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Rapid emergency response decisions from a radiation release are necessary in order to prevent the general public from being exposed to a potential radiation hazard. A one meter exposure rate measurement is all that is necessary to establish relocation and food control areas when the ground is contaminated at the Protective Action Guide minimum response levels. With the results of these calculations, a known one meter exposure rate is all that is necessary to establish relocation and food control areas for a release from the WNP-2 commercial nuclear power plant or a release from a waste tank at the Hanford site. The calculated one meter exposure rate for WNP-2 is 1.32 μR/hr at twenty-four hours. The calculated one meter exposure rate for the Hanford tanks is 14.97 μR/hr.

Rapid Establishment of Emergency Action Areas as a Consequence of Large Scale Radioactive Material Releases from Fixed Nuclear Facilities

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1.0 INTRODUCTION

1.1 Objective

The objective of this thesis is to provide state decision makers with a method of making rapid decisions to protect the public from radiation exposures in the event of large scale releases of radioactive material from fixed nuclear installations. A vast majority of the individuals responsible for the well being of the population during a nuclear event do not have adequate knowledge of radiation and radioactive materials. This thesis is intended to provide pertinent information that will enable them to make rapid informed decisions concerning which protective measures should be implemented for the protection of the public. This will be accomplished by showing how relocation areas and food control areas are established using field team measurements. This thesis will also present calculated exposure rates from two accident scenarios at the Hanford Nuclear Site. The first accident scenario is from the Washington Public Power Supply Systems Nuclear Plant Number 2 (WNP-2) which is a commercial power plant. The second scenario involves the waste tanks located on the Hanford Site which are a byproduct of nuclear weapons production. Current emergency response planning is for releases of iodine from nuclear facilities. There is no emergency response based on releases of cesium, strontium, or plutonium. Concern over the possibility of releases from the Hanford tank farm increased after a release from a similar facility in the Soviet Union in 1993.

1.2 Civil Response in US

The purpose of civil response is to prevent the public from being exposed to radioactive materials as the result of a nuclear incident, excluding nuclear war. If there is a nuclear accident in the US, the owner of the facility uses a location designated as the Emergency Operations Facility (EOF) to collect and distribute information related to the event. This information includes the amount of radioactive materials released from the plant, the location of the radioactive material in the environment as well as the location and status of emergency support groups. The information along with recommendations is given to the political decision maker who is located at the State Emergency Operations Center (EOC). The decision maker, who is usually the state governor, uses the information to assist in deciding which protective action recommendations to implement in order to minimize exposure to the public as well as emergency personnel. This involves identifying areas of potential hazards, and in conjunction with local authorities, define areas to which the population can return, areas where people must be relocated, and areas where food control procedures must be implemented. The role of the Nuclear Regulatory Commission in this process is to provide assets and technical advice to the local decision makers. The reason this chain of decision making authority and information transfer is necessary is best illustrated by examining the sequence of events which occurred during the Three Mile Island (TMI) accident.

1.3 The TMI Event

The main focus of this work is the civil response to an accident at a fixed nuclear facility. Examination of the civil response to the March 28, 1979 accident at unit number 2 of TMI is best done by first understanding the actual sequence of events and then looking at the civil reaction to the events. It will show how uncoordinated and confusing the events that took place over the three days of the accident were. The accident began at 03:30 when a clogged resin bed caused water to enter a service air line which caused the condensate polishing isolation valve to drift shut. The booster pumps then tripped because of loss of suction. Failure of the booster pumps caused the feedwater pumps to shut down and the turbine tripped off line. A pressure transient results. The relief vaesults. The relief valve on the pressurizer remains stuck open rele coolant water, steam, and radioactive gases into the containment building. At fifteen minutes into the accident, the reactor coolant drain tank disk fails which causes the pressure to rise in the containment building. The reactor coolant drain tank is used to supply and store water from the primary side. The water that drains into the sump tank is automatically transferred into the auxiliary building.

1.3.1 Wednesday March 28, 1979

In the auxiliary building technicians noticed that the auxiliary sump was overflowing and a sample from the main feedwater line had a dose rate reading of 600 mrem/hr. At 06:40 a site emergency was declared. For the next half hour radiation

levels in the containment building continued to rise. At three hours and thirty minutes (07:02) a general emergency was declared. This identifies the possibility of offsite radiological danger. The first step in the procedure following declaration of a general emergency is to notify the general public. According to the procedures at the TMI plant the following individuals and organizations are to be contacted [1]:

1. The Commonwealth of Pennsylvania Emergency Management Authority (PEMA)
2. The region I office of the Nuclear Regulatory Commission (NRC), which is located in King of Prussia Pennsylvania
3. The licensee, Metropolitan Edison's (Met Ed) President
4. The operator, GPU's President and Vice-President
5. The Met Ed public information office.

At 07:02 the following people and agencies were contacted. The Commonwealth of Pennsylvania Emergency Management Authority (PEMA). PEMA in turn contacted the State Bureau of Radiation Protection (BRP) and the civil defense councils of Dauphin and Lancaster counties. Lancaster county authorities then contacted the York County civil defense office. The office of the Radiological Assistance Program (RAP) of the Department of Energy (DOE) at the Brookhaven National Laboratory was also contacted. A line between the control room and the BRP office in Harrisburg is established. The governor was notified. The NRC notification took over half an hour since there was no one at the Region I office in King of Prussia.

