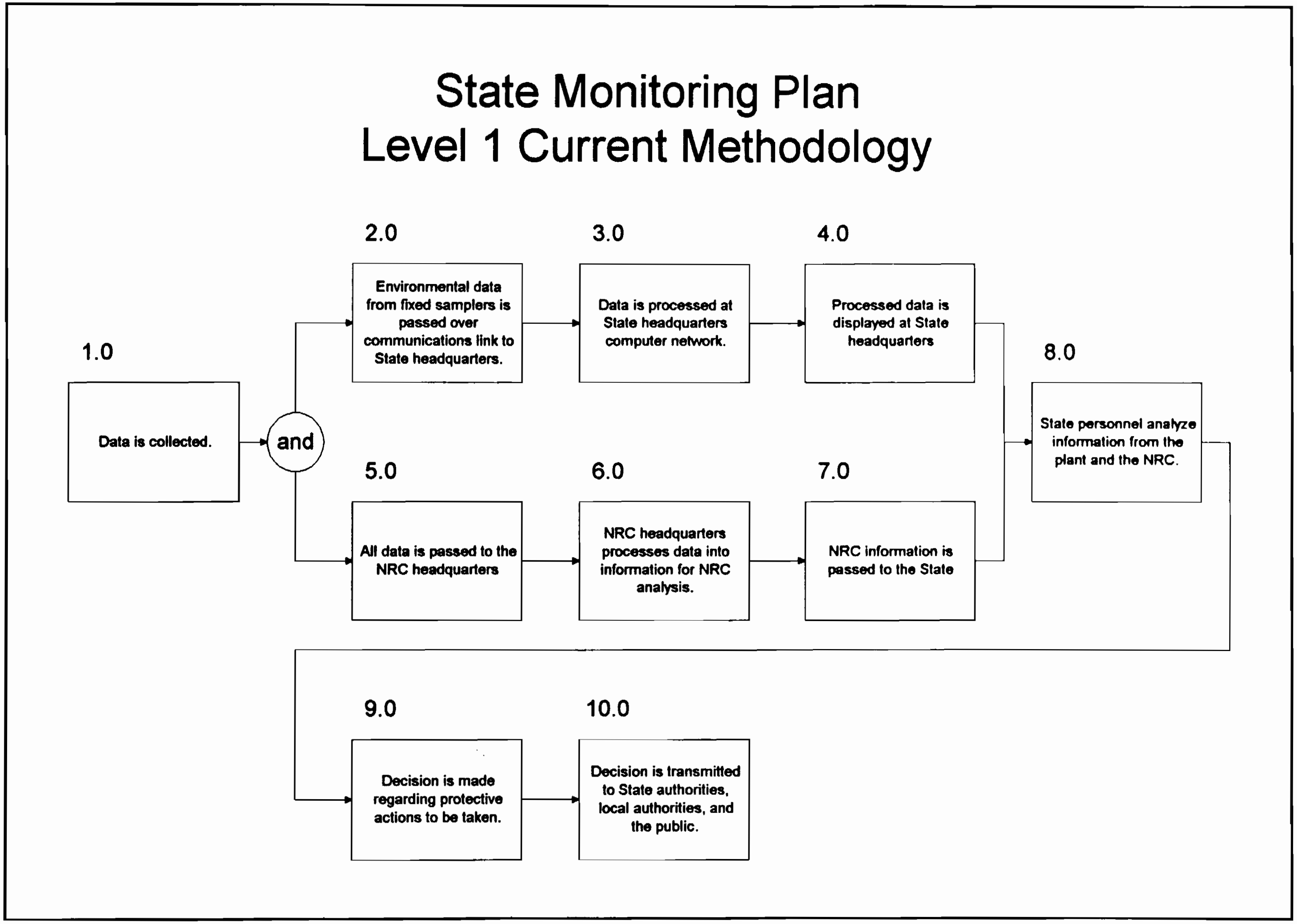

Figure 5 Functional Description of the current monitoring system

III. **Description of Problems Associated with the Current System:** The State has determined that the information provided by the NRC is not timely or adequate to enable the decisionmaking required of State personnel. The current system includes an inherent time delay of at least one hour. The designers of the system realized that the operators of the facility had two responsibilities in the event of an accident. The first was to combat the casualty and attempt to mitigate the consequences of the accident, the second was to notify the State to allow them to take the necessary protective actions. It was recognized that quick responses by the operators would result in the facility being able to mitigate the consequences of an accident in all but the most incredible accidents. To allow the operators to take the necessary actions to mitigate the accident, it was determined that a one hour time delay between the time an emergency was declared and the time that the data collection system would be activated would be prudent. Without a decision making system to aid the State's analysts, this one hour delay often results in several hours of inaction. Delays of up to four hours have been noted in the past during exercises and drills.

Site personnel currently use two methods to determine the dose to the reactor plant's neighbors. The most direct method is to send monitoring teams into the effected areas with portable equipment. These monitoring teams attempt to gather data directly from the plume. Because of the inherent risk to the off site monitoring teams and the constraints to free movement provided by buildings and natural obstructions, the data obtained by the off-site teams is often hit or miss. In past drills and exercises this has resulted in confusion for the State's decision makers.

In the second method, the facility personnel utilize diffusion theory to attempt to project the dose downwind from the fixed monitoring stations. Figure 6, Figure 7 and Figure 8, also provided by Dr. Miller depict the effects that nearby buildings and various changes in the terrain such as hills and valleys may have on the direction that a plume of radionuclides might travel. Figure 6 depicts the problems that can be associated with a nearby large building. Because of the eddies and turbulent paths formed around such a building, it is necessary to place the fixed environmental monitors at least 0.5 mile away from the reactor building. The effects are also noted around structures such as high power transmission lines. Figure 7 depicts the effects that a hilly terrain represented by the shaded areas might have on the wind and therefore, the dose projections. In this figure, the length of the arms of the wind rose represents the weighted average wind velocity. In Figure 8, the effects of large bodies of water such as Lake Michigan are noted. A plume that is originally blown away from the shore line can return inland at another location further up or down the coast. This unexpected change in wind direction can result in a large dose to neighbors of the plant, who are a significant distance away from the plant. In each of these cases, it is necessary to note that the local meteorological conditions are chaotic in nature and cannot be adequately predicted using current computer codes with a few meteorological stations.

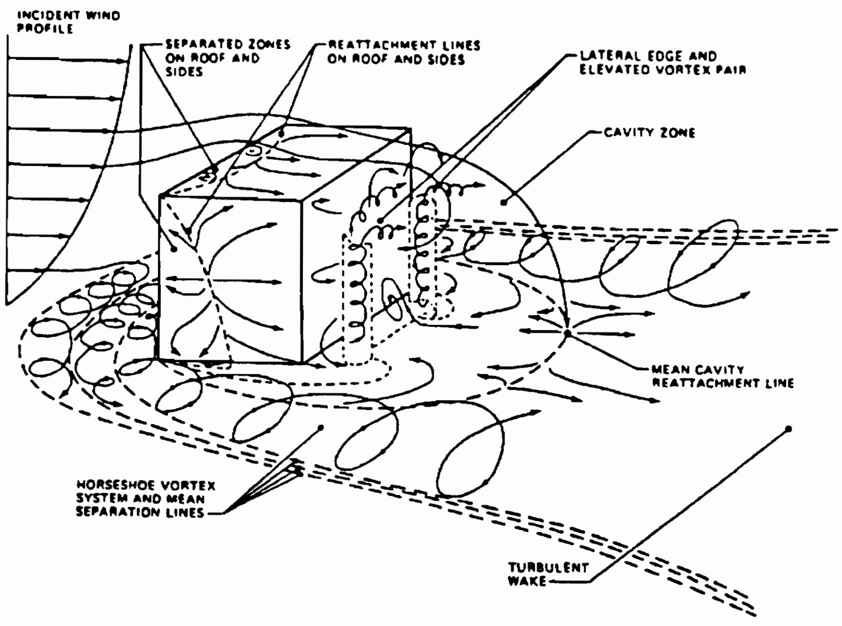

Figure 6 The effects of building wake on a plume

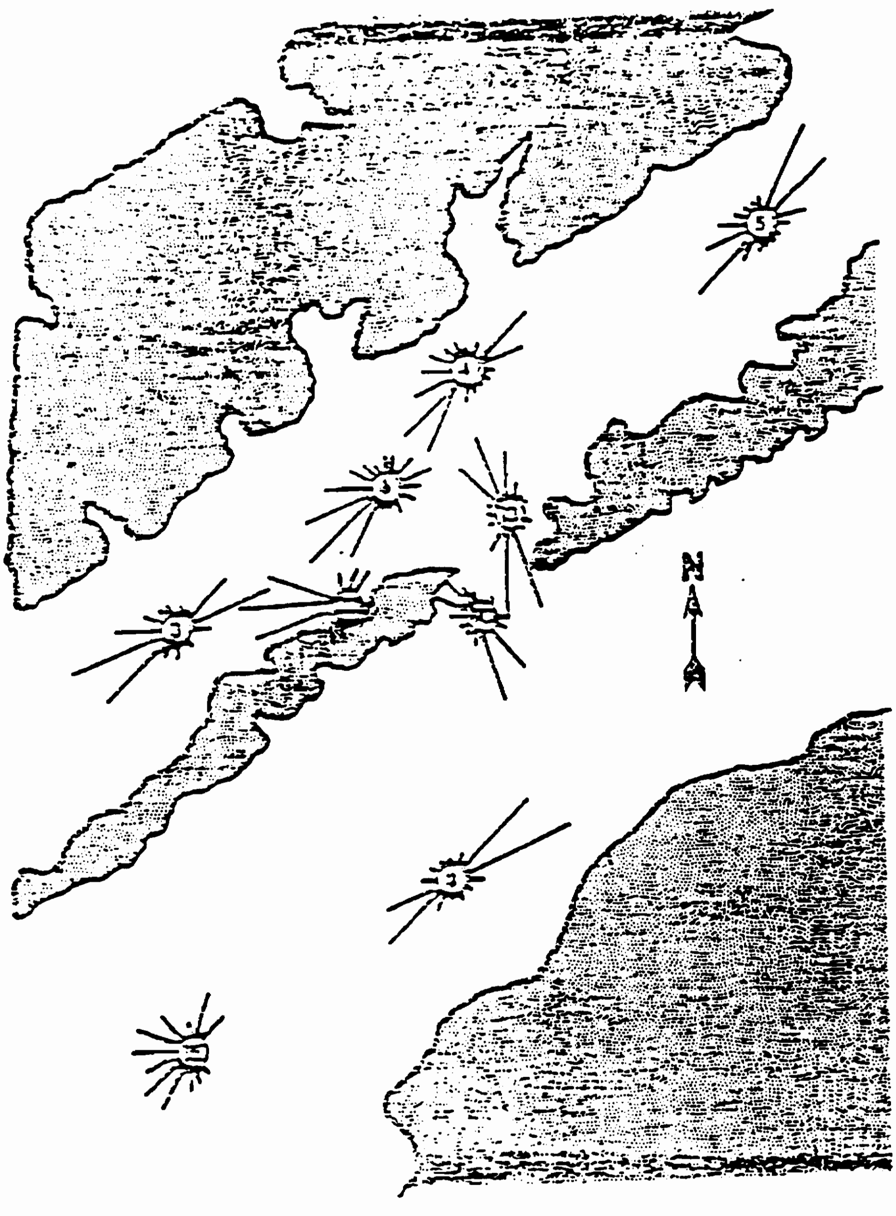

Figure 7 The effects of terrain on wind direction

TRAJECTORY RESULTING FROM SEA BREEZE

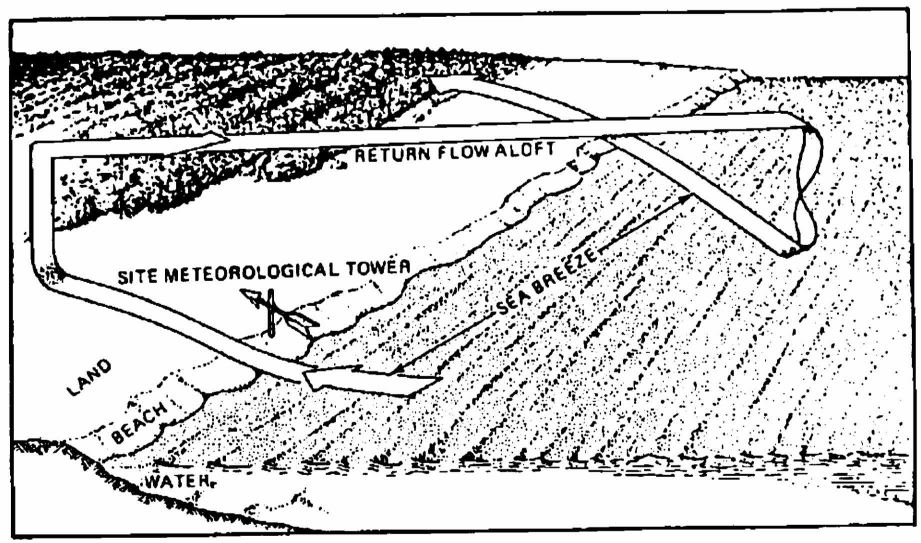

Figure 8 The effect of a large body of water on wind direction

The off site data provided by the Department of Energy is not guaranteed to arrive until twenty-four hours after the accident begins. It therefore, does not aid in the initial decision making, but does help the State in making the necessary decisions regarding corrective actions to be taken after the populations are evacuated from a major accident.

Therefore, essentially no useful off site data is provided in time for the State to make its decision to shelter or evacuate the local population.

In the worst case scenarios, the State has less than two hours from the beginning of the accident to take necessary protective actions, an inherent one hour delay could result in members of the public exceeding the recommended dose of twenty-five rem external exposure or 100 rem exposure to the thyroid. Since the city of Zion contains approximately 25,000 people, a dose of twenty-five rem would result in the potential for:

$$X=N*R*D$$

$$X=312.5$$

where: N is the exposed population - 25,000, R is the risk of a lethal cancer per person per dose - $5x10^{-4}$ deaths per person per rem

D is the dose received - twenty-five rem, and

X is the number of excess cancer fatalities.

Since the normal incidence of lethal cancer is about 20%, approximately 5,312 people would be expected to die of cancer instead of the expected 5,000 deaths had no accident occurred. These deaths would be expected to occur over a period from seven to forty years following the accident.

In addition to the time delay, the State is frustrated with the fact that the information provided by NRC and the data provided by the facility is not able to be integrated easily. This failure is because the information provided by the NRC does not contain all the raw data used to process the information and the facility does not transmit the manually collected data. This lack of consistency increases the difficulty of the State's decision making process.

The State is therefore, dissatisfied with the current system. The State would like to obtain a system that can provide data in a real time mode and help the

State in making decisions regarding protective actions that should be taken to protect the public. This data should be able to be integrated with the date currently received from the facility and should be in a format compatible with D Base III. The system should contain the necessary decision making software to provide the State with the ability to determine the projected dose to the public from the external gamma radiation and the internal contribution from the radioiodine. Since the wind direction and speed are variable, this information must be updated at least every three to five minutes.

IV. **Description of the Steps Used in The Completion of This Project**:

Modern technology should allow the State to place a system, which does not impose additional risks to workers or impose an inherent time delay, near the nuclear facility. In order for this system to be economical, it should utilize a few detectors and yet provide the real time information required by the State. Because of the need to obtain data off site as close to the area where people are expected to be exposed, the system would be composed of a few fixed detection systems augmented by some type of remote monitoring system.

To address this problem a prototype site was required. Because of the author's familiarity with the Zion Nuclear Power Station in Zion, Illinois, that plant was chosen as the prototypical site.

A needs analysis was performed based on information gathered from the State and from emergency planing experts.

A feasibility analysis was performed for this site using the following alternatives:

- The use of a manual system similar to the current system, with the exception that the State would have their own set of detectors and utilize their own personnel, and, therefore, could control the inherent delay time. This system was used as the control system.

- The use of a limited number of fixed detectors and a remotely controlled land based vehicle containing similar detectors. The fixed detectors would provide an early warning system to the State that an accident was in progress and the initial direction of the plume.

Detectors would be mounted on the vehicle to quantify the actual radiation levels and deposition of radioiodine.

- The use of a limited number of fixed detectors and a remotely controlled fixed wing aircraft. The fixed detectors serve the same purpose as in the previous option and the fixed wing aircraft houses another set of detectors with a function similar to those used on the land vehicle.

- An identical option to the previous option except a remotely controlled helicopter replaces the fixed wing aircraft.

All four alternatives failed to meet the operational requirements which had been defined based on discussions with personnel at the State. Therefore, a fifth alternative was developed based on discussions with the manufactures of hot air balloons and airships. It was determined that the use of a combination of fixed detectors, a small remotely controlled land vehicle, and a remotely controlled airship could meet the operational requirements.

Following the selection of the fifth altrenative:

1. The life cycle of the system was determined.

2. A systems maintenance concept was developed.

3. The system's operations were functionally defined.

4. An analysis was made to select the types of detectors to be used and to optimize the number of fixed detectors.

5. A short life cycle cost analysis was completed to determine the potential life cycle cost of the preferred system.

6. A sensitivity analysis relating the effects of reliability, mean time between preventive maintenance and mean down time on the availability of the system.

The remainder of the system's process was described in detail for the life cycle of the system.

V. **Needs Analysis:** From the description of the problems associated with the current system a needs analysis was performed. Each aspect of the current system currently determined to be a problem was linked to a basic need of the system. In addition, several other needs are defined based on discussions with the State and other emergency planning experts. The following listing is a summary of the identified needs.

A. Both gamma radiation levels and the radioiodine concentrations are required.

B. Both on site (at the fence line) data and off site data are required. The detectors should be able to detect radiation levels and radioiodine concentrations that would result in doses to the public of 0.1 rem TEDE or 0.5 rem to the thyroid.

C. The on site gamma radiation levels should be provided continuously, in real time.

D. The data should be in D Base III format to allow integration with the current data received from the utility. The data base structure must match data provided by the utility.

E. The system should provide the capability to compute off site doses based on a diffusion model with inputs from the off site data as well as the on site data.

F. The system should provide the necessary information to allow the State to make the decision to take protective actions before anyone in the general public exceeds a dose of one rem TEDE or five rem to the thyroid.

G. The system provides the necessary information to allow the State to take protective actions so that no one exceeds a dose of five rem TEDE or twenty-five rem to the thyroid.

H. Because the health and safety of the public depend on this system, the system should be available at least 95% of the time.

I. Because an accident could continue for up to twenty-four hours, and the risk of a release is greatest within the first thirty-six hours, both the on-site data collection system and the off-site data collection system should be available for thirty-six hours following a reactor accident.

J. The system should be inherently safe and pose no undo risk to the public. Since the risk of a death from a reactor accident is approximately 10^{-6} deaths per year, the system should not pose a greater risk to the public than this value.

K. The system should be able to provide reliable information to the State.

L. The system should not pose a significant risk to the environment.

VI. **Feasibility Study**: Because of the need to integrate data already provided in a format compatible with IBM compatible systems, the data processing was restricted to IBM compatible equipment. Four alternatives were initially pursued for the data collection equipment. They were:

- The use of a manual system similar to the current system. In this system the State owned and operated their own set of detectors. State personnel would be responsible for the operation and maintenance of these detectors. This system would allow the State to control the delay time. Off site teams of personnel could be maintained by the State and local authorities could be trained to supplement the off site teams. This system would require the use of multiple vehicles to dispatch the teams. It is anticipated that both land vehicles and water based vehicles would be required. These vehicles could be used for other purposes to support the state park next to the facility but equivalent vehicles must be available always for use in their primary mission of emergency preparedness. The major problem experienced by this system is the inherent risk to the workers who must enter the plume to retrieve the data. It is anticipated that these workers could receive a dose more than the federal limit for occupational radiation exposure. Although this limit is set for normal occupational doses and not emergency response, it is preferable to remain within this limit based on ensuring the health and safety of the work force. In addition, experience with a highly trained workforce employed by the utility suggests that this alternative do not provide highly reliable information. This alternative is to be used only if no other alternatives are available.

- The use of a limited number of fixed detectors and a remotely controlled land based vehicle containing similar detectors. The fixed detectors would provide an early warning system to the State that an accident was in progress and to provide the initial direction of the plume. Detectors mounted on the vehicle would be used to quantify the actual radiation levels and deposition of radioiodine. The vehicle would be remotely controlled via an off site team and would be able to traverse city streets and sidewalks. The major problems associated with this option are that it is limited to city streets and sidewalks and cannot move across rough terrain or water. Since the Zion Plant is located on Lake Michigan and the plume could move out over Lake Michigan and return to land some distance down the shore line, this alternative would not provide off site data in cases where the wind direction is offshore. This option was therefore, removed from consideration.

- The use of a limited number of fixed detectors and a remotely controlled fixed wing aircraft. The fixed detectors serve the same purpose as in the previous option and the fixed wing aircraft houses another set of detectors with a function similar to those used on the land vehicle in that they quantify the actual radiation and contamination levels in areas near the potentially exposed personnel. This system has the ability to measure the radiation and contamination levels in the plume should the plume move over a large body of water such as a lake or a river. The problem associated with this option is that to meet the requirement to collect data off site for thirty-six hours multiple aircraft would be required. There are many inaccessible locations on aircraft that cannot be adequately decontaminated. The volume of radioactive waste that would be generated by these multiple aircraft would be large.
- The identical option to the previous option except a remotely controlled helicopter replaces the fixed wing aircraft. Helicopters can hover in one area when the wind speed is low. The same difficulties arise here as in the fixed wing aircraft. Since the helicopter has the additional advantage of being able to hover, the use of a fixed wing aircraft is discarded.

The two remaining options from the initial set are a system composed of fixed detectors and the manual collection of off site data and a system composed of fixed detectors and a helicopter for off site detection.

As the project progressed, additional information was gained concerning the generation of waste. Currently, the State of Illinois does not have a federally approved facility to dispose of radiologically contaminated waste. There are only two such facilities available in the United States. One is located in Hanford, Washington and one in Barnwell, South Carolina. Both facilities are expected to preclude the acceptance of out of State waste later this year. It is expected that a bidding war will result and pleas will be filed to allow other states to ship waste to these two facilities. It is also expected that should the states of South Carolina and Washington choose to allow the other states to continue to use their facilities an exaggerated fee will be charged. Currently, some states are paying as high as $1000 per cubic foot of waste. Prices are expected to increase by as much as an order of magnitude. Future price increases are even more uncertain. It is therefore, highly desirable to limit the volume of waste generated.

Since the use of the manual system was highly undesirable, the use of hot air balloons or weather balloons was pursued. The use of hot air balloons or weather balloons was ruled out because they were uncontrollable and non-retrievable. A vendor of hot air balloons suggested that the two airship vendors in the United States be contacted. One of the vendors proved to be out of business. The other vendor, Thunder and Colt Helium Airships provided the details of their British built airship. The airship met all of the needs and did not require multiple aircraft. A large portion of the controls is contained within the envelope that is easily decontaminated. The volume of waste was therefore, reduced significantly. However, because the airship could not be instantly inflated, a secondary monitoring platform was required. The two options for this platform were to duplicate the sixty-four monitoring locations used by the State or to optimize the fixed monitoring stations and utilize a remotely controlled land based vehicle to carry a detector package around the perimeter of the site. For the purposes of this report the later option will be discussed.

VII. **Operational Requirements**:

A. Mission: The mission of this system is to detect any release of radioactive isotopes from a nuclear power plant, determine from the level of release if any actions are required by the State, suggest what actions are to be taken and continue to keep the State informed of environmental conditions for the duration of the accident and for the period immediately following the accident. Based on the preferred option obtained from the feasibility study the system consists of:

1. A subsystem composed of fixed monitors and communications equipment. This Fixed Monitoring Subsystem (FMS) is used to detect the initial release and to transmit the initial radiological data to the Command and Communications Subsystem (CCCS). It will transmit data related to the gamma radiation levels and the concentration of radioiodine. It is to be at the fence line or 0.5 miles away from the reactor plant building whichever is greater. The communications

equipment will be required to provide continuous information regarding the gamma radiation levels.

2. A Remotely Operated Surface Monitoring Subsystem (ROSMS) is used to monitor the radiological release at the site boundary or the Lake Shore whichever is closer and can provide more refined data from the center of the plume.

3. A subsystem composed of an airship, the Remotely Operated Airborne Monitoring Subsystem (ROAMS) which is used to monitor the center of the plume downward of the site.

4. A CCCS, is used to collect the data provided by the other three subsystems and convert it to useful information. It helps in the decision making process, to display the information and to control the communication equipment, the ROSMS and the ROAMS.

5. Facilities are needed to house the State decision making authorities, command, communication, control, and monitoring equipment

6. Equipment is required to display the information and aid in the decision making.

B. The primary scenario expected is as follows:

1. The FMS detects the initial release and sends a signal to the CCCS.

2. The CCCS directs the ROSMS to the area expected to be the center of the plume.

3. The ROSMS moves to the area expected to be the center of the plume and begins to monitor for radionuclides.

4. Based on meteorological conditions and data received from the ROSMS, the CCCS refines the predicted center of plume location and redirects the ROSMS to the new center of the plume.

5. As data is received by the CCCS, a decision is made to activate the Emergency Management Command Center (EMCC) and to deploy the ROAMS.

6. The ROAMS is activated by the CCCS, and is inflated and fueled by a remote team at the FSC. It is then detailed to the center of the

plume where it monitors the environmental conditions within the plume downwind of the facility.

7. Redirection of the ROSMS and the ROAMS is continuously controlled by the CCCS based on the changing meteorological conditions and the data received from these platforms.

8. Once the EMCC is activated the CCCS continues to provide information to the EMCC as well as provide suggested actions for EMCC personnel to take.

C. Performance and Physical Parameters: The CCCS, the FSC, and the ROAMS should be located within five miles of the Zion Station preferably on State owned property. The State owns several square miles of property in the immediate area designated as a state park. The ROSMS will be located on the boundary of Zion Station property and can traverse the entire perimeter of the site.

D. Use Requirements: Unlike most systems, this system is never expected to perform its actual mission. In this regard it resembles a missile system. The FMS and the CCCS are expected to be operational twenty-four hours per day. The ROSMS is expected to be deployed at a minimum of once per month for training and preventive maintenance and be available for deployment twenty-four hours per day. The ROAMS system is expected to be able to be deployed twenty-four hours a day and be deployed at a minimum of once per quarter for thirty-six hours for training missions and computer software upgrades and preventive maintenance.

E. Operational Deployment and Distribution: The pilot program is expected to be deployed at the Zion Nuclear Power Station. The ROAMS system can be deployed from the FSC and is preferred to be at the Zion Beach State Park that is next to the Zion Station. The EMCC is expected to be at the State capital of Springfield. Eventually, if the pilot program is successful, the system is expected to be utilized at each of the power stations in the State. The system is expected to be operational thirty-six months after the letting of the contract.

F. Operational Life Cycle: The Zion Nuclear Power Station has an expected remaining lifetime of 7 years following the installation of the system. There is a high probability that a plant life time extension will be attempted at the end of this period. Because of the expected lifetime of the Zion Nuclear Power Station, the system is expected to be operational for seven years with periodic preventive and corrective field maintenance. The plant equipment overhaul is expected to occur at the 7-year point, and will provide the opportunity for upgrade to more modern equipment. The total lifetime of the system is expected to be 14 years.

G. Operational Skill Factors: The system operators are expected to be high school graduates with an equivalent of two years technical training in each phase of the system.

H. Environment: The system is expected to operate year round in the northern Illinois area near the shores of Lake Michigan. The FMS, the ROSMS, and the ROAMS are expected to operate in adverse weather encountered in the region. Specifically, at temperatures between -30^0 F and 120^0 F at humidities between 20% and 100% relative humidity. The ROSMS is expected to operate in fifty year weather conditions (i.e., wind speed, gusts, etc.). The ROAMS is expected to operate in rain and light snow. Heavy precipitation lessens the effects of the release because the radionuclides are washed from the atmosphere; therefore, it is not necessary for the ROAMS to be operational in the most severe weather conditions (i.e., fifty year weather conditions). Because the reactor plant is designed for seismic loadings up to 0.25 G, the system should also be able to withstand a seismic event of 0.25 G.

I. Maintenance Concept: As with any system a reliable maintenance program is important. However, the health and safety of thousands of people rely on this system's performance should it be required. Having a required availability of 0.95 means that the system's maintenance program must be well thought out and administered. By design this prototypical system must have most of its maintenance performed at the organizational level. No intermediate or depot type facility is planned for this potentially one-of-a-kind system. Therefore, maintenance will either be performed by the organizational personnel, be performed by factory representatives who will come on site to perform the maintenance or will be shipped to the vendor.

The following sections provide some details on the thoughts related to the maintenance concept:

1. Organizational Maintenance: Most failures of the system can be repaired on location by operational personnel. This will require the systems to be composed of simple replaceable modular parts to the maximum practicable extent. Usually the parts will be considered non-repairable. Maintenance will be limited to periodic checks of equipment, visual inspection, cleaning, some servicing, minor adjustments, and removal and replacements of components and equipment.

(1) In order to ensure the high availability, the system will utilize a self test and diagnostics capability whenever practicable.

(2) Component parts will be standardized where practical. As an example, each of the detector subsystems, (the FMS, ROSMS, and ROAMS) will utilize a standard detector package.

Since parts are generally replaced rather than repaired, the mounting and accessibility of each part must be considered.

2. Personnel Skill Level: The personnel who will be maintaining the system in the FSC are typical operational personnel. They are not required to be trained mechanics, but will be required to be trained to make simple replacement type repairs. No more than six weeks of schooling on system maintenance should be required for these personnel.

The maintenance scheme should consider that any repairs during a mission would require working on equipment that could result in high exposure rates to the workers, possibly above overall guidelines. Therefore, where practical, the principles of time, distance, and shielding should be factored into the design of the FMS, the ROSMS and the ROAMS.

3. Intermediate Maintenance: The system should be free from intermediate maintenance to the maximum degree possible, since off-site teams from the vendor will be required to come on site to provide this service.

All test and support equipment should be provided as a part of the pilot plant demonstration. This equipment will include all the necessary flight test equipment for the ROAMS, and also the test equipment for the standard detector package. Where practical all check sources will be of less than licensable quantities.

The field shop facility must be able to work on contaminated equipment and may expose the technicians to relatively high radiation fields.

4. Depot-Producer Maintenance: There should be no planned preventive depot or producer level maintenance on the system or subsystem level. However, individual components such as the engines or the electronic equipment may require overhaul and/or calibration.