At 07:45 Met Ed relays to BRP that there appeared to be enough radioactive gas in the containment building to produce a serious offsite release. BRP relayed the message to PEMA for preparation for possible evacuation of Goldboro and nearby Brunner islands. PEMA then relays this message to the York County authorities. Field teams are dispersed to take downwind measurements. One half hour later, the field team radiation level measurements are available and they show no significant releases. BRP cancels their advice for evacuation preparations.

The radiation readings inside of containment increased from 200 R/hr to 6000 R/hr in approximately one hour (from 07:52 to 08:52). This led to the assumption that there was some core damage and radioactive materials were being released to containment. This caused concern in the control room pertaining to inhalation of airborne nuclides possibly in the ventilation system. It was therefore required, at 11:00 hours, for all personnel in the control room to wear respirators. This action fragments the emergency operations facility. Those individuals who cannot get into the unit-2 control room, because of lack of respirators, set up a secondary command post in the control room of the adjacent unit number 1. Beginning at 11:30, an effort to cool the steam generators enough to establish convection flow on the primary coolant side was made by discharging steam from the secondary side of the steam generators into the atmosphere. This was done in an effort to cool the steam generators enough to establish convection flow on the primary coolant system side. The discharge was a roaring jet of steam that rushed up the side of the containment building. The Met Ed president who was on the east shore across from the plant saw

the discharge and had it stopped because of his concern that the steam may have been slightly radioactive. The discharge was also stopped because it was very noticeable and may cause unnecessary concern. Stopping this discharge deprived the plant of a potential path that existed for the removal of heat from the primary system.

The Lt. Governor wanted a briefing of the plants' status for the governor's office. The two most senior utility decision makers left the site for two and half hours to brief the governor's office.

At 19:50, the operators put one of the two main coolant pumps into normal operation. This placed the reactor into a forced cooling mode and ended the major phase of the accident.

1.3.2 Thursday March 29, 1979

Day two of the TMI accident had the first releases of radioactive materials from the facility. At 04:30 the makeup tank pressure was high due to accumulation of radioactive and hydrogen gases. In order to alleviate the problem gas was vented from the tank for short periods through the vent header. The operators later become aware that the vent header leaks and radioactive gases are released through the auxiliary building exhaust system out to the atmosphere. A reading at fifteen feet above the stack was 3000 mR/hr. The Lt. Governor contacts the NRC in Washington asking whether it would be wise to advise school children to stay indoors in the Goldsboro area. The NRC responds by saying the radiation levels are well below EPA guidelines. This was the first time since the accident began that a high-level Federal

official has become involved in the matter of precautionary protective action measures for the public. Later that day it was determined that the radiation levels did not warrant evacuation.

By the afternoon 400,000 gallons of water had accumulated in the discharge tanks. Since the tanks were threatening to overflow GPU, deemed it necessary to discharge the water into the Susquehanna river and received NRC approval to do so. The BRP was notified of the discharge to the river. Forty thousand gallons were discharged to the river before the Lt. governor stopped the discharge. A short while later, the State Department of Environmental Research was credited with issuing the order to continue the discharge with the Lt. Governor's consent. The discharge continued.

At 16:15, a 100 ml sample of primary coolant water was collected. A 1000 R/hr dose rate was established. This dose rate indicated significant fuel damage involving an estimated 10% of the core radioactive inventory.

Late in the afternoon the NRC returned to business as usual and continued working on a report to congress. All five commissioners and eight of the top NRC staff officials were at the meeting.

1.3.3 Friday March 30, 1979

At 06:00 the makeup tank pressure increased to 80 psi. This high pressure caused the relief valve to open and all the water from the makeup tank flows into the reactor coolant bleed tank. In order to relieve pressure the operators began venting the

makeup tank. Each venting of the makeup tank results in a release into the auxiliary building and through its exhaust system out to the atmosphere. The operators are aware of this and make preparations to monitor and cope with the releases. At 07:00 PEMA and BRP are notified of the venting and of what was termed a planned but uncontrolled release. The dose rate measurements from the release were 1200 mR/hr at 130 feet above the stack and 14 mR/hr at the site boundary. PEMA was notified by the operations supervisor for unit 2, at 08:40, that the plant had an uncontrolled release and that all non-critical personnel may be evacuated. PEMA was also notified that they should prepare to evacuate the population downwind of the plant. BRP sends field teams out to the area. The NRC misinterprets where the 1200 mR/hr dose rate was measured. They believed it was at the site boundary not knowing that the dose rate was 130 feet above the stack. Because of this, at 09:15, the NRC recommendation was made to go ahead and evacuate the population out to 10 miles, first beginning with the population within 5 miles. PEMA notifies the state civil defense agency but does not notify the governors office. When the governor is finally informed he countermands the evacuation order. At 09:45 the BRP completed its checks with the NRC on site and was convinced that evacuation was not necessary. It was decided that the most the population should do was to stay inside during the morning hours. At 10:25 the governor announces "by NRC advice, I am advising pregnant women and pre-school age children to leave the area within a five mile radius of the TMI facility until further notice. School closures in this area are recommended"[1]. This segment of the population was selected because they are the

most sensitive to radiation exposure. It was later determined that the day's releases had a dose rate of 1 to 20 mR/hr on site and there was no threat to the public.

1.3.4 Results of TMI

As a result of the accident at TMI it was established that the deficiencies in commercial reactor safety were not hardware problems, they were management problems. TMI showed how unprepared the nuclear power industry was for an accident. Agencies that were suppose to be contacted had no one to handle incoming calls. The Emergency Operations Facility (EOF) was fragmented between the unit 1 and unit 2 control rooms making communication difficult. Unnecessary recommendations for protective actions were made by a number of different agencies which did not confirm their sources. TMI illustrated how the reactor industry had ignored critical areas of operator training, human factors engineering, utility management, and technical qualifications. It was also found that before March 28, 1979 there was a complacency within both the utility and the NRC. Following TMI there were a number of changes made in the civil response to nuclear power plant accidents in the United States.

1.4 Post TMI US Civil Response to Nuclear Power Plant Accidents

The lessons of TMI were that the response to a nuclear plant emergency may be of short duration with no off-site response actions necessary, or could require an

off-site response that is time consuming, comprehensive, and complex. The latter type of response would require many different actions and large numbers of personnel from local, state, and federal agencies as well as volunteers and the general public. Current emergency planning requires the pre-establishment of EOF and EOC locations, emergency planning zones and emergency classification levels.

1.4.1 Emergency Planning Zones

Current federal guides specify two planning zones. The first emergency planning zone is the plume exposure zone and the second zone is the ingestion exposure zone [2].

The plume exposure emergency planning zone is the area enclosed within a ten mile radius of the nuclear plant. The major concern within this zone is the airborne release of radioactive material which may pose a threat to individuals who come in contact with it. The contact may be external or internal. External contact is caused by the radiation given off by the plume and by individuals walking through areas of ground deposition. Internal contact is caused by the inhalation of radioactive materials from the plume.

The ingestion exposure emergency planning zone is the area contained within a fifty mile radius of the nuclear plant and includes the plume emergency planning zone. The major concern with this zone is the internal deposition of radioactive materials. The internal contact is caused by ingestion of food and water that have radioactive material in them and/or inhalation of resuspended radioactive materials. The

resuspended radioactive materials are caused by being blown or kicked up and are again suspended in the air. A lesser concern is external contact caused by direct contact, such as walking through a ground deposition area.

1.4.2 Emergency Classification Levels [2]

There are four emergency classification response levels for a nuclear facility. The four classifications are an unusual event, alert, site area emergency, and a general emergency.

An unusual event is an event that may cause a reduction in the level of safety at a nuclear plant. This type of event does not involve any release of radioactive materials to the environment and does not require off-site response or monitoring.

An alert is an abnormal plant condition that may potentially release radioactive materials to the environment. The state and county officials are notified. There are no actions required of the public.

A site area emergency is an abnormal condition with a threat of a release of radioactive material to the environment. The state and county officials will be notified. The public will also be notified of a site emergency. There are no actions required of the general public.

A general emergency is an event which is in progress, or has occurred, and has had an actual release, or a threatened release, to the environment. The state and local officials are notified. The population at risk of exposure is immediately notified. The public within the emergency planning zones, especially those in potentially dangerous areas, will be advised to take some protective action.

1.5 Hanford Pu/Sr/Cs Source Term

The source term used for the Hanford tank problem presents an entirely different problem than that for nuclear power plant accidents. In power plant accidents iodine is the predominant radionuclide in the source term. Iodine is not used as a source term for the Hanford tanks because it is no longer present except for very small quantities. The radioactive materials of major concern in the Hanford tanks are cesium, strontium, and plutonium because they have half lives that are many years in length [3]. At the time of the writing of this thesis, sampling is being performed on the tanks at the Hanford site to determine radioactive material composition of the wastes in the tanks. The following assumptions are made for the source term of the Hanford tanks.

1. The total inventory of the tanks is based on those estimates found in TRAC-0151-VA [3].

2. The inventory is divided equally among the 177 tanks.

1.6 Tomsk Release

On April 6, 1993 at a military site sixteen kilometers north of the city of Tomsk there was a release of radioactive material to the surrounding environment. The purpose of the Tomsk site was to produce weapons grade plutonium for the Soviet Unions nuclear armaments. The accident occurred at one of the PUREX type reprocessing plants where fuel, from the plutonium production reactors, is cut into pieces and dissolved in nitric acid. Most of the fission products, particularity cesium and strontium, are separated from the solution through the addition of an organic solvent. Traces of other materials such as zirconium, niobium, and ruthenium remain in the mixture. To remove them, nitric acid is added to the solution. There is a danger at this point in that the acid can explosively react with a thin organic layer on the surface. To avoid this, compressed air is used to mix the solution to prevent the formation of the organic layer. On this day the compressed air was not used/or not used adequately enough, and the result was an explosion that blew apart sections of the roof and wall of the building.

There were two releases from this accident. The first release was through the hole created by the collapsed wall. This release contaminated an area approximately 1500 m^2. The second release was in the form of gas and dust which passed through the ventilation system and out the stack. This release contaminated an area approximately 200 km^2 where the measured dose rate was 19 μrem/hr [4]. The area that was contaminated was located northeast of the Tomsk site and included a village, Georgievka which had a population of approximately 200. The dose rate in

Georgievka was measured to be between 18-45 μrem/hr in mid-April. The highest measured dose rate from the release was 3000 μrem/hr which was located on the facility site. Seventy percent of the activity released was in the form of short lived isotopes. These isotopes included ^{95}Nb and ^{106}Ru. The beta-gamma radionuclide release was estimated at 7.5%. If the amount of plutonium released was in the same ratio then 23 kg of plutonium was released to the environment.