VIII. **Functional Description of the System**: The following provides a detailed functional description of the system:

A. <u>Description of the Level One Function of the State Monitoring Plan:</u> The State must be able to collect all data required to adequately analyze the situation at a nuclear power station or processing facility operated within its boundaries. Once collected, the data must be transmitted over a data communications link to a remotely operated facility where the data will be processed and displayed to allow the analysis to be made. The facility must have an adequate computational capability to allow the analysis of the data, and to assist the State in making its emergency action decisions. Normal operations will allow the remote facility to process environmental data to provide assurance to the State that the utility is complying with all environmental requirements. Figure 9, which follows provides a functional description of the complete prefered system. Because of the major changes from the current system the functional references do not match those used in Figure 5.

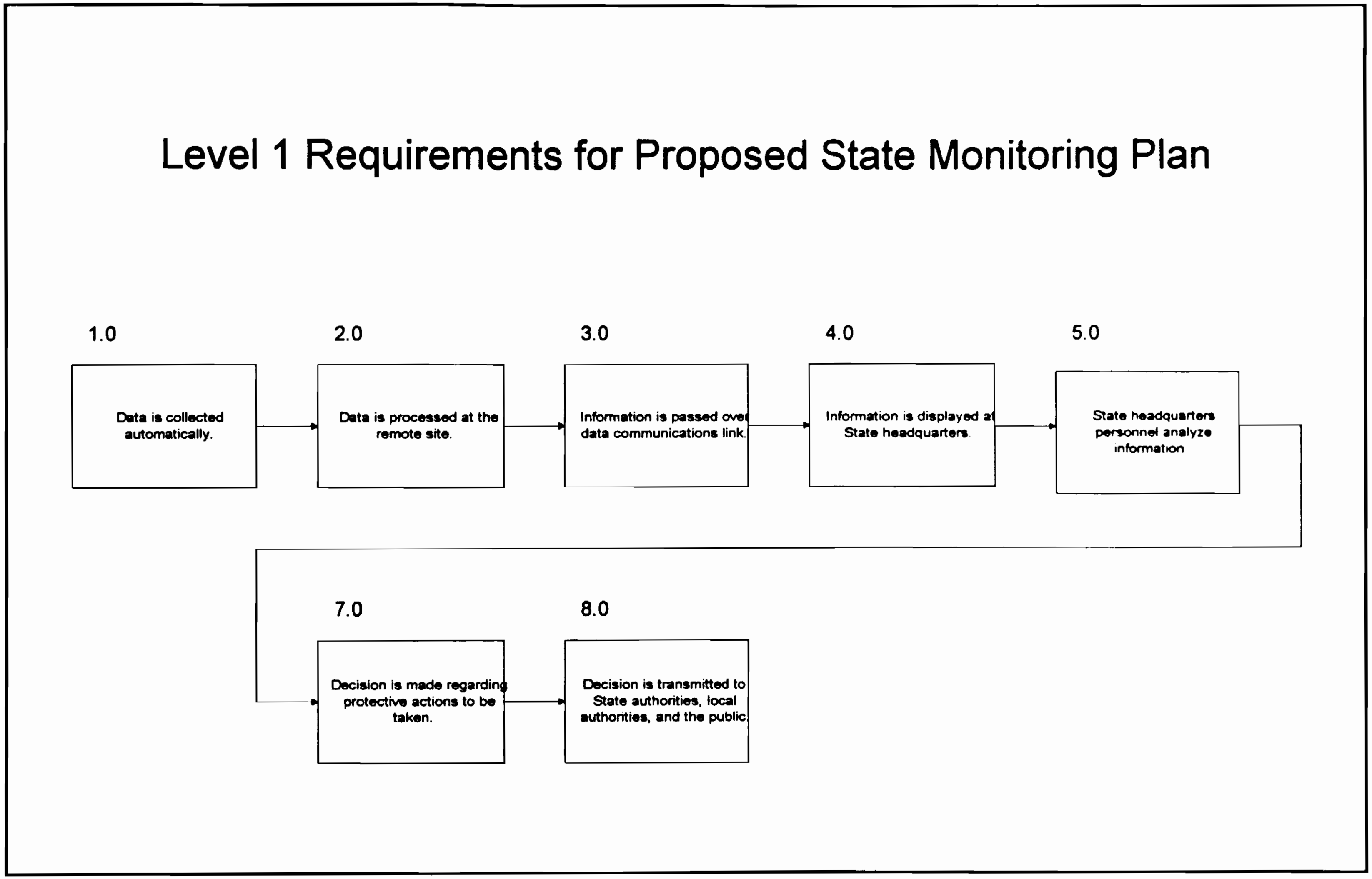

Figure 9 Level 1 functional requirements

B. Description of the Level Two Functions of the Data Collection System: The data collection system should be able to collect both environmental data and emergency data. The environmental sensors are very sensitive, and will periodically collect data from the environment, sample the data, and provide the needed information to the State environmental control center.

Sensors in the emergency data collection system are required to quickly determine a potential accident that results in the release of radioisotopes.

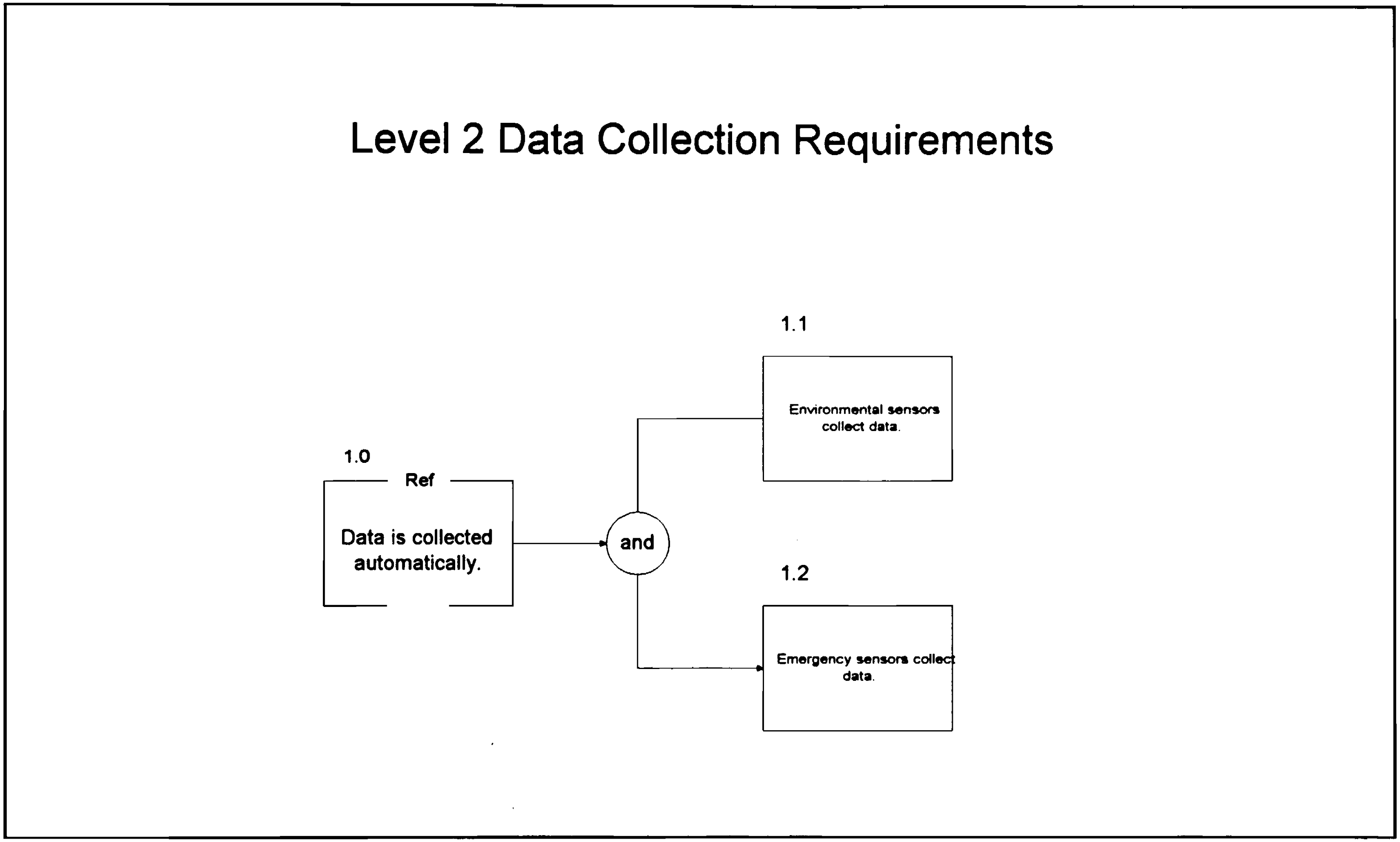

Figure 10 Level 2 functional requirements

C. Description of the Level Three Functions of the Emergency Data Collection Subsystem: In the case of a reactor accident, the emergency sensors collect data from several sources. Depending on the type of accident each of these sensors has the ability to provide the first alert to the State. Only the emergency environmental data sensors are of interest for the system to be designed. A brief outline of each system is included for completeness.

1. The station radiological data sensors collect data from the station's installed radiation detectors. These include such detectors as high radiation alarms, criticality alarms, and airborne radioactive particulate alarms.

2. The plant performance sensors collect data involving station specific parameters such as system pressure, power level, and temperature.

3. The meteorological sensors collect data from the plant's meteorological station located on top of a tower at the station's western most boundary. Data such as wind speed, wind direction, and the stability category are collected at this station. This data is fed to the CCCS via land time to aid in dose calculations and in controlling the ROSMS and ROAMS position.

4. Stack monitors collect radiological data from near the top of the stack. These isokinetic samplers collect data from any potential releases of radioactive iodine, fission products, or activation products that might be released through the stack.

5. The emergency environmental data sensors collect data regarding any release that is unexpected from the station and has the potential of resulting in the State or the Federal governments taking corrective actions. This system is the focus of this report.

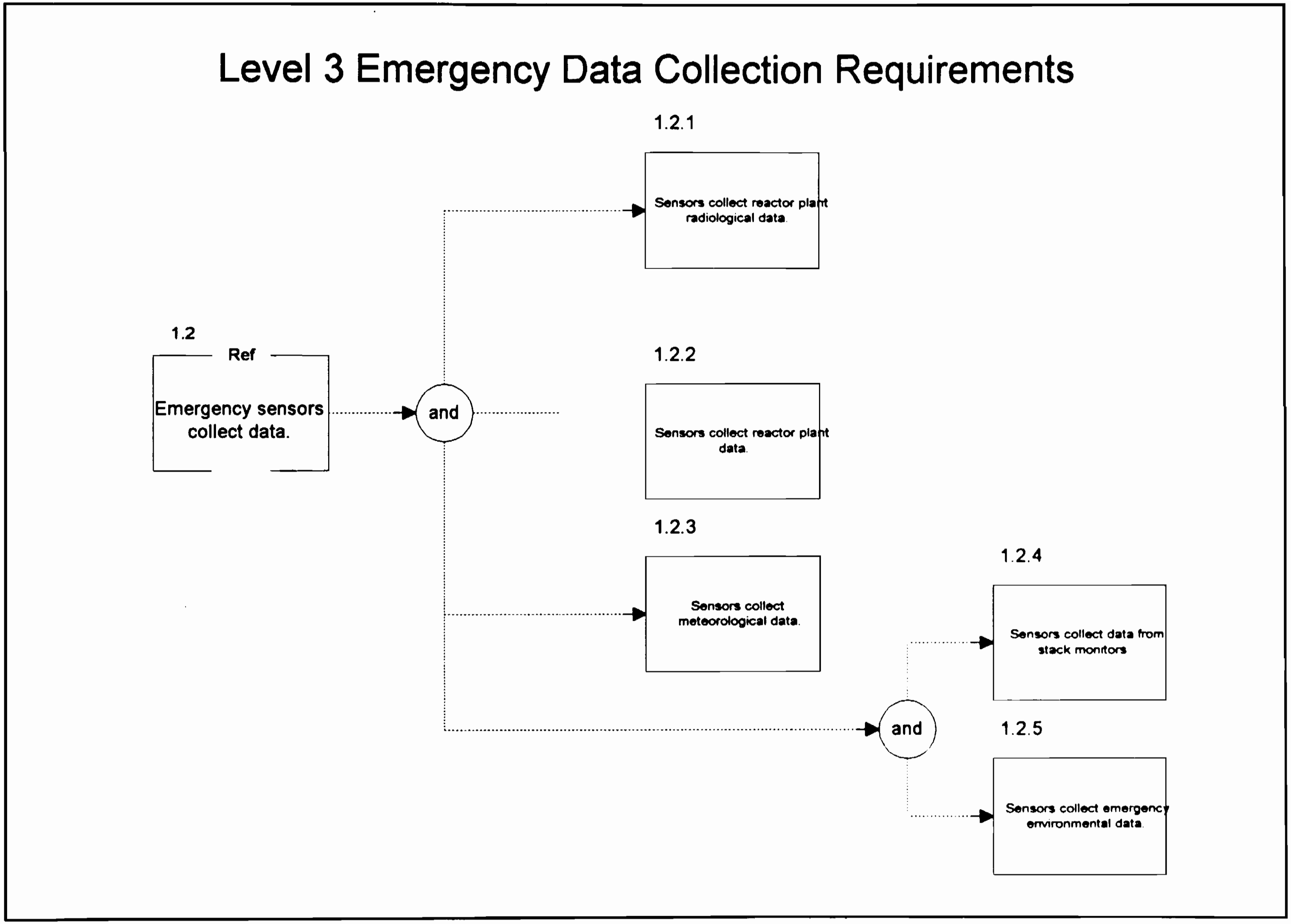

Figure 11 Level 3 functional requirements

D. Description of the Level Four Functions of the Emergency Environmental Data Collection Subsystem: There are two types of emergency environmental monitors. Those operated by the utility and are activated when the utility makes the decision to declare an emergency and those desired to be obtained for the State and operated by State personnel.

1. The utility is required to collect data in the case of an emergency and to report the data to the NRC. In the state of Illinois, this data is also sent to the State. However, an inherent delay exists in this system since the data link is not activated until one hour after a state of emergency is declared by the utility. Based on information obtained after the 3 Mile Island incident and the Chernobyl accident, this is expected to result in a delay of several hours from when the first radiological data might be detected.

2. The State collects the data from the utility's sensors and by the procurement of this system will also be able to collect data in a real

time mode from its own fixed monitoring system (FMS). This data is passed from the sensors to a command, communications, and control substation (CCCS).

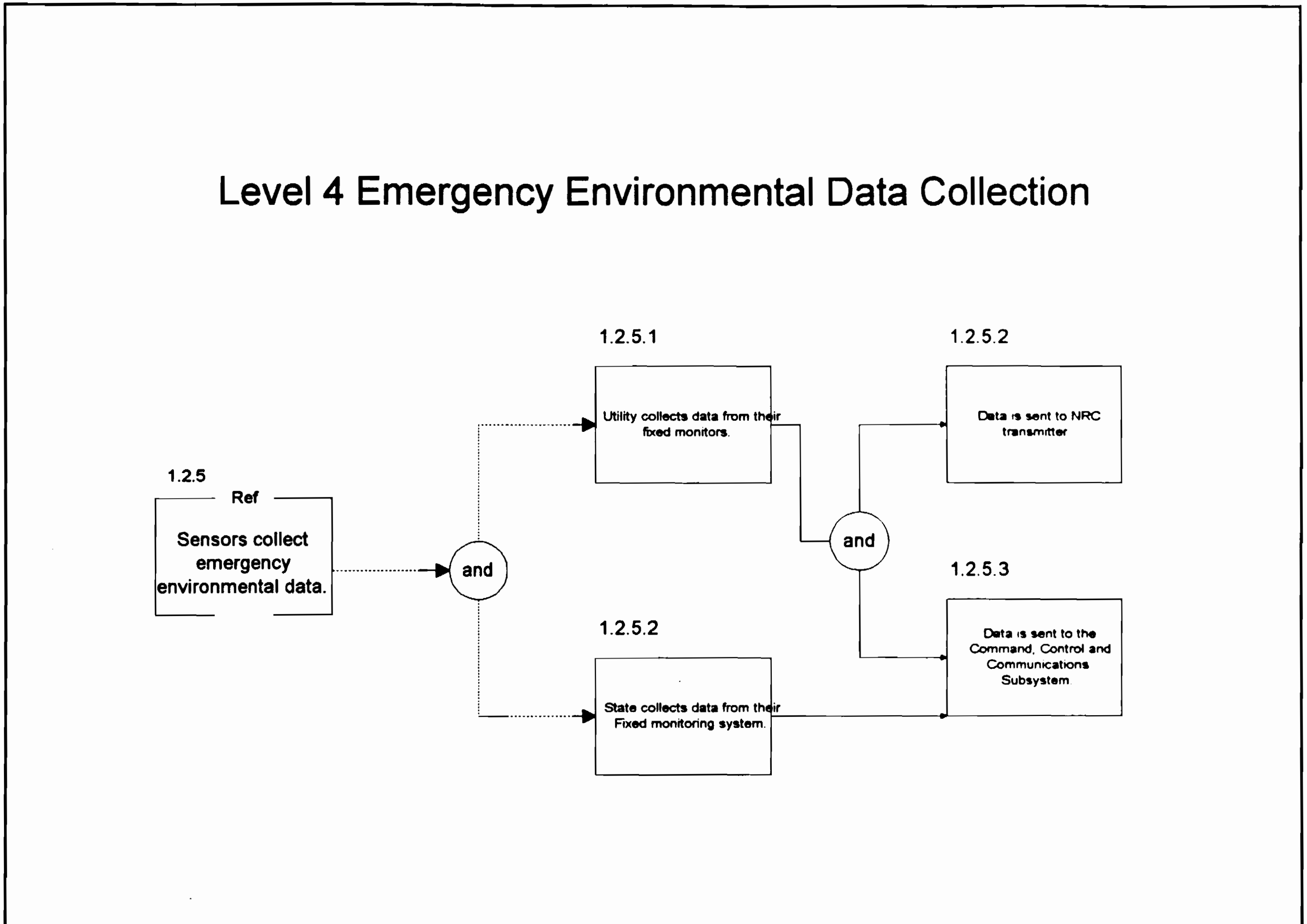

Figure 12 Level 4 functional requirements

E. Description of the Level Five Functions for the Emergency Environmental Data Collection Subsystem: At the command, control and communication subsystem (CCCS) the data is analyzed and a determination is made whether to activate the remotely operated surface monitoring subsystem (ROSMS). If activated the ROSMS moves to the predicted center of the plume, acquires its first data, and transmits the data to the CCCS. The CCCS decides the ROSMS position and maintains it in the center of the plume. The CCCS directs the Field Support Center (FSC) to inflate and fuel the airship and to activate the remotely operated airborne monitoring subsystem (ROAMS), and sends the activation signal to the State Emergency Monitoring Command Center (EMCC). The CCCS directs the ROAMS to the center of the plume where it collects data and transmits the data back to the CCCS. From the data received the CCCS maintains the ROAMS in the center of the plume. Once the EMCC is activated, data is continuously transmitted to the EMCC until the connection is terminated by the EMCC. The EMCC personnel analyze this data and decide actions to be taken by the neighbors of the nuclear facility.

This system is functionally described in Figure 13 and Figure 14.

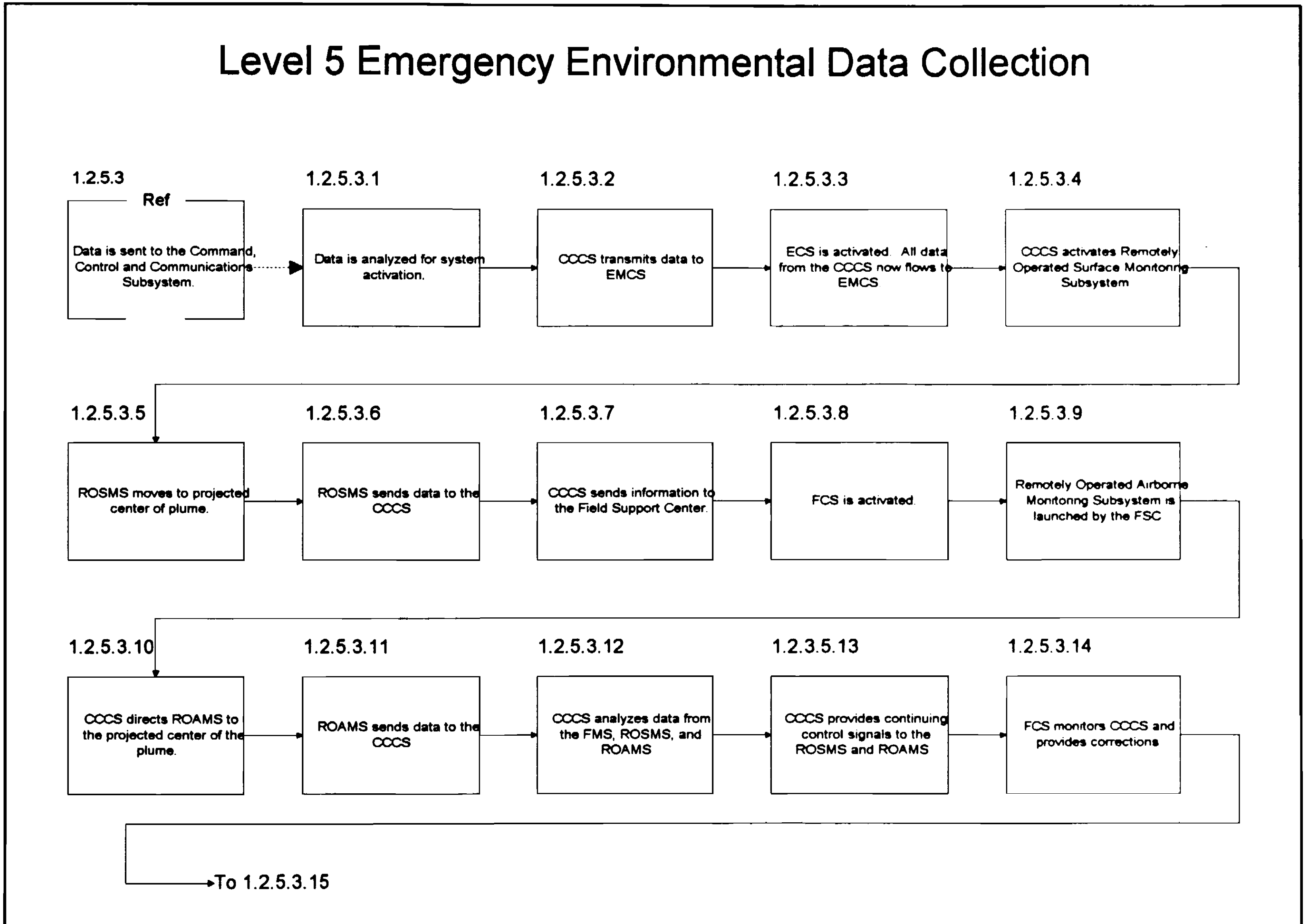

Figure 13 Level 5 functional requirements

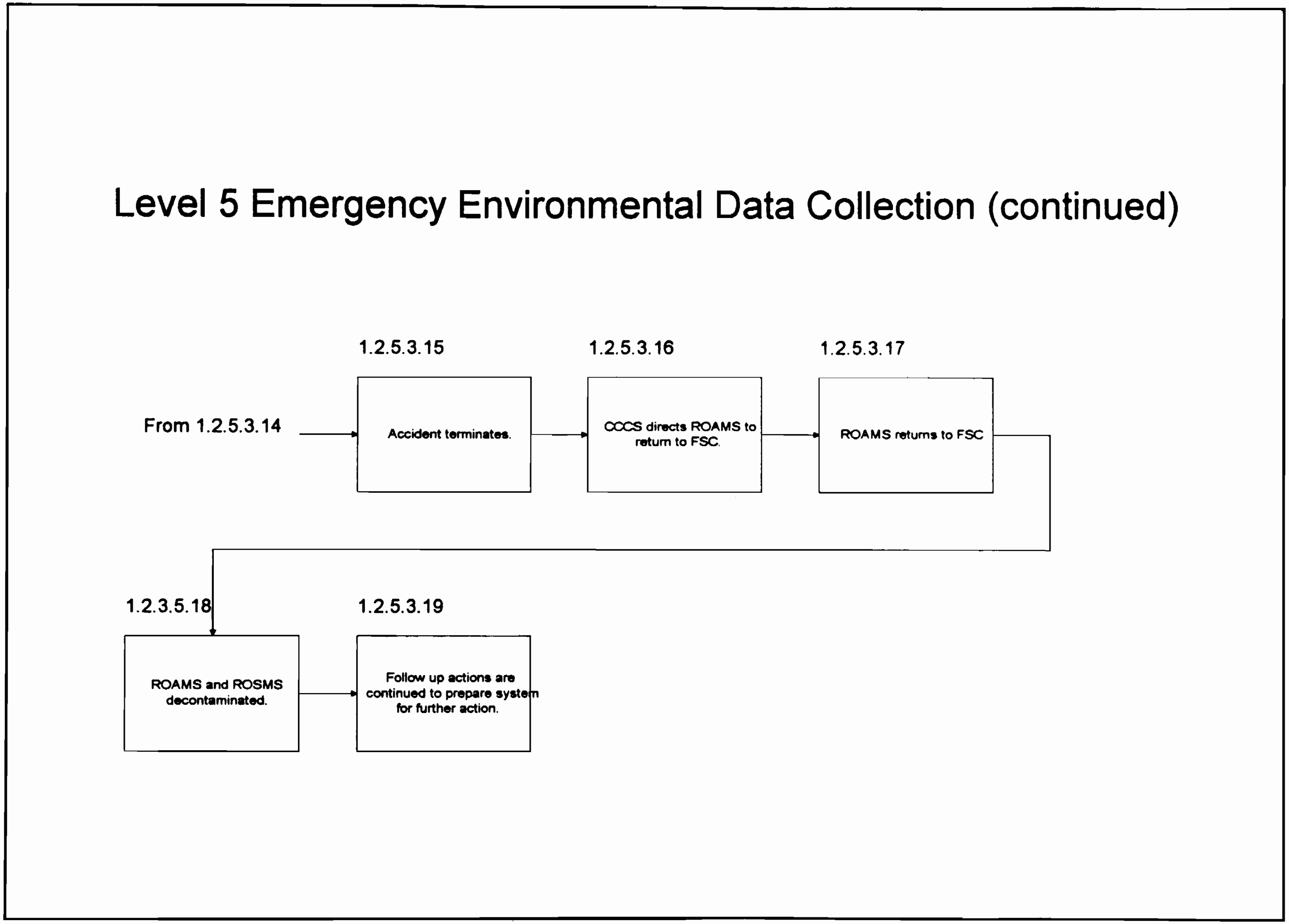

Figure 14 Level 5 functional requirements continued

IX. **Analysis**: Three main areas of analysis were conducted as a part of this project. These were the selection of the types of detectors to be used in all subsystem and the number of stations required for the FMS, the life cycle cost analysis, and a sensitivity analysis comparing reliability, the mean time between preventive maintenance and the mean maintenance down time to attempt to determine which factor would greatly affect systems availability. Each of these analyses is discussed below.

A. Detector Analysis: A review of major vendor information and the equipment used in the current environmental monitoring system identified that expensive pressurized ion chambers (approximately $10,000 per unit) are typically used for gamma dose rate determination. These detectors are necessary for the quantification of the dose at the extremely low levels required if one was to utilize only the fixed detectors for dose projections. This is required because the site has chosen to install sixty-four of these detectors at the perimeter of the site boundary. The detectors are spaced evenly around the northern western and southern boundary. This results in the detectors around the northern, western and southern sites being placed more then 500 feet apart. The detectors on the eastern boundary are closer. More detectors were required around the eastern boundary to account for the fact that the normal 0.5 mile separation from buildings could not be met because of the presence of Lake Michigan. The detectors are not expected to measure the highest dose rate that occurs at the center of the plume, but to extrapolate the dose from the limited data that is available. A high very low minimum delectability level is therefore required, since the actual center of the plume may pass over an area between two detectors. The use of a similar system would require duplication of these type monitors. It was hoped that a significant cost savings could be met if the State used more economical Geiger Muller tubes or moderately priced scintillation detectors. The preferred option would make this possible. The FMS would only be required to detect the fact that a release had occurred and the ROSMS and later the ROAMS can move directly to the center of the plume and obtain actual measurements of the dose rate. The analysis that follows determines first if the less expensive gamma detectors could be used and secondly quantifies the savings obtained from the use of these detectors.

The basic diffusion theory that is used employs the equation:

$$\chi = \frac{Q'}{2 \cdot \pi \cdot \sigma_y \cdot \sigma_z \cdot V_{avg}} \cdot \exp\left(-\frac{y^2}{2 \cdot \sigma_y^{\,2}} \right) \cdot \left[\exp\left[-\frac{(z-h)^2}{2 \cdot \sigma_x^{\,2}} \right] + \exp\left[-\frac{(z-h)^2}{2 \cdot \sigma_z^{\,2}} \right] \right]$$

Where χ = the release in Curie ,
Q' = dose rate to a person standing in the plum.
σ_x=the diffusion rate in the down wind directio n
σ_y=the diffusion rate in the cross wind directio n
σ_z=the diffusion constant in the up directio n
V_{avg} = the average velocity of the wind in the downwind direction on
h= the vertical distance the person is standing from the height of the ground at the release point
z=the height of the release point from the groun l
y=the distance away from the center of the plume the person is standing in the cross wind direction

Although this equation utilizes the diffusion rates in three dimensions it is actually onl: a one dimensional representation of the dose rates down wind from the release since it does not utilized the three components of the wind veloci y.

The actual program used by the codes have been modified to account for more parameters such as precipitation and thermal mixing layers but remain a one dimensional equation. For the analysis that will follow the Rascal 2 computer code will be utilize(..

This code is approved and provided by the NRC. It is valid for releases which are not affected by obstructions or changes in wind velocity or meteorological conditions. Therefore it should be valid for the monitors whose placement is not affected by Lake Michigan. The goal in these calculations is to first of all determine the minimum detectable activity level and to compare it to published values for the equipment and then to set the number of detectors. For a first cut we will look at airborne detectors for the radioiodin:

For the worst case velocity a value of 1 m/sec is often used. This is valid since a dead calm is not often encountered in area near large bodies of water and the dose rate is inversely proportional to the wind velocit y.