According to the Russian Minister of Atomic Energy there was no need to evacuate the population of the town since radiation levels were only slightly above background [5]. Remediation procedures, which involved removal of contaminated snow and washing down contaminated areas, proceeded following the accident.

The United States has a number of military sites similar to the one found near Tomsk. The site of major concern in this thesis is the Hanford Site which is located in Eastern Washington State.

1.7 References

1. Rogoni, M. and Frampton, G. T. Jr. "Three Mile Island. A Report to the Commissioners and the Public". Volume 1. Nuclear Regulatory Commission Special Inquiry Group.

2. Manual Of Protective Action Guides And Protective Actions For Nuclear Incidents, Environmental Protection Agency, EPA 400-R-92-001, October 1991.

3. "Historical Perspective of Radioactively Contaminated Liquid and Solid Wastes Discharged or Buried in the Ground at Hanford", TRAC-0151-VA. April 1991.

4. Bennett, B., Gonzales, A., and Webb, J., "Explosion at Tomsk 7", Nuclear Engineering International, Volume 38, No. 467, June 1993.

5. "Waste Tank Explosion at Tomsk Weapons Plant", Nuclear News. May 1993.

2.0 LITERATURE REVIEW

2.1 Emergency Response to Nuclear Events in the Pacific Northwest

The states of Oregon and Washington have agreed to act in conjunction when decisions are made concerning response actions to nuclear events. This is accomplished in uniformity of data flow from the Emergency Operations Centers (EOC) to the Governors of the two states. The Emergency Operation Center is the location where all pertinent information is assembled and distributed on a need to know basis. This information is then used by the Governor of the state to make emergency evacuation decisions.

2.2 The Trojan Report

The State of Oregon has developed a new method which allows the states to make prompt decisions where food control actions need to be taken while waiting for laboratory analysis and aerial monitoring results [1]. This method allows the state to quickly identify and hold potentially contaminated foods before analysis is completed. This method also allows normal operations to continue in areas where there is little likelihood of contamination.

2.3 Phases of Nuclear Accident

The responses to a nuclear incident in the United States are classified into three phases: early, intermediate, and late phases [2]. There is no definite time table for each of the phases but they provide a useful outline for decisions in emergency response.

The early phase is the time period where the incident is in progress and decisions are based on the current conditions of the nuclear facility and on the predictions for worsening conditions. Decisions are also made on actual environmental measurements when they are available. Evacuation and sheltering are the primary emergency actions used during the early phase. These actions are performed to prevent the public from having direct exposure to radiation from both external and source radiation inhalation. The early phase may last as short as a few hours or as long as a few days. The early phase is described as the period from the beginning of the accident to the period where the plant is under control and any releases of radioactive material have ended. This phase is also referred to as the emergency phase.

The intermediate phase is the period where the incident and all releases have been brought under control [2]. Reliable environmental measurements are used to make any additional decisions on public concerns. There are two types of protective actions used during the intermediate phase. The first protective action is relocation and decontamination to protect the public from external and inhalation of radioactive source materials. The decision also has to be made whether to decontaminate and

reoccupy contaminated areas or condemn them. The second protective action is to place restrictions on the use of contaminated food and water. The intermediate phase begins when the emergency at the plant has ended. Protective actions that are taken within the plume emergency planning zone continue or, if deemed necessary, are implemented. Protective actions may also be taken in the ingestion emergency planning zone. The intermediate phase may last anywhere from a few weeks to a many months. This phase is also referred to the reentry phase.

The late phase is where recovery actions take place to reduce the radiation levels in the environment to acceptable levels [2]. The recovery phase begins when protective actions in the plume and ingestion emergency planning zones are ended. This phase may begin and end at different times in different areas due to deposition of radioactive materials, its location, the type of radioactive materials, and the quantity present. The recovery phase may overlap the reentry phase. Acceptable radiation levels allow unrestricted access to the area. The late phase may last from a few months to a number of years.

2.4 Field Team

In the event of a nuclear related accident at the Washington Nuclear Plant Number 2 (WNP-2), or a release from one of the 177 waste tanks located at the Hanford site, exposure rate measurements will be made at a height of 1-meter above the ground and the data will be used to help establish geographic areas for which protective measures will be taken. These areas are defined as the restricted,

relocation, and the food control areas. These decisions are made while waiting for laboratory analysis and aerial monitoring results. This method consists of a field crew measuring exposure rates at one meter to help establish contamination levels for that area. The field crew also takes soil/plant samples which are analyzed in a laboratory. The one meter exposure rate will determine if the area is contaminated at levels greater than/or near the federal response level for protective action guides (PAGs). This measured dose rate will also help establish temporary food control area parameters until the soil/plant samples can be analyzed and a very accurate dose rate can be established.

When the following conditions are met, field teams begin collecting 1-meter exposure rates [1]:

1. plant conditions are stabilized and no further release is predicted,
2. the plume has dispersed and can no longer be tracked, and
3. early phase sheltering and/or evacuation have been completed.

The data measurements are collected quickly so the time required to develop the relocation area and food control areas is minimized. As laboratory analysis and aerial monitoring are completed, the boundaries can be adjusted as needed.

2.5 Relocation Area

The relocation area is an area with controlled access from which the population has to be relocated in order to prevent chronic exposure to radiation [2]. The relocation area consists of an area where the radioactive exposure rate, due to ground

deposition of radioactive materials, could exceed the EPA intermediate phase PAG for the first year exposure of 2 rem. The 2 rem dose is a projected sum of the dose equivalent from external gamma radiation and the committed effective dose equivalent from inhalation of resuspended radionuclides [2]. The boundary is first established along a 1-meter exposure dose rate line of 500 μR/hr. The 500 μR/hr exposure rate represents a first year integrated dose which is less than the EPA relocation PAG [1]. This value is easily measured since it is well above background levels. The exposure rate is measured within the first 24 hours following the event. The following assumptions are used for creation of the relocation area:

1. the isotopic mix remains uniformally constant and is independent of the physical/chemical form of the isotopes,

2. the exposure is from an infinite, uniformally contaminated ground source and occurs at a height of 1-meter above the ground,

3. beta exposures to the skin, ingestion of dirt, and inhalation are considered insignificant and are therefore neglected,

4. the exposure due to food and water ingestion is considered independently and is therefore neglected,

5. the ratio of effective dose to air exposure is 0.7 and

6. the effective dose is reduced due to natural decay. Shielding from homes or other structures is not considered.

2.6 Food Control Area

The food control area is an area which surrounds the relocation area and within which food control measures are taken [2]. The food control area surrounds the area where the ^{131}I deposition could exceed the FDA response level of 0.13 $\mu Ci/m^2$ for the WNP-2 scenario [3]. The FDA response level for the Hanford tanks is a deposition of ^{137}Cs with a concentration of 3.0 $\mu Ci/m^2$ and/or a deposition of ^{90}Sr with a concentration of 0.5 $\mu Ci/m^2$ [3]. Protective actions are taken for the following foods: milk, fruits, vegetables, grains, meats, and other food stuffs. For milk the protective action necessary is to hold the milk to allow the short lived isotopes to decay away. For fruits and vegetables the protective action is to wash, brush, or scrubbing to remove surface contamination. For grains milling and polishing are done to remove surface contamination. For meat and meat products, intake of ^{137}Cs uptake by the meat pathway may exceed that for milk. If the cesium level in the milk is approaching the response level then protective actions should be implemented for meat. The boundary is initially established using a theoretical dose rate line representing an equivalent 1-meter exposure rate of 2 $\mu R/hr$ [1]. This exposure rate, which is valid for the first 24 hours of decay, indicates an ^{131}I activity concentration less than the FDA response level. The 2 $\mu R/hr$ exposure rate is a first year integrated dose rate for an ^{131}I activity concentration less than the FDA response level. The assumptions used in creation of the food control area are:

1. the plume, and ground deposition of the plume, are iodine dominated for the WNP-2 scenario and the Hanford tanks deposition is dominated by ^{137}Cs and ^{90}Sr,

2. 100% of the short term gamma ray dose rate at 1-meter is from radioiodine for the WNP-2 scenario and is ^{137}Cs-^{137m}Ba dominated for the Hanford scenario,

3. the radioiodine isotopic deposition mix is proportional to the radioiodine core inventory ratios for the WNP-2 scenario and the isotopic deposition mix for the Hanford tanks is proportional to the tank inventory,

4. the radioiodine isotopic deposition mix remains uniformally constant and is independent of the physical/chemical forms of the iodine for the WNP-2 case and the deposition mix is uniformally constant and independent of physical/chemical forms from the Hanford tanks,

5. the exposure is from an infinite uniformally contaminated ground surface and is assumed to occur at a height of 1-meter above the ground and

6. the ratio of effective dose to air exposure is 0.7.

2.7 Food Control Area Boundary

Since a dose rate of 2 μR/hr is below natural background levels it cannot be directly measured. Instead a 20 μR/hr dose rate line is developed from field team measurements. This is used in conjunction with the 500 μR/hr line to extrapolate to a 2 μR/hr dose rate line. The 20 μR/hr measurement is approximately 2 to 3 times that of background and is readily measured.

The assumptions used in creation of the food control area are [3]:

1. the dose rate is from ground exposure only,

2. deposition is uniform and proportional to the isotopic concentration in the plume,

3. wind stability is unknown or varied over time of release and

4. off centerline scaling methods are reasonable and conservative

The relationship between the measured dose rates of 500 μR/hr and 20 μR/hr at known distances from the release point is shown below:

$$20\ \frac{\mu R}{hr} = 500\ \frac{\mu R}{hr}\ \left(\frac{d_{500}}{d_{20}}\right)^{x} \qquad \textbf{(2-1)}$$

where

d_{500} = distance from source to 500 μR/hr dose rate line

d_{20} = distance from source to 20 μR/hr dose rate line and

X = atmosphere (wind) stability factor.