Converting this velocity to mi/h :

$$V := 1 \cdot \frac{m}{sec} \cdot 3600 \cdot \frac{sec}{hr} \cdot 1 \cdot \frac{km}{10^3 \cdot m} \cdot 1 \cdot \frac{mi}{1.61 \cdot km} \qquad V = 2.24 \cdot \frac{mi}{hr}$$

Since the detectors are located at the site boundary which is 0.5 miles from the reactor building we ill determine thexposure time at 0.5 miles from the reactor. We first need to calculate time for the cloud to reach 0.5 miles.

$$t_1 := 0.5 \cdot mi \frac{1}{2.24 \cdot \frac{mi}{hr}} \qquad t_1 = 0.22 \cdot hr$$

If we assume person remains at that point for seven hours. (This is the total release time
used in the RASCAL run which most closely approximates the emergency protection guides we are utilizing.,
we can calculate the exposure time.

$$t_e := 7 \cdot hr - t_1 \qquad t_e = 6.78 \cdot hr$$

From the Rascal Run this results in a committedthyroid dose of 3.2 rem at 0.5 miles at centerline of plume can be shown to correspond to a release of

$$\chi := 1.73 \cdot 10^{-5} \cdot Ci$$

Assume this concentration is uniformly released and inhaled, compute concentration of radiodine.

Given that the reference man inhales 2400m^3 per 2000 hours.

$$C := \frac{\chi}{t_e} \cdot \left(\frac{2000 \cdot hr}{2400 \cdot m^3} \right)$$

$$C = 2.13 \cdot 10^{-6} \cdot \frac{Ci}{m^3}$$

Determine concentration of plumes boundary 4^{o} from centerline fro Rascal runs.

$$C_{45} := 2.12 \cdot 10^{-6} \cdot 10^{-3} \cdot \frac{Ci}{m^3} \qquad C_{45} = 2.12 \cdot 10^{-9} \cdot \frac{Ci}{m^3}$$

Compute activity from 1 minute air sample.

$$A := 20 \cdot \frac{ft^3}{min} \cdot \frac{(0.3048 \cdot m)^3}{ft^3} \cdot 1 \cdot min \, C_{45}$$

$$A = 1.2 \cdot 10^{-9} \cdot Ci$$

Convert to counts per minute assuming a 30% efficient detector.

$$D := A \cdot 3.7 \cdot 10^{10} \cdot \frac{\left(\frac{d}{sec}\right)}{Ci} \cdot 1 \cdot \frac{count}{3 \cdot d} \cdot 60 \cdot \frac{sec}{min}$$

$$D = 8.9 \cdot 10^{2} \cdot \frac{count}{min}$$

This is well within the detectability of any type instrument so we could reasonably accept four detectors when attempting to detect the minimum accident based on thyroid dose. Figures 15-19 on the following pages depict sample Rascal runs for these calculations.

Plume Model — Maximum doses at selected distances (rem)

Distance (miles)	.5	1.0	2.0	5.0	10.0
(km)	.8	1.6	3.2	8.0	16.1
Acute Bone Total	4.8E-02	3.1E-02	2.9E-02	1.8E-02	9.0E-03
Total EDE (EPA)	1.9E-01	1.2E-01	1.0E-01	6.2E-02	3.3E-02
Thyroid (EPA)	3.2E+00	2.1E+00	1.6E+00	1.0E+00	5.5E-01
Acute Lung	5.3E-02	3.5E-02	2.7E-02	1.7E-02	9.2E-03

Acute Bone Total = Acute Bone Inh. + Cloud Shine + Init. Ground Shine
Total EDE = Cloud Shine + 4-Day Ground Shine + CEDE Inhalation

Acute Bone Inhalation	4.4E-03	2.9E-03	2.3E-03	1.4E-03	0.0E+00
Cloud Shine	3.5E-02	2.3E-02	2.3E-02	1.5E-02	8.0E-03
Initial Ground Shine	9.2E-03	5.7E-03	4.1E-03	1.7E-03	0.0E+00
4-Day Ground Shine	3.0E-02	1.9E-02	1.5E-02	8.3E-03	3.8E-03
CEDE Inhalation	1.2E-01	8.0E-02	6.3E-02	3.9E-02	2.1E-02

NOTE: All values below 1.0E-03 have been set to zero.

Summary of ST-DOSE inputs 08/24/93 02:51

ááá

Title: 1MW Wash1400 Source Term 5 Stab D Straight-Line Plume
Plant & Unit: ZION UNIT 1
Release Height: 0 M Building Wake: Y Calculation Radius: 25 mi (40 km)

ááá

Event	date	time		Meteorological Data						
Shut Down										
Rel->Cont				date	time	winds		stb	mix	precip
Rel->Envi	08/24/93	00:00	1	08/24/93	00:00	90	1 M/S	D	500 M	NONE
Rel End	08/24/93	04:00	2							
Expos End	08/24/93	07:00	3							
			4							

ááá

Source Term: WASH-1400 Categories
Reactor Power: 1 Mw(t)
Select PWR or BWR fractions: P
WASH-1400 source term: 5
Source term results

A total of 6.9E+04 Ci were released.

Nuclide	Release (Ci)	Nuclide	Release (Ci)	Nuclide	Release (Ci)
Kr-85	5.7E+01	Kr-85m	2.4E+03	Kr-87	4.8E+03
Kr-88	6.9E+03	Sr-89	3.1E+01	Sr-90	1.2E+00
Sr-91	3.7E+01	Y-91	2.8E+00	Mo-99	3.2E+01
Tc-99m	3.2E+01	Ru-103	2.2E+01	Ru-106	4.8E+00
Sb-127	1.0E+01	Sb-129	5.5E+01	Te-131m	2.0E+01
Te-132	2.0E+02	I-131	8.4E+02	I-132	1.2E+03
I-133	1.7E+03	I-134	1.9E+03	I-135	1.5E+03
Xe-131m	9.9E+01	Xe-133	1.7E+04	Xe-133m	6.0E+02
Xe-135	3.3E+03	Xe-138	1.7E+04	Cs-134	2.2E+01
Cs-136	9.0E+00	Cs-137	1.4E+01	Ba-140	5.3E+01
La-140	3.7E+00	Ce-144	2.0E+00	Np-239	3.9E+01
Rb-88	6.9E+03	Rh-106	4.8E+00	Xe-135m	1.5E+03
Ba-137m	1.4E+01	Pr-144	2.0E+00		

Figure 15 Sample Rascal Run

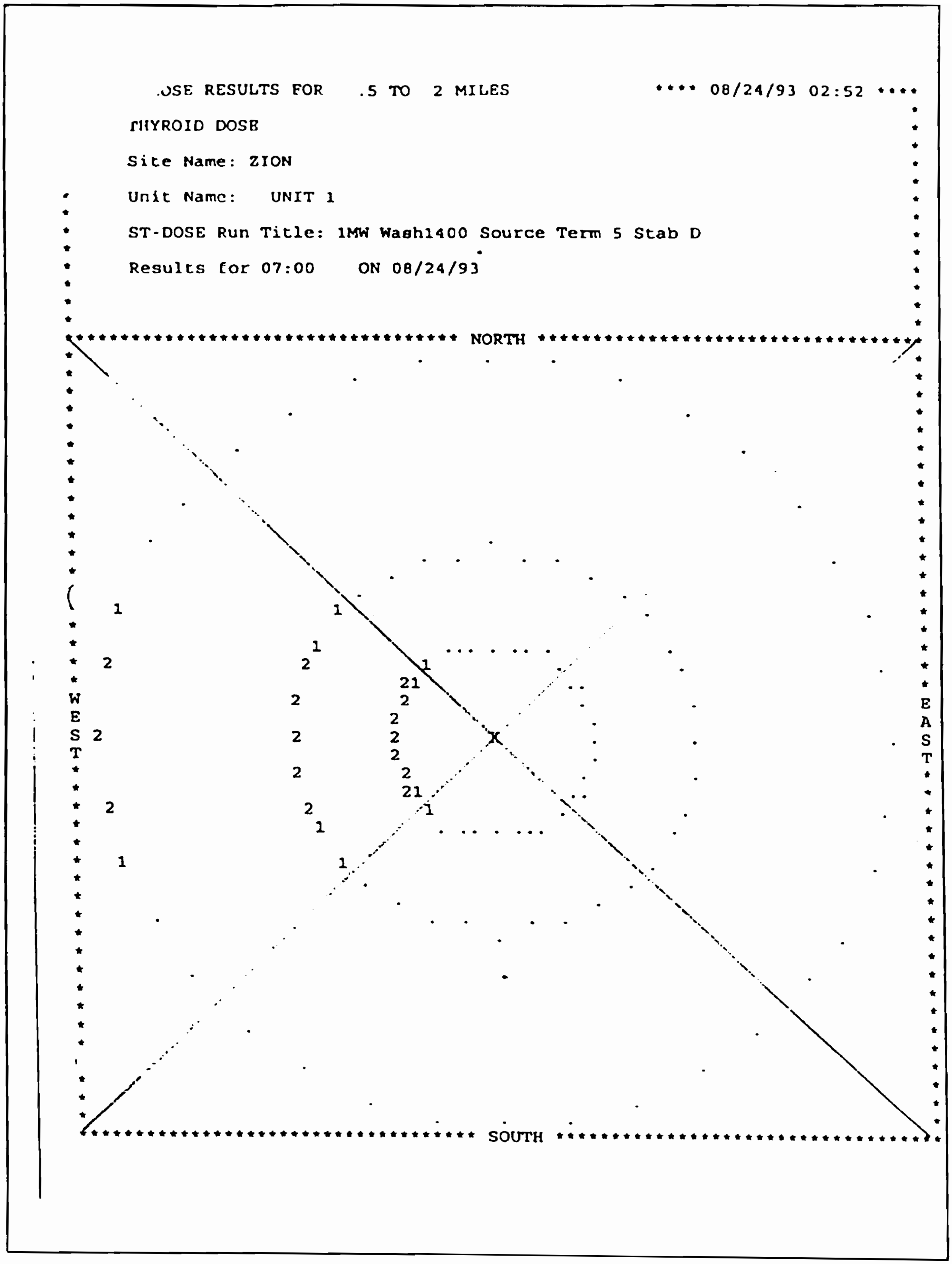

Figure 16 Sample Rascal Run

```
-DOSE RESULTS FOR   .5 TO  2 MILES              **** 08/24/93 02:52 ****

    Key to Graph Symbols

 1 = 0.001 to 0.5 rem

 2 = 0.5 to 5 rem

 3 = 5 to 25 rem
     EPA PAG RANGE
 4 = 25 to 1500 rem

 5 = 1500 to 3000 rem

 + = > 3000 rem
     Acute Effects Possible

              MAXIMUM VALUE

 Maximum value =  3.2E+00  rem             RADIAL DISTANCE OF CIRCLES
                                                  (IN METERS)
 Distance and Bearing from Source
      .5  miles  (  .8  km)                         800.
     270. degrees                                  1600.
                                                   3200.

*********************************** Page 2 ***********************************
```

Figure 17 Sample Rascal Run

DOSE RESULTS FOR .5 TO 2 MILES **** 08/24/93 02:52 ****

CLOUD SHINE DOSE

Site Name: ZION

Unit Name: UNIT 1

ST-DOSE Run Title: 1MW Wash1400 Source Term 5 Stab D

Results for 07:00 ON 08/24/93

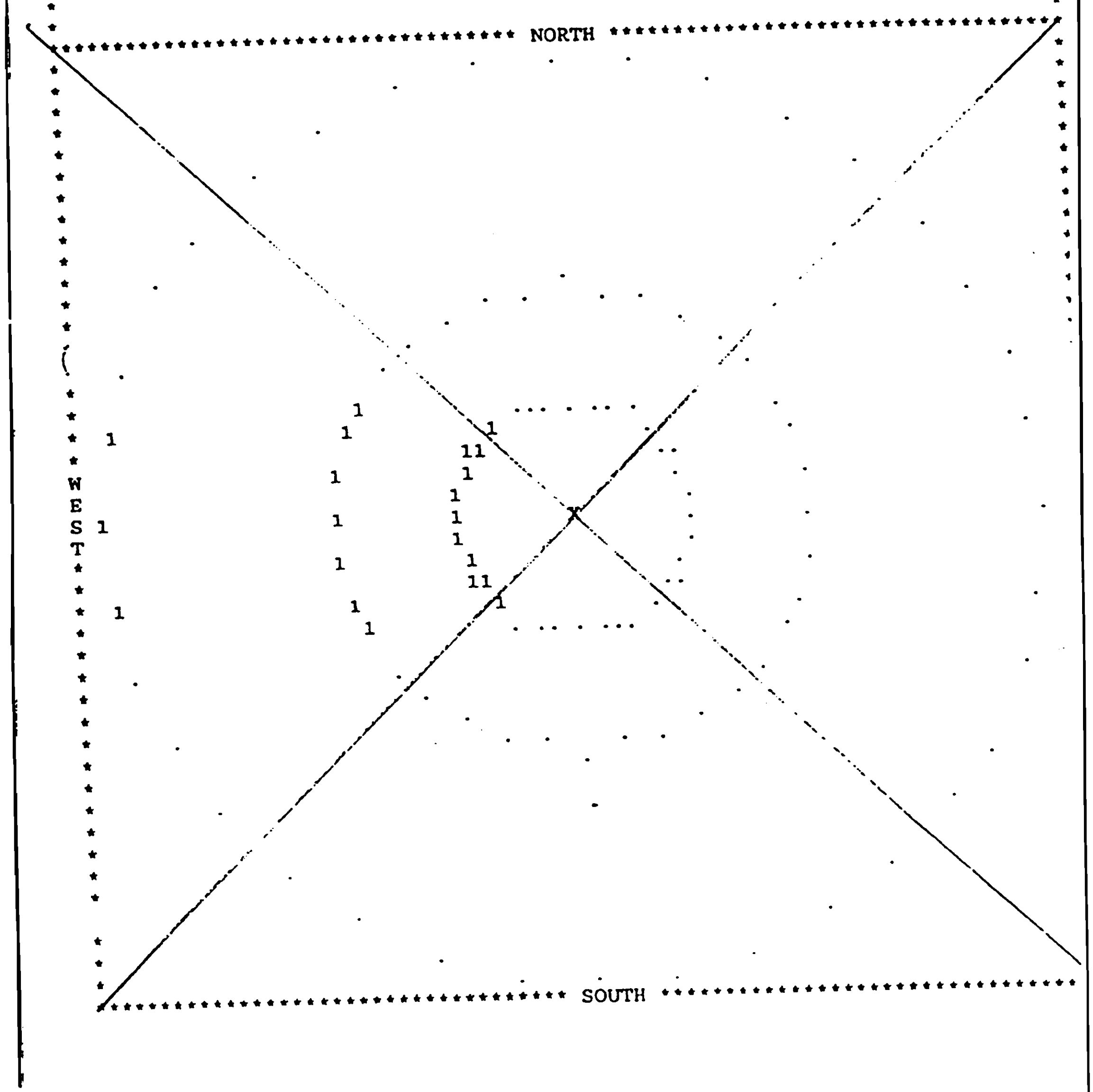

Figure 18 Sample Rascal Run

```
 DOSE RESULTS FOR   .5 TO  2 MILES                  **** 08/24/93 02:52 ****

   Key to Graph Symbols

   1 - 0.001 to 0.1 rad

   2 = 0.1 to 1.0 rad

   3 = 1 to 5 rad
       EPA PAG Range
   4 - 5 to 50 rad

   5 - 50 to 220 rad
       Early Health Effects Possible
   + = > 220 rad
       Early Deaths Possible

              MAXIMUM VALUE

 Maximum value =  3.5E-02  rad            RADIAL DISTANCE OF CIRCLES
                                                (IN METERS)
 Distance and Bearing from Source
       .5  miles  (  .8  km)                        800.
     270. degrees                                  1600.
                                                   3200.

*********************************** Page 2 ***********************************
```

Figure 19 Sample Rascal Run

The determination of the gamma dose is much simpler. Utilizing the rascal runs for TEDE that follow it can be easily determined that for doses as low as two rem at the center of the plume doses as high as one mrem would be noted at 45 degrees from the center of the plume. This corresponds to approximately 0.1 mrem/hour assuming a constant dose rate. Since standard Geiger Muller tubes can easily detect dose rates several orders of magnitude lower, we can use as few as four fixed monitoring stations. To avoid the effects brought on by the nearness to the lake these stations can be placed at 45 degrees skewed from the cardinal points of the compass. The following Rascal Run (in Figures 20-21) depicts this analysis.