Wind stability is unknown, so the X value in the above equation is unknown. The wind stability can be calculated by solving eq. 2-1 for X and using measured field team data to calculate a site specific value for X. The following equation shows how the wind stability factor is calculated:

$$\ln\left(\frac{20}{50}\right) = \ln\left(\left(\frac{d_{500}}{d_{20}}\right)^{X}\right)$$

$$\ln\left(\frac{20}{50}\right) = X \ln\left(\frac{d_{500}}{d_{20}}\right)$$

$$X = \frac{\ln\left(\frac{20}{500}\right)}{\ln\left(\frac{d_{500}}{d_{20}}\right)} \qquad \textbf{(2-2)}$$

To calculate the 2 μR/hr dose rate line, use eq. 2-1. Evaluate at a distance, d_2, the distance from the source to the 2 μR/hr exposure rate line.

$$2\ \frac{\mu R}{hr} = 500 \frac{\mu R}{hr}\ \left(\frac{d_{500}}{d_2}\right)^X$$

d_2 = distance from source to theoretical 2 μR/hr dose rate point

Solve for the d_2 value.

$$\frac{2}{500} = \left(\frac{d_{500}}{d_2}\right)^X,$$

$$\left(\frac{2}{500}\right)^{\frac{1}{X}} = \frac{d_{500}}{d_2},$$

$$d_2 = \frac{d_{500}}{\left(\frac{2}{500}\right)^{\frac{1}{X}}}.$$

Hence, an expression relating the distance between the food control boundary to the source as a function of distance to the relocation boundary and the atmospheric wind stability factor, X.

$$d_2 = d_{500}\ \left(\frac{2}{500}\right)^{-\frac{1}{X}} \qquad \textbf{(2-3)}$$

The above equations are based on measured data and do not allow for the decay of radioisotopes due to time delay of data collection.

2.8 References

1. "Lessons Learned from the 1991 Trojan Nuclear Plant Post-Emergency Exercise. A new method to control food and protect the public", 2nd Edition, Oregon Department of Energy, Oregon State Health Division, and Columbia County Oregon Emergency Services. April 1993.

2. Manual Of Protective Action Guides And Protective Actions For Nuclear Incidents, Environmental Protection Agency, EPA 400-R-92-001. October 1991.

3. Federal Register Volume 47, No. 205, October 22, 1982.

3.0 APPLICATION TO WNP-2

WNP-2 is a 1100 MWe nuclear power plant designed by General Electric[1]. It is located on the Hanford site approximately 10 miles north of Richland, Washington and 40 miles north of the Oregon border.

3.1 Radioiodine Calculations for the WNP-2 Core

The calculations done in this section are necessary in finding the isotopic concentration for the radioiodine isotopes in the WNP-2 core. A ground deposition value of 0.13 $\mu Ci/m^2$ of ^{131}I at the initial time of the release is assumed since this is the contamination rate at which protective actions are implemented [3]. The results from these calculations are used to calculate the 1-meter exposure rates for the different isotopes of radioiodine. The 1-meter exposure rates are calculated for the first 96 hours following a release to show exposure rates over time that meet the 0.13 $\mu Ci/m^2$ protective action guide limits.

The core inventory of iodine at WNP-2 is calculated from data found in the WNP-2 Final Safety Analysis Report (FSAR) [2]. Section 15 of the WNP-2 FSAR outlines the assumptions for the design basis accident which could result in a large scale release of radioactive material. The assumptions made in this calculation are:

1. reactor fuel has an irradiation time of 1000 days
2. 0.32% of halogen activity is in the fuel rod plenum
3. 770 fuel rods are damaged

4. the fuel lattice is 8X8

5. 764 fuel assemblies make up one core

6. $1.4x10^3$ Curies of ^{131}I concentrated in the condenser

The assumptions governing the deposition in the environment are:

1. The atmospheric release and subsequent deposition is iodine-dominated,

2. Effectively, 100 per cent of short term gamma dose rate at one meter is from radioiodine,

3. The radioiodine isotopic deposition mix is proportional to the radioiodine core inventory ratios,

4. The radioiodine isotopic deposition mix remains uniformally constant and is independent of the physical/chemical forms of iodine,

5. The exposure is from an infinite, uniformally contaminated ground surface and is assumed to occur at a height of one meter above the ground,

6. The ^{131}I area deposition equals 0.13 $\mu Ci/m^2$ [3] and

7. The effective dose rate to exposure ratio is 0.7 [4].

In the WNP-2 facility, there are 64 fuel pins per assembly and thus 48896 fuel pins in the reactor.

In order to calculate the amount of ^{131}I present in the fuel pins of the reactor the above assumptions specify that 0.32% of the halogen activity is in the fuel plenum. Using this value and the fact that 1,400 curies of ^{131}I is released from 770 damaged fuel pins, the total amount of ^{131}I present in the 770 fuel pins is the 1400 curies divided by the percent of halogen activity in the fuel rod plenum. Thus 437,500 Curies of ^{131}I is present in the 770 fuel pins. To solve for the total number of Curies of ^{131}I in the core a ratio is used. The following ratio equation is used to find the total

amount of activity of ^{131}I in the core:

$$\left(\frac{437500\ Curies}{770\ fuel\ pins}\right) = \frac{X}{48896\ fuel\ pins}$$

Thus the entire core contains 2.778×10^7 Curies of ^{131}I.

The core inventories for ^{132}I, ^{133}I, ^{134}I, and ^{135}I were calculated in the same manner. Table 3.1 shows the core inventory of activity concentrations for the iodine isotopes in the core of the WNP-2 reactor. The table shows that the isotope with the greatest inventory is ^{134}I which has an inventory of 7.34×10^7 Curies.

Table 3.1 Iodine Isotope Concentrations for WNP-2

Isotope	Core Inventory (Curies)
^{131}I	2.78E+07
^{132}I	4.37E+07
^{133}I	6.35E+07
^{134}I	7.34E+07
^{135}I	5.75E+07

The dose rate conversion factor for uniform ground contamination is found in NRC documentation and has the units of rem/hr/Ci/m^2 [5]. In order to be useful for this work the units of the dose rate conversion factor must be converted from rem/hr/Ci/m^2 to mrem/yr/μCi/m^2. The conversion is as follows:

The exposure rate conversion factor is calculated by taking the dose-rate conversion factor and multiplying it by the following conversions:

$$\left(\frac{\frac{mrem}{yr}}{\frac{\mu Ci}{m^2}}\right) X \left(\frac{1.0E\text{-}03\ rem}{mrem}\right) X \left(\frac{\mu Ci}{1.0E\text{-}06\ Ci}\right) X \left(\frac{1\ year}{8.7E\text{+}03\ hr}\right) =$$

$$\frac{1.14E\text{-}01\ \frac{rem}{hr}}{\frac{Ci}{m^2}}.$$

$$dose\text{-}rate\ conv.\ x\ \frac{1000\ \frac{\mu R}{mR}}{0.7\ x\ 365.25\ \frac{days}{yr}\ x\ 24\ \frac{hr}{days}} = \frac{0.163\ \frac{\mu R}{hr}}{\frac{\mu Ci}{m^2}}.$$

The 0.7 value is the effective dose rate to exposure rate ratio [3].

The half-lives, decay constants, dose rate conversions, and exposure rate conversions for the WNP-2 iodine isotopes are listed in Table 3.2. Table 3.2 shows that the exposure rate conversion for ^{131}I is 3.30223 μR/hr/μCi/m^2. This value will be used later in the calculations to help determine the 1-meter exposure rate for ^{131}I.

Table 3.2 Various Parameter for WNP-2

Isotope	Half-Life (hours)	Decay Constant (hours^{-1})	Dose-Rate Conversion (rem/hr/ μCi/m^2)	Dose-Rate Conversion (mrem/yr/ μCi/m^2)	Exposure-Rate Conversion (μR/hr/ μCi/m^2)
I-131	192.96	0.003591	2.31	20.26	3.30223
I-132	2.30	0.301030	13.10	114.91	18.72695
I-133	20.80	0.033317	3.52	30.88	5.03197
I-134	0.88	0.790194	14.70	128.94	21.01421
I-135	6.50	0.106615	8.27	72.54	11.82228

The isotopic activity is calculated using the decay equation and has units of Curies. The equation is shown below:

$$A = A_o e^{-\lambda t}$$

where

A = Activity,

A_o = Initial activity,

λ = decay constant and

t = time.

The isotopic activities were calculated for the following time intervals: 0, 12, 24, 36, 48, 72, and 96 hours. These time intervals were chosen since they represent the time frame in which all field team measurements will be made. Table 3.3 shows that after 96 hours the dominant isotope is ^{131}I. The table also shows that within the first 96 hours of the release the ^{132}I and ^{134}I activity will be virtually zero. The isotopic activities over time for the WNP-2 reactor are listed in Table 3.3.

Table 3.3 Isotopic Activity of Iodine for WNP-2

Isotope	0 hrs	12 hrs	24 hrs	36 hrs	48 hrs	72 hrs	96 hrs
I-131	2.8E+07	2.7E+07	2.6E+07	2.4E+07	2.3E+07	2.1E+07	2.0E+07
I-132	4.4E+07	1.2E+06	3.2E+04	8.5E+02	2.3E+01	1.7E-02	1.2E-05
I-133	6.4E+07	4.3E+07	2.9E+07	1.9E+07	1.3E+07	5.8E+06	2.6E+06
I-134	7.3E+07	5.6E+03	4.2E-01	3.3E-05	2.5E-09	1.4E-17	8.3E-26
I-135	5.8E+07	1.6E+07	4.5E+06	1.2E+06	3.4E+05	2.7E+04	2.1E+03
Gross	2.7+E08	8.6E+07	5.9E+07	4.5E+08	3.7E+07	2.7E+07	2.2E+07

3.1.1 Isotopic Fraction

The isotopic fraction of total curies released is used to define which isotopes have the largest concentrations. The isotopic fraction is calculated by dividing the isotopic activity by the gross activity for that time step. Table 3.4 contains the isotopic fractions of the iodine isotopes found in the WNP-2 core. The data shows that after 96 hours 88% of the activity from the deposition is caused by ^{131}I and that ^{132}I, ^{134}I, and ^{135}I have such small activity fractions that there is limited contributions to the 1-meter exposure rate calculations.

The radioiodine isotope of major concern in a commercial power plant release is ^{131}I [5]. The isotopic concentrations, of the iodine isotopes, are normalized to 0.13 $\mu C/m^2$ of ^{131}I for the WNP-2 calculations [3]. The calculation consists of the isotopic activity fraction times the ^{131}I concentration divided by the ^{131}I activity fraction. The results of this calculation are summarized in Table 3.5. The data show that at 96 hours the largest concentration is ^{131}I but for the first 24 hours is the dominant isotope.