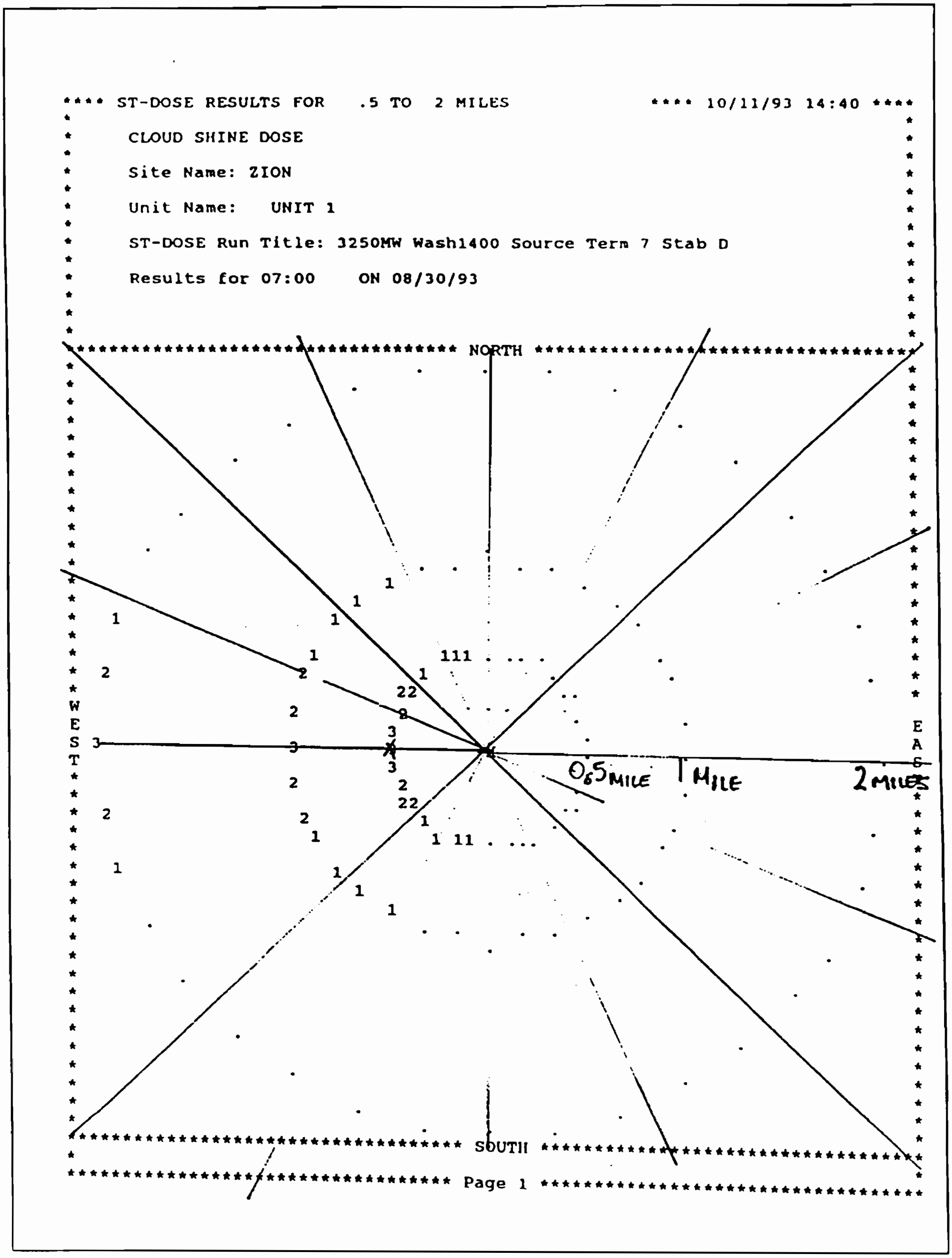

Figure 20 Sample Rascal Run

```
**** ST-DOSE RESULTS FOR   .5 TO  2 MILES              **** 10/11/93 14:40 ****
*                                                                             *
*                                                                             *
*     ******************************************************************     *
*     *                                                                *     *
*     *   Key to Graph Symbols                                         *     *
*     *                                                                *     *
*     *                                                                *     *
*     *  1 = 0.001 to 0.1 rad                                          *     *
*     *                                                                *     *
*     *  2 = 0.1 to 1.0 rad                                            *     *
*     *                                                                *     *
*     *  3 = 1 to 5 rad                                                *     *
*     *      EPA PAG Range                                             *     *
*     *  4 = 5 to 50 rad                                               *     *
*     *                                                                *     *
*     *  5 = 50 to 220 rad                                             *     *
*     *      Early Health Effects Possible                             *     *
*     *  + = > 220 rad                                                 *     *
*     *      Early Deaths Possible                                     *     *
*     *                                                                *     *
*     ******************************************************************     *
*                                                                             *
*                                                                             *
*                 MAXIMUM VALUE                                               *
*     ****************************************                                *
*     *                                      *   RADIAL DISTANCE OF CIRCLES  *
*     * Maximum value =   1.7E+00   rad      *         (IN METERS)           *
*     *                                      *                                *
*     * Distance and Bearing from Source     *            800.                *
*     *      .5  miles  (   .8  km)          *           1600.                *
*     *     270. degrees                     *           3200.                *
*     ****************************************                                *
*                                                                             *
*                                                                             *
*                                                                             *
*                                                                             *
*********************************** Page 2 ************************************
```

Figure 21 Sample Rascal Run

Table 1 below depicts the life cycle costs of the two subsystems. Apparently the life cycle cost of the detectors will help to offset the cost of the entire system.

Subsystem	Unit Cost (K$)	Quantity Needed	Total Initial Cost (K$)	Maintenance Cost (K$,1994)	Total Cost
FMS	2.0	4.0	8.0	1.0	9.0
ROSMS	2.0	1.0	2.0	0.2	2.2
ROAMS	2.0	1.0	2.0	0.2	2.2
FSC (spares)	2.0	2.0	4.0	0.5	4.5
TOTAL			16.0		18.0
Ionization Detectors	10.0	64.0	640.0	79.2	719. 2

Table 1 Life Cycle Cost Analysis of the Detectors

In performing this analysis, an estimate was provided by the vendor for the number of instruments that would be required to be stocked as spares. These instruments would be utilized to replace detectors that periodically require calibration. The detectors are essentially hardened and enclosed in a steel casing. In discussions with the personnel at Zion station and with personnel at The Savannah River Site, personnel from these facilities said that with care these detectors should not fail over the lifetime of the facility. Savannah River has had similar detectors in use for over fifteen years. A net present value method was utilized in determining the calibration cost. It assumes a 7% inflation rate and that the equipment will require calibration on an annual basis for fourteen years. Wordperfect's built-in function for computing net present value was utilized.

B. Life Cycle Cost Analysis: The net present value method based on amortized costs was utilized to determine the life cycle cost of the system . Table 2 below provides a summary of the analysis. All values are based on a 14-year life time with an inflation rate of 7%. Dollar values are expressed in thousands of dollars.

Cost Categories /Subsystems	FMS	ROSMS	ROAMS	CCCS	FSC	TOTAL
R&D Cost	0	10	10	100	15	
Production / Construction Cost	40	60	525	10	150	
Design	10	20	10	5	15	
Logistical Support (annual)	2	5	25	2	2	
Documentation	2	2	1	1	5	
Operational Cost(annual)	2	50	100	25	100	
Maintenance Cost (annual)	2	50	100	40	100	
D&D cost	8	15	112	22	33	
Software	10	100	200	25	10	
Total	116	1114	2756	735	1970	6690

Table 2 System Life Cycle Cost

These total values were arrived at by assuming the payment occurred at the end of each annual period for the annualized costs that the D&D cost was incurred at the end of fourteen years and that the remainder of the costs was incurred at the end of the first period. These assumptions are only valid if the system never has to function as designed to combat an emergency in the event that an emergent situation occurred, the life cycle of the contaminated equipment would be greatly shortened. The following paragraphs briefly discuss the methods used to allocate the projected costs.

1. R&D: The R&D costs for the FMS were considered negligible since it is composed of equipment that can be bought off the shelf. For the ROSMS and ROAMS minimal R&D efforts would be required except in the area of control software that is broken out separately. The funding is this area is provided to ensure that the detector package is adequately interfaced with the vehicles. Analysis may also be required to ensure that the system be seismically qualified. The CCCS will require R&D funding to support the use of fuzzy logic for the controls of the ROSMS and especially the ROAMS. This R&D effort is discussed later in this report. The FSC will require minimal R&D to ensure that the satellite network be designed correctly and the necessary alarms are available.

2. The design and production and construction costs were based on the values supplied by the vendors of the subsystems and a general contractor who discussed the building requirements for the FSC.

3. The logistical support funding was based on requirements for similar equipment.

4. The operational and maintenance costs were based on vendors estimates and salary projections for the necessary crew.

5. The standard D&D estimates for nuclear systems are projected to be 20% of the initial cost.

6. The major software development is in the coding of the control software for the ROSMS and the ROAMS.

C. Sensitivity Analysis: A sensitivity analysis was performed using the basic equations for the availability to determine where the most effort should be spent to achieve the high availability required. In the analysis provided below, the reliability, the mean time between preventive maintenance and the mean down time were varied. The graphs in Figure 22 depict the sensitivity of availability to these parameters. The top edge of the areas represents the possibility for the availability to be at the corresponding value. For example, a quick review of the first curve depicting the dependence of the availability on the reliability shows an edge that is nearly flat with a corresponding high availability. This suggests that availability is relatively insensitive to reliability since it might be possible to arrive at an availability of 0.95 with a relatively low reliability. In the second curve a relatively few data points were plotted and the curve becomes jagged instead of smooth. The importance of this curve can be shown by smoothing out the upper edge of the curve. If this is done, it can be noted that the availability is much more sensitive to the mean time between preventive maintenance ($MTBM_s$). It can be shown that unless the $MTMB_s$ is greater than $2*10^4$ seconds or approximately six hours, it is impossible to reach availabilities approaching 0.95. Similarly the bottom curve shows that for very small increases in mean maintenance down time, it quickly becomes impossible to reach availabilities of 0.95. From this analysis a significant amount of effort would be spent if one were developing a maintenance plan that pays strict attention to scheduled maintenance and to designing the system for maintainability. It can be concluded therefore, that these two factors will play most heavily in achieving the required systems reliability.

Let t be equivalent to the operation time of 40 hours and vary R the reliability by 0.02 between 0.80- and 1.0. Then

$$R=\exp(-\lambda*t)$$

If we solve this equation for λ, which is the failure rate we have,

$$\lambda=-\ln(R)/t$$

Now by substitution into the equation for the mean time between failure we obtain MTBF as a function of R.

$$MTBF(R)=-t/\ln(R)$$

Equating the mean time betwen unscheduled maintenance with the mean time between failure:

$$MTBM_u(R)=MTBF(R)$$

The mean time between maintenance is a function of the mean time between scheduled maintenance and the mean time between unscheduled maintenance and can be written as

$$MTBM(MTBM_u,MTBM_s)=1/(1/MTBM_u+1/MTBM_s)$$

Since MTBMu is a function of R this equation can be written as:

$$MTBM(R,MTBM_s)=1/(1/MTBM_u+1/MTBM_s)$$

In order to shorten the notation it is noted that

$$MTBM(MTBM_s)=MTBM(R,MTBM_s)$$

If we vary $MTBM_s$ between 0.25 hour and 160 hour we can obtain a comparision of the effects of the sheduled maintance time.

Likewise, by variing the mean down time between 1 hour and 40 hours we can obtain a comparision of teh effects of the down time on availability.

$A(MTBM, MDT)=MTBM(MTBM)/(MTBM(MTBM_s)+MDT)$ or

$A(MTBM_s, MDT)=MTBM(MTBM_s)/(MTBM(MTBM_s)+MDT)$

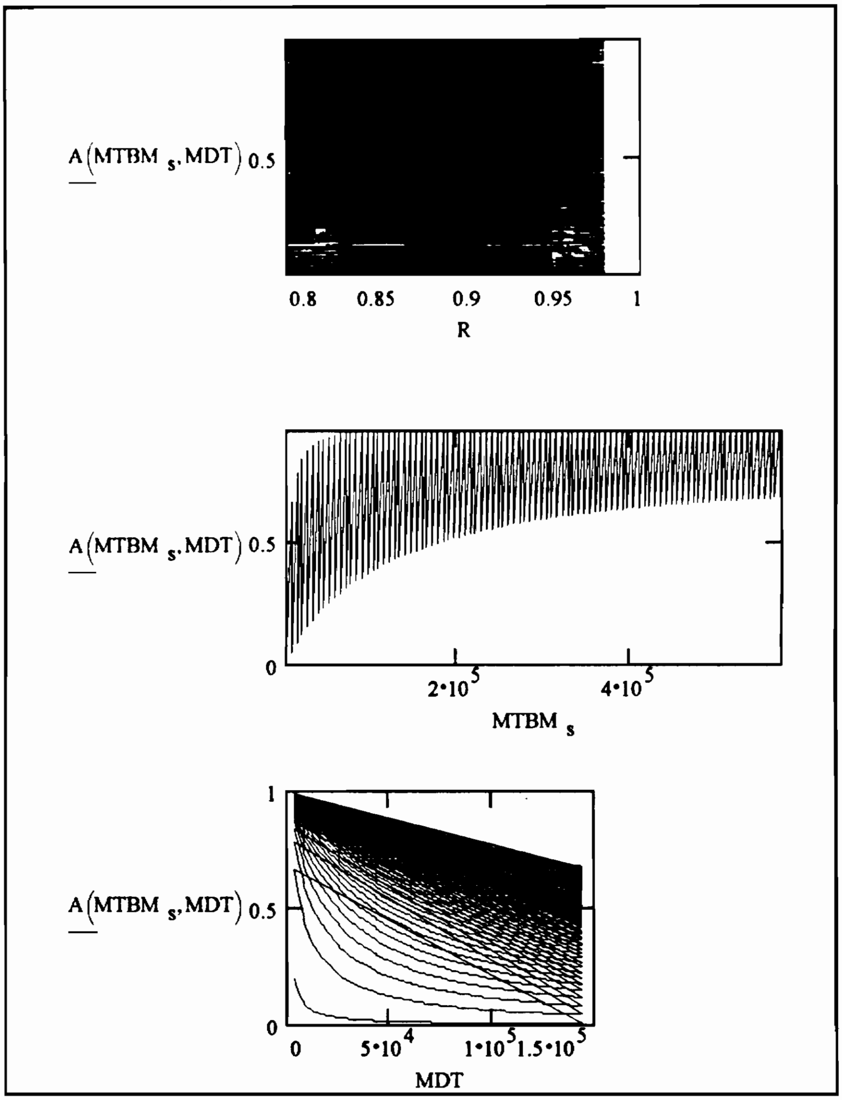

Figure 22 Sensitivity Analysis

X. Description of the Components of the Emergency Environmental Data Collection Subsystem: The following section provides a brief description of the subsystems contained in the preferred option of the Emergency Environmental Data Collection system.

A. Fixed Monitoring Subsystem (FMS): The fixed monitoring system consists of four monitors placed 45 degrees offset from the cardinal points of the compass 1/2 mile away from the station. The monitoring station can detect an accident that would result in the population at the boundary of the station in receiving one rem TEDE or five rem to the thyroid dose in two hours. RASCAL 2[1] was utilized to determine the dose. Several outputs from RASCAL 2 runs are summarized in the analyses. These outputs are the basis for the selection of four monitors. From the plots attached to the outputs it can be seen that any significant accident can be detected (although not characterized) by one of the detectors in the FMS.

These detectors include:

1. Geiger Muller radiation monitors which detect the amount of radiation available directly from the plume.
2. Iodine monitors which detect the amount of radioactive iodine contained in the plume. Radioactive iodine is the major contributor to thyroid cancer.
3. Transmitter which transmit the data to the CCCS in the FSC via radio waves and a Land Line connection with the FSC.

To avoid the possibility of a malfunction because of detector saturation, the FMS should consist of instruments that are capable of measuring gamma radiation exposure rates up to approximately 1 rad/hr. Movable shielding and/or multiple detectors could be provided as necessary to ensure the system is capable of measuring gamma radiation in the energy spectrums of concern to 1000 R/hr.

a. Performance and Physical Parameters:

(1) Air Sampling - Collection of airborne radioactivity should be accomplished by sample collection equipment composed of an air mover and a sample collection media. The air mover should be compact, able to be powered by Direct Current (DC) electricity, and must meet the performance criteria of ANSI N 320-1979.[2]

The media for collecting the radioiodine separate particulate and gaseous radioactivity and can retain the radioiodine and reject the noble gases. The sample collection components consist of a high efficiency particulate air (HEPA) type prefilter placed before the absorber type filter medium cartridge. The HEPA filters function is to remove the particulate fraction in the air sample. A silver zeolite absorber medium should follow the HEPA filter, and should be used to collect the radioiodine. Noble gases collected by the medium should be discounted by use of the medium's predetermined noble gas retention factor.

To preclude the exposure of personnel while the silver zeolite absorber material should be installed on a revolving carousal. When not in use, the absorber(s) should be enclosed in a protective section of the carousal. When required, the absorber would be positioned (rotated) into the flow path from HEPA filter, and air from outside the cabinet should be drawn through the absorber medium for one minute. Upon completion of drawing air, the absorber would be rotated to the shielded radiation detector where it would be counted for one minute. At the completion of the count, the used absorber should be rotated back into the protective section of the carousal where it could be later retrieved for further analysis.

The radioiodine adsorbent media cartridge should be analyzed by use of a shielded Geiger Muller pancake detector. Radioiodine activity should be determined from measured counts by correcting for detector efficiency and interfering short-lived radionuclides.

To simplify multiple samples, a twelve-discjuke box arrangement, with twelve cartridge disc carousals should be used. This would support sampling every fifteen minutes over three days. A more conservative sampling regime could be used to increase the maximum duration.

As part of the Built-In-Test (BIT) function, the radiation detector should be exposed to a check source before and after each measurement.

(2) Radiation Measurement - A Geiger-Muller Detector should be used to measure gamma radiation resulting from noble gases, particulate and cloud shine.

As part of the BIT function, the radiation detector should be periodically exposed to a check source before and after each measurement.

(3) Communications - The primary and secondary communications system for communication, command and control will utilize Very High Frequency (VHF) radio bands. The primary and secondary systems will differ only by the paths used to transmit and receive and the secondary systems of repeaters will be located along different paths. VHF at 150 to 160 mhz will be transmitted at a power of twenty-five to fifty watts for a range of fifty to 100 miles respectively. Repeater antennas will typically have a height of 50 feet and will operate with a 10-db gain.

(4)Primary power will come from an AC source, with conversion to DC as necessary. Secondary power will be provided by DC Battery.

b. The following provides a general description of the instruments to be used:

(1) Shielded low range Geiger Muller beta gamma pancake detector with a range of zero to 10^6 counts per minute.

(2) GM beta gamma detectors with a range of 0.1 mr/hr to 1 R/hr (augmented with electronic circuitry to detect onset of saturation, and a cutout instrument).

(3) Airborne sampling systems with a sampling rate of twenty ft^3/min. Radioiodine should be collected by silver zeolite adsorbent filter media cartridge component.

(4) Radioiodine activity analysis should be accomplished by use of a shielded beta gamma pancake detector.

Power will be maintained to meet dependability requirements. The quality of the power will be such that the minimum sensitivity and detectable activity design criteria are met. Secondary power, estimated at eighty amp hours, will be available in the case of a loss of primary power. It will be sufficient to periodically operate the air sampler carousel and counters for three days as well as providing power for communications and local controls.

B. Remotely Operated Surface Monitoring Subsystem (ROSMS):_ The ROSMS should be a remotely operated system that will carry instruments similar to those provided in the four monitoring stations of the FMS. It is expected that the ROSMS and the ROAMS will carry a full FMS package. The ROSMS system would be mounted on a movable platform attached to a cable (similar to a cable car) and be electrically powered. The system can travel completely around the perimeter of the site at a height of 2 meters (at the entrance to the station the system would be elevated to 6 meters to allow the passage of vehicles). The ROSMS can monitor the plume as it moves around the perimeter. It is intended that the CCCS would maintain the ROSMS in the center of the plume as the meteorological conditions change and the direction of the plume is shifted.

C. Remotely Operated Airborne Monitoring Subsystem (ROAMS): The ROAMS can be inflated and activated within two hours and provide detailed information about the plume after it leaves the site boundary. It would carry instruments similar to those maintained at the FMS. Currently no data is available from the plume after it travels past the site boundary except from data gathered from manned remote monitoring teams on the ground. The ROAMS would be directed to the predicted center of the plume by the CCCS based on data collected from the ROSMS, the FMS and the facility owned equipment. The ROAMS airship should be a two-place helium airship of approximately 42,000 cubic feet displacement. When filled it should contain approximately 32,000 cubic feet of helium and the remainder of the displacement should be occupied by to compressed air balloonets foreword and aft. The balloonets are inflated or compressed to keep the shape of the airship constant as the helium expands or contracts with altitude. The balloonets and the helium bags are prevented from being over pressurized by relief valves that are automatically operated by the pressure. The CCCS/pilot can operate these relief valves if an over pressurization is detected and they fail to automatically open.

The airship should be controlled by four fins mounted to the stern of the ship two in the horizontal direction and two in the vertical direction. In addition a rudder should be mounted in the airstream of the propulsion fan.

It can be controlled remotely or piloted by a one man crew. The controls should be standard fly by wire controls utilizing DC motor actuators. Back up components employing analogue circuits should also be provided. It should have the ability to operate in VFR day/night operation mode. Video cameras should be mounted on the gondola fore and aft and on the sampling platform. These cameras allow the CCCS operator to have an adequate view of the airships flight path and the area surrounding the sampling platform.

The ROAMS airship should be no longer than 100 ft and have a diameter of approximate 40 feet. The maximum overall height including the gondola should be 47 feet. The empty weight of the airship should be less than 1 ton and it can be carried in a standard semi trailer when empty. The maximum payload should be approximately 1000 lbs including approximately 400 pounds of fuel.

The maximum speed should be forty-five knots with a duration time of fifteen hours at a cruise speed of twenty knots. The maximum cruise height should be 9500 feet. The ship should have a maximum climb rate of at least 1200 feet per minute and a maximum descent rate of at least 1400 feet per minute. The pitch angle limits should be +30° to -25°.

The airship should contain the standard communications package as well as a control package allowing the CCCS to provide remote control. The airship should have a standard avionics package consisting of a 720-channel VHF NavCom radio, transponder (Mode C equipped), ADF, VOR and SSR. In addition the instrumentation package should contain an airspeed indicator, altimeter, rate of climb meter, magnetic compass, directional gyro, helium temperature, helium pressure, air temperature, air pressure, engine tachometer, oil pressure, oil temperature, voltmeter, amp meter, cylinder head temperature, and fuel gauge. All indications should be repeated back to the CCCS at thirty second intervals.

The electrical components should be powered by an alternator included as a part of the propulsion package. The alternator can deliver enough power to operate the standard detection package and the airship's hotel circuits.

The ROAMS should can be flown as a nonpowered lighter that airship.

D. Command, Communications, and Control Subsystem (CCCS): The CCCS would be a remote computer station, complete with the ability to communicate with the FMS, the ROSMS, the ROAMS, and the EMCC. It can provide the communication linkups in a manner that allows the ROSMS and the ROAMS to be remotely controlled.

1. Performance and Physical Parameters: The CCCS will be an IBM compatible P5 66 MHZ PCI or better system. The system contains 32 MB of ram and two 1.2 GB mirrored hard disks. A 1.44 MB 3.5 inch floppy disk will also be provided. A write once read many times optical disk storage system will be provided for long term storage of data.

It will operate on the windows operating system and MS-DOS 6.0 or equivalent.

The system will have a 19 inch super VGA non-interlaced display. The keyboard should be a standard IBM AT keyboard. A mouse will be provided to allow easy graphical user interface manipulation. The entire CCCS including communications equipment will be rack mounted in a seismically protected rack.

A table top Hewlett Packard laser printer and a stand alone plotter is included with the CCCS.

The CCCS will be networked with the station computer system to allow read only access to the system by the state. An IEEE 802.3 compatible Ethernet port is provided for that reason.

The CCCS will contain proprietary software necessary for the command control and communications with the station, the

ROSMS, and the ROAMS. PC-anywhere remote control software will be utilized to maintain communications with the State EMCC.

The CCCS will contain three separate single board processors for the transmission command, communications and control functions. These processors will have 80386 microprocessors with 80387 math coprocessors and will operate at 33 MHZ. These microprocessors will allow for parallel processing of information packets in the CCCS.

The operator will be able to manually override the ROAMS control functions to preclude accidental collisions with unknown hazards and to allow the ROAMS to be controlled manually in the case of a system failure.

Other displays available are the CCCS test and diagnostic displays and also a video display of the EMCC.

The CCCS will operate on 110V AC. Station power and emergency power will be provided for the operation of this equipment in addition the CCCS has an interruptible power supply which will provide up to thirty-six hours of power in the event the station is not able to provide power to the CCCS. The entire CCCS will be mirrored for redundancy. The CCCS will be password protected to preclude unauthorized access to the CCCS.

The CCCS will contain a series of modems to provide the CCCS functions these modems will be 14,400 baud Hayes compatible modems. Each modem is protected from voltage spikes from external sources.

2. Use Requirements: All radiation monitors will be polled twice per minute and the data stored in the computers memory and hard disk for up to twenty-four hours. At the end of the 24-hour period the data will be archived to a write once read many times

optical disk storage system. In addition each monitor will have a diagnostic test performed once every twenty-four hours. This test will be performed on each monitor between the hours of 0000 and 0400. The diagnostics will poll the monitor for approximately fifteen seconds set up the test procedure that will be returned to the CCCS after a 15-second operation.

3. Operational Deployment and Distribution: The CCCS will be deployed inside the FSC. It is anticipated that operators will be available twenty-four hours per day to perform maintenance and to operate the subsystem. It is expected to be operational eighteen months after the letting of a contract.

XI. **Systems Life Cycle Description**: The following description of the system life cycle is derived from the system used by the Department of Energy and some options of NRC.

As defined by the DOE the Key Decisions are:

Key Decision 0 - Approval of Mission Need - The mission needs were identified by State personnel and are discussed above. Alternate approaches remain to be identified and reviewed. The Japanese Government is currently performing research on the controllers required for this system to become functional.

Key Decision 1 - Approval of New Start - Essentially the project has reached a point where the approval to start has been reached and preliminary design has begun.

Key Decision 2 - Approval to commence Detailed Design

Key Decision 3 - Approval to commence Construction,

Key Decision 4 - Commence Operations,

Key Decision 5 - has been added because if the project were every successfully installed and a need arose to use the project a decision point would have to be made about how to best D&D the equipment based on the current best technology at the time.

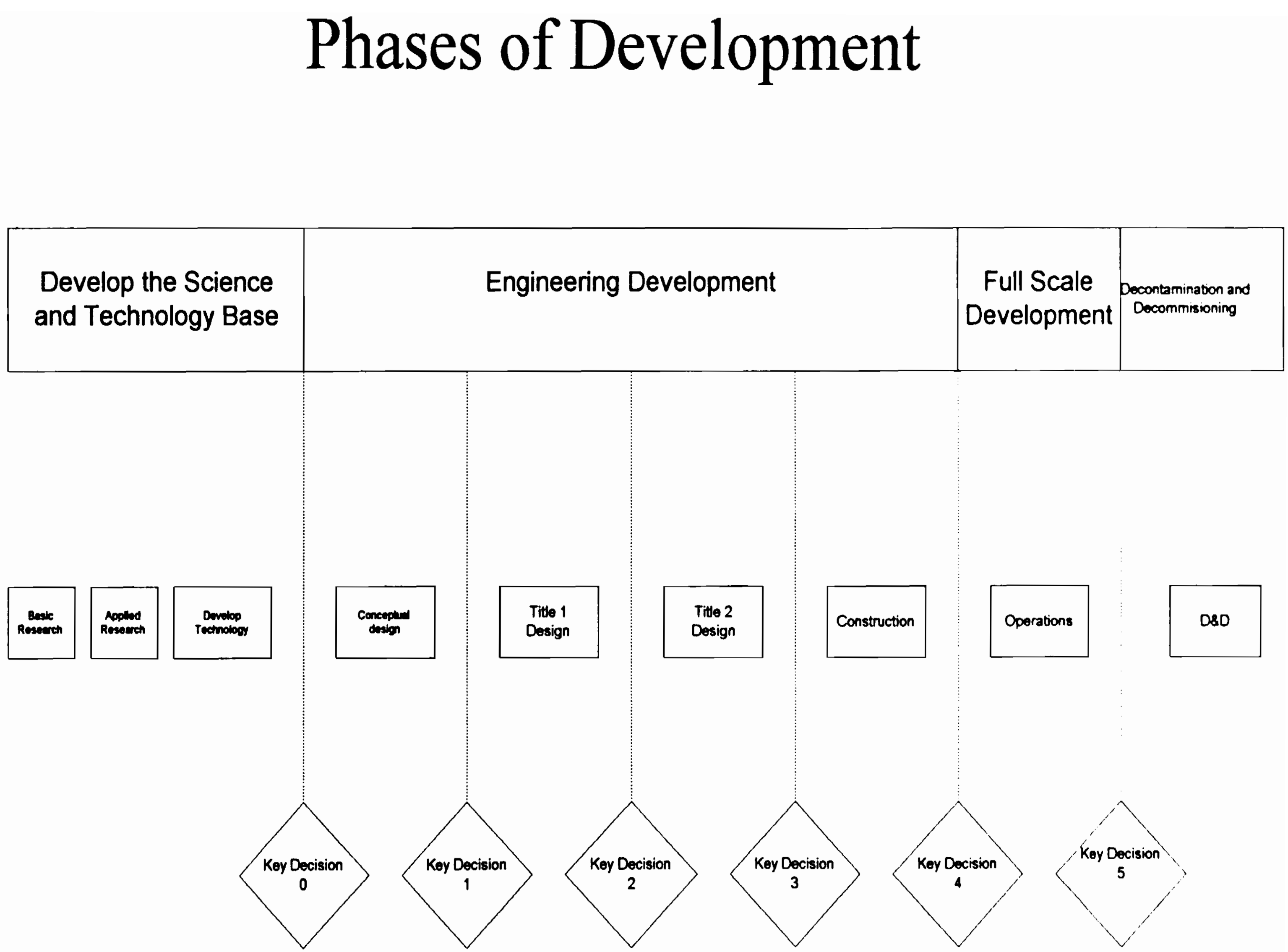

Figure 23 Phases of the life cycle

XII. **System Functional Interfaces:**

A. Establishing the Design Team: The design team should be an interdisciplinary team. The following disciplines are envisioned and should be represented on the design team. At least one member of the design team should be a certified professional engineer. A certified health physicist should also be utilized. Each design document and report should be reviewed and approved by these personnel.

1. Aeronautical Engineering: At least one aeronautical engineer should be represented on the design team. His primary responsibilities should consist of ensuring the design of the ROAMS is adequate and supports the mission at hand.

2. Reliability Engineering: A qualified reliability engineer would ensure that the availability of the system meets the requirements set forth in this specification.

3. Safety Engineering: A safety engineer should be used to review all plans for the design of this system and ensure that the system is safe to operate. This person should be familiar with the aspects of probability risk assessment.

4. Manufacturing Engineering: A manufacturing engineer should be a member of the design team to ensure that the system can be easily manufactured.

5. Environmental Engineering: An environmental engineer should be a member of the design team to ensure that the manufacturing, operation, maintenance and decontamination and decommissioning (D&D) of the equipment can be performed in an environmentally sound manner.

6. Logistics Engineering: A logistics specialist should be present to ensure that the system is designed in a way that allows supply support of the system. This aspect of the team could play a significant role in ensuring the system availability is met.

7. Human Factors Engineering: The design team should include an experienced human factors engineer to ensure that the system can be operated and maintained effectively and efficiently.

8. Maintainability Engineering: A maintainability engineer should be a member of the design team to ensure that the system can be maintained in a way that allows the system to meet the availability requirements. As shown in the sensitivity analysis this discipline is critical to the system meeting its required availability.

9. Electrical Engineering and Computer Sciences: Electrical engineers and computer scientists should be represented on the design team to ensure that the equipment power, instrumentation,

control, and communications equipment is adequate to allow the system to meet its mission.

10. Mechanical Engineering: Mechanical engineering should be represented to ensure that the equipment can meet the rigorous demands placed on it during operation in the expected environment.

11. Civil Engineering: Civil engineering should be responsible for the structural soundness of the equipment as well as the seismic response and the maintaining the systematic design process.

12. Nuclear Engineering: Nuclear Engineering should be involved to ensure that the system interfaces with the station are adequate. The nuclear engineer should also interface with the health physicist in performing, ALARA reviews of the system to ensure it can be operated and maintained in a manner that results in the

exposures to personnel and the generation of waste is maintained ALARA.

13. Health Physics: The health physics personnel should perform ALARA reviews, be responsible for the determination of the sensitivity requirements for the instrumentation and placement of monitors as well as the selection of monitors.

B. Effectiveness Characteristics:

1. Cost Effectiveness: The cost analysis for evaluating detail design alternatives should be accomplished utilizing a net present value methodology. Disbursements should be considered to take place at the end of the year in which they occur. The following types of cost should be considered in this analysis:

a. Research and Development Cost

b. Investment Cost

c. Operation and Maintenance Cost

d. Decontamination and Decommissioning Cost

2. System Effectiveness: The system effectiveness can be considered the probability that the system will successfully complete all aspects of the mission within one hour of the initiation signal and will remain in operation for thirty-six hours following initial operation. Based on the experiences at Three Mile Island and Chernobyle it is anticipated that the system can provide all relative data within thirty-six hours. If longer operational times are required, the system should can be quickly serviced and placed in operation.

3. Availability: The operational availability of the system should be determined using a Monte Carlo Analysis. The availability should not be below 95%.

4. Performance: To meet the needs of the system the CCCS should process information to provide recommendations within two

seconds of receiving data from the field and commands from the operators in the EMCC.

The FSC should provide capabilities to inflate, fuel and deploy the ROAMS within two hours from the time of alert as detected by the FMS.

The ROAMS should be capable of reaching the center of the radioactive release and provide real time monitoring capability within thirty minutes.

D. Decontamination and Decomissioning (D&D) Requirements:

The following outlines the D&D requirements by subsystem in its life cycle. Time periods in the life cycle include: 1) operation and maintenance during the operational cycle; and 2) disassembly and disposal at decommissioning.

Because of the EMCC's remote location, no deposition of radioactivity is expected and disassembly and disposal of its equipment should follow Federal, State and local laws and regulations.

During the Operational Phase, the FMS, ROSMS, ROAMS and FSC may become contaminated. The FSC should be able to accommodate decontamination of the FMS, ROSMS, and ROAMS equipment upon return from being deployed in the cloud released from the station. This decontamination should be approached in two phases. The first phase of decontamination is an emergent requirement during the accident phase and should be sufficient to allow removal and transport for monitoring equipment for analysis, and to support access for preventive and corrective maintenance. The second phase of decontamination is during the post-accident period, and should be determined based upon the cost benefit analysis of decontamination or replacement/disposal.

The FSC should be outfitted with a decontamination facility capable of performing decontamination of the FMS, ROSMS and ROAMS. This capability should include a facility to decontaminate components from the FMS, ROSMS and ROAMS, as well as a gross wash down capability for decontaminating the ROAMS upon return from the field.

Disposal of radioactive waste should be in accordance with Federal, State and local laws and regulations.

The FSC should be designed to minimize the intake of particulate and gaseous radioactivity during the accident phase. This feature is primarily for protection of personnel manning the facility during the accident phase, and may be used to mitigate the impact of post accident phase decontamination. Decontamination during the post-accident period should be determined based on the cost benefit analysis of decontamination or replacement/disposal.

D. Safety Analysis: A safety analysis should be accomplished by an independent authority's analysis of: 1) the hazard of each subsystem, and 2) a probabilistic risk assessment for each subsystem. It is intended to cover the aggregate operations of the total system and not the separate operations of each subsystem.

The safety analysis should be completed following detailed design, but before final design so that changes to reduce the known or postulated hazards may be considered.

Subsystem design changes following detailed design will be considered if the risk of a particular event or feature is greater than 10^{-6}. (i.e., no more than one death per 10^{-6} years of reactor operation from the operation of this system is acceptable.)
A total document review should be accomplished for each major operation planned by for the system including training, maintenance and decommissioning.

E. Environmental Assessment: In anticipation that the system will require approval of Federal or State environmental authorities, an environmental assessment should be completed for the operation and maintenance of the system. This assessment should include the operation of all equipment as well as the FSC and the intermediate maintenance facility. It should include analysis identifying that the use of all hazardous materials has been minimized. It should also include an analysis of all fuel storage locations for the ROAMS to ensure that leakage is minimized. All applicable State, local and Federal laws, regulations and requirements should be met.

XIII. **Conclusions and Recommendations**: The objective of this project was to provide a system that allows the State to adequately protect their citizens while being good stewards of the States resources. The use of this system will result in all of the States needs being met. The use of an airship and remotely controlled vehicle to monitor airborne releases have distinct advantages over the current system. The airship can hover and yet remain airborne for long periods. If left adrift, it will travel at the same speed as the plume and, therefore, be able to more closely approximate the doses received by people on the ground as well as depositions on plant and soil, which can eventually lead to groundwater contamination. Research conducted during the development of this report into the abilities of the airship has identified further actions that could be taken by private industry to help the States and Foreign enterprises. The major offset to these advantages is the initial cost of the system. It is expected that the initial cost of the system would be in excess of $700,000. This was obtained from discussions with vendors. By completing this project I have been exposed to the use of the systems engineering approach. Further work is required in the area of fuzzy logic control for flight before the project could actually be suplemented.

XIV. **Area Requiring Additional Research:** As the requirements for the system were allocated to the various components of the system, a feasibility analysis was required to determine the control mechanism of the airship and the land vehicle. Four alternatives were chosen:

- Piloted aircraft,
- Manual remote control, similar to the way model aircraft are controlled,
- Computerized remote control, similar to autopilots,
- Fuzzy logic control.

The use of a piloted aircraft was discarded because of the risk to the pilot from exposure to ionizing radiation. The anticipated dose could have chronic effects (i.e., it could exceed 100 rem TEDE). These effects could include symptoms such as nausea, erythema, changes in blood characteristics, nervous system disorders and even death.

The use of manually controlled remote aircraft was eliminated following discussions with several experienced pilots of radio controlled aircraft who stated the likelihood of a major accident would be significantly higher than 10^{-6} deaths per year.

The use of an autopilot was dismissed because of the inability to navigate around buildings and high power lines and the inability to deal with chaotic behavior of the meteorology when attempting to locate the center of the plume.

After careful review, it was determined that the use of fuzzy logic held promise for the control of such a system. Fuzzy logic has been used in Japan for a number of years and has resulted in the control of passenger trains with 15% greater fuel efficiency and significantly improved ride. It has been used to control steam engines, cement kilns, the Sony Handy Cam video recorder, and high speed trains. Fuzzy logic is fast becoming a major systems development tool in Europe and Japan. It offers tremendous advantages over the conventional digital control both in cost and simplicity, as well as in function. The best way to describe fuzzy logic is to use the preferred option as an example.

The ROSMS would be controlled by fuzzy logic to ensure that it quickly found the center of the plume and that it remained even as meteorological conditions changed. For the purposes of this explanation, let's assume that only two parameters affect the movement of the ROSMS to the center of the plume, the speed of the ROSMS and the distance from the center of the plume. This is a over simplification, since wind speed, isotopic concentration, and mix of radioisotopes, sample times of the detectors and many other factors play into the movement of the ROSMS. However, with each increase in factors, the number of dimensions rises by one, and the problem quickly goes beyond the capabilities of this visual example. Typical control devices would have rules similar to:

- If the ROSMS is to the left of the center of the plume move it right.
- If the ROSMS is to the right of the plume move it left.

These controllers are digital in nature and threrfore, move the ROSMS either right or left. In a fuzzy logic controller many more rules are utilized; two rules that might be used are:

- If the ROSMS is slowly moving to the right and the position of the ROSMS is a great distance from the center of the plume, speed up the motor.
- If the ROSMS is approaching the center of the plume rapidly from the right and is near the center of the plume, make the motor slow down.

The key to these rules is that they are not digital. If the ROSMS is moving at its top speed, it is clearly moving fast and one could assign a unit vector could be assigned to its velocity. All other motion would be assigned a vector along the direction of the unit vector with a magnitude somewhat less than one. Therefore, moving at a speed of 5 miles per hour, when the ROSMS has a top speeds of 20 miles per hour, is moving at 0.25 fast or 0.75 slow. For the fuzzy controller to work the rules must be expressed in a way so that the computer can understand the logic. Standard logic terms can be used to express this for example:

- IF velocity is small in the positive direction, and position is large negative, THEN motor voltage is large positive.
- IF velocity is large in the positive direction, and position is small negative, THEN motor voltage is small positive.

Fuzzy logic is more effective with controllers similar to this type, because it precludes overshoot and reduces energy consumption. However, it is heavily reliant on the programming ability and on the knowledge base provided, and, therefore, can be subject to instabilities and even chaotic behavior when the incorrectly programmed logic results in a singularity. To further complicate these problems, it is impossible currently to adequately debug the program once an instability has been detected. It would therefore, not be prudent to use this type of controller in an airship. However, at the rate of advancement of fuzzy logic controllers, it is believed that a controller could be developed within approximately six months to one year, which is within the development time of this system.

Glossary

Absorbed Dose - The energy imparted by ionizing radiation per unit mass of irradiated material. The units of absorbed dose are the rad and the Gray.[3]

Airborne Radioactive Material - Radioactive material dispersed in the air in the form of dusts, fumes, particulates, mists, vapors, or gases.[4]

ALARA (As Low As Reasonably Achievable) - The act of making every possible effort to maintain exposures as far below the dose limits as is practical consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to the state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest.[5]

Collective Dose - The sum of the individual doses received in a given period of time by a specified population from exposure to a specified source of radiation.[6]

Committed Dose Equivalent - ($H_{T,50}$) The dose equivalent to organs or tissues of reference (T) that will be received from an intake of radioactive material by an individual during the 50-year period following the intake.[7]

Committed Effective Dose Equivalent - ($H_{E,50}$) The sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to those organs or tissues ($H_{E,50}$)=$\Sigma W_T H_{T,50}$).[8]

Deep Dose Equivalent (H_d) - The dose equivalent at a tissue depth of 1cm from external exposure to ionizing radiation.[9]

Dose Equivalent (H_T) - The product of the absorbed dose in the tissue, quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem.[10]

Effective Dose Equivalent (H_E) - The sum of the products of the dose equivalent to the organ or tissue (H_T) and the weighting factors applicable to each body organ or tissues that are irradiated ($H_E=\Sigma W_T H_T$).[11]

External Dose - That portion of the dose equivalent received from radiation sources outside the body.[12]

Internal Dose - That portion of the dose equivalent received from radioactive material taken into the body.[13]

NRC - Nuclear Regulatory Commission. - The agency of the federal government assigned the responsibility of regulating the commercial use of nuclear power and nuclear equipment.

Monitoring - The measurement of radiation levels, concentrations, surface area concentrations or quantities of radioactive material and the use of the results of these measurements to evaluate potential exposures and doses.[14]

Radiation (ionizing radiation) - Alpha particles, beta particles, gamma rays, x-rays, neutrons, high speed electrons, high speed protons and other particles capable of producing ions. Radiation as far as this paper is concerned does not include nonionizing radiation such as microwaves.[15]

Rem - The special unit of any of the quantities expressed as dose equivalent. The dose equivalent in rems is equal to the absorbed dose in rads (100 ergs/ gm) multiplied by the quality factor.[16]

Stochastic Effects - Health effects that occur randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold. Heredity effects and cancer incidence are examples of stochastic effects.[17]

Total Effective Dose Equivalent (TEDE) - The sum of the deep dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures).[18]

Weighting Factors (W_T) - The proportion of the risk of stochastic effects resulting from irradiation of an organ or tissue (T) to the total risk of stochastic effects when the whole body is irradiated uniformly.[19]

References

1. NUREG/CR-5247 PNL - 8454 Rascal Version 2 Users guide.

2. ANSI N 320-1979

3. Code of Federal Regulations Title 10 Part 20 - Standards for Protection Against Radiation

4. Ibid.

5. Ibid.

6. Ibid.

7. Ibid.

8. Ibid.

9. Ibid.

10. Ibid.

11. Ibid.

12. Ibid.

13. Ibid.

14. Ibid.

15. Ibid.

16. Ibid.

17. Ibid.

18. Ibid.

19. Ibid.

VITA

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