Table 3.4 Isotopic Fraction of Total Curies Released for WNP-2

Isotope	0 hrs	12 hrs	24 hrs	36 hrs	48 hrs	72 hrs	96 hrs
I-131	0.10	0.31	0.43	0.55	0.64	0.79	0.88
I-132	0.16	0.01	5.4E-04	1.9E-05	1.1E-08	7.7E-11	5.4E-13
I-133	0.24	0.49	0.49	0.43	0.35	0.21	0.12
I-134	0.27	6.5E-05	7.3E-08	7.2E-13	6.8E-18	5.3E-26	3.7E-33
I-135	0.22	0.19	0.08	0.03	9.4E-3	9.8E-04	9.4E-06

Table 3.5 Isotopic Concentration Normalized to an I-131 Concentration of 0.13 ($\mu R/m^2$) for WNP-2

Isotope	0 hrs	12 hrs	24 hrs	36 hrs	48 hrs	72 hrs	96 hrs
I-131	0.13	0.12	0.12	0.11	0.11	0.1	0.09
I-132	0.20	5.3E-03	1.5E-04	3.8E-06	1.1E-07	7.7E-11	5.5E-14
I-133	0.30	0.19	0.13	0.09	0.06	0.03	0.01
I-134	0.34	2.5E-05	2.0E-09	1.5E-13	1.2E-17	6.7E-26	3.8E-24
I-135	0.27	0.07	0.02	5.6E-03	1.6E-03	1.2E-04	9.4E-06

3.1.2 1-Meter Exposure Rates

The isotopic exposure at one meter is calculated to find what the expected exposure rates will be for each isotope of iodine in the event of a release from the WNP-2 reactor. The 1-meter exposure rate is calculated by multiplying the isotopic concentration by the isotopic exposure rate conversion. Table 3.6 shows the isotopic exposure rate for the iodine isotopes in the WNP-2 core. The exposure rate at time zero is 16.14 μR/hr and quickly drops to 2.31 μR/hr at twelve hours. The table shows that at 96 hours ^{131}I is the dominant isotope.

The isotopic exposure rate fraction is used to determine which isotopes contribute most to the exposure at specified times following a release and subsequent ground deposition. The exposure rate fraction are by taking the isotopic dose rate and dividing by the gross dose rate. ^{131}I has the highest exposure rate fraction at 96 hours. The isotope of radioiodine that dominates the exposure rate for the first 12 hours of the release is ^{135}I. The isotope that dominates from 12-36 hours following the accident is ^{133}I. The isotopic exposure rate fraction for the WNP-2 core is shown in Table 3.7.

Table 3.6 Isotopic Exposure Rate at 1-Meter (μR/hr) from WNP-2

Isotope	0 hrs	12 hrs	24 hrs	36 hrs	48 hrs	72 hrs	96 hrs
I-131	0.43	0.40	0.40	0.36	0.36	0.33	0.3
I-132	3.83	0.10	2.8E-03	7.2E-05	2.0E-06	1.4E-09	1.0E-12
I-133	1.49	0.97	0.68	0.43	0.30	0.14	0.06
I-134	7.21	5.3E-04	4.2E-08	3.1E-12	2.4E-16	1.4E-24	8.0E-33
I-135	3.18	0.85	0.25	0.07	0.02	1.5E-03	1.21E-4
Gross	16.14	2.31	1.32	0.86	0.67	0.47	0.36

Table 3.7 Isotopic Exposure Rate Fractions For WNP-2

Isotope	0 hrs	12 hrs	24 hrs	36 hrs	48 hrs	72 hrs	96 hrs
I-131	0.03	0.17	0.30	0.42	0.53	0.71	0.83
I-132	0.24	0.04	2.1E-03	5.4E-05	2.9E-06	3.1E-09	2.9E-12
I-133	0.09	0.42	0.51	0.33	0.44	0.29	0.17
I-134	0.45	2.3E-04	3.2E-08	2.3E-12	3.6E-16	3.0E-24	2.2E-32
I-135	0.20	0.37	0.19	0.05	0.03	3.1E-03	3.1E-4

3.2 Analysis of Results

From Tables 3.6 and 3.7 it can be seen that after 96 hours the exposure rate is dominated by ^{131}I. The 1-meter exposure rate after 24 hours is 1.32 μR/hr which is smaller than background. Field team measurements will not be able to differentiate this from background if the area is contaminated at the PAG minimum of 0.13 $\mu Ci/m^2$. The contamination levels will have to be determined by laboratory analysis of soil and plant samples. Until the analysis is complete, the food control area boundary will be

set up using the methodology described in section 2.7 of this thesis. As laboratory analysis is completed the food control boundaries may be adjusted. The 1-meter exposure rate at 24 hours for the Trojan report was 2.64 μR/hr [6]. The difference between the exposure rate from WNP-2 and Trojan is caused by use of a different dose conversion factor. The Trojan report uses a dose conversion factor from the Department of Energy (DOE), while this thesis uses a dose rate conversion factor from the Nuclear Regulatory Commission (NRC) [4]. The NRC dose rate conversion factor is half the DOE dose rate conversion factor. Figure 3-1 shows the exposure rate verses time for the iodine isotopes. This figure allows individuals to determine what the exposure rate will be for a given time following the release assuming the area has a ground deposition which is at the PAG minimum. These levels show at what 1-meter exposure rate protective actions need to be taken. Figure 3-2 shows the exposure rate fractions for the individual isotopes of iodine. This figure shows that for the first two hours of the release ^{134}I is the leading contributor to the exposure rate. For the hours two through twelve ^{135}I is the dominant isotope. For hours twelve through forty-four ^{133}I is the dominant isotope. ^{131}I dominates the exposure rate following forty-four hours after the release.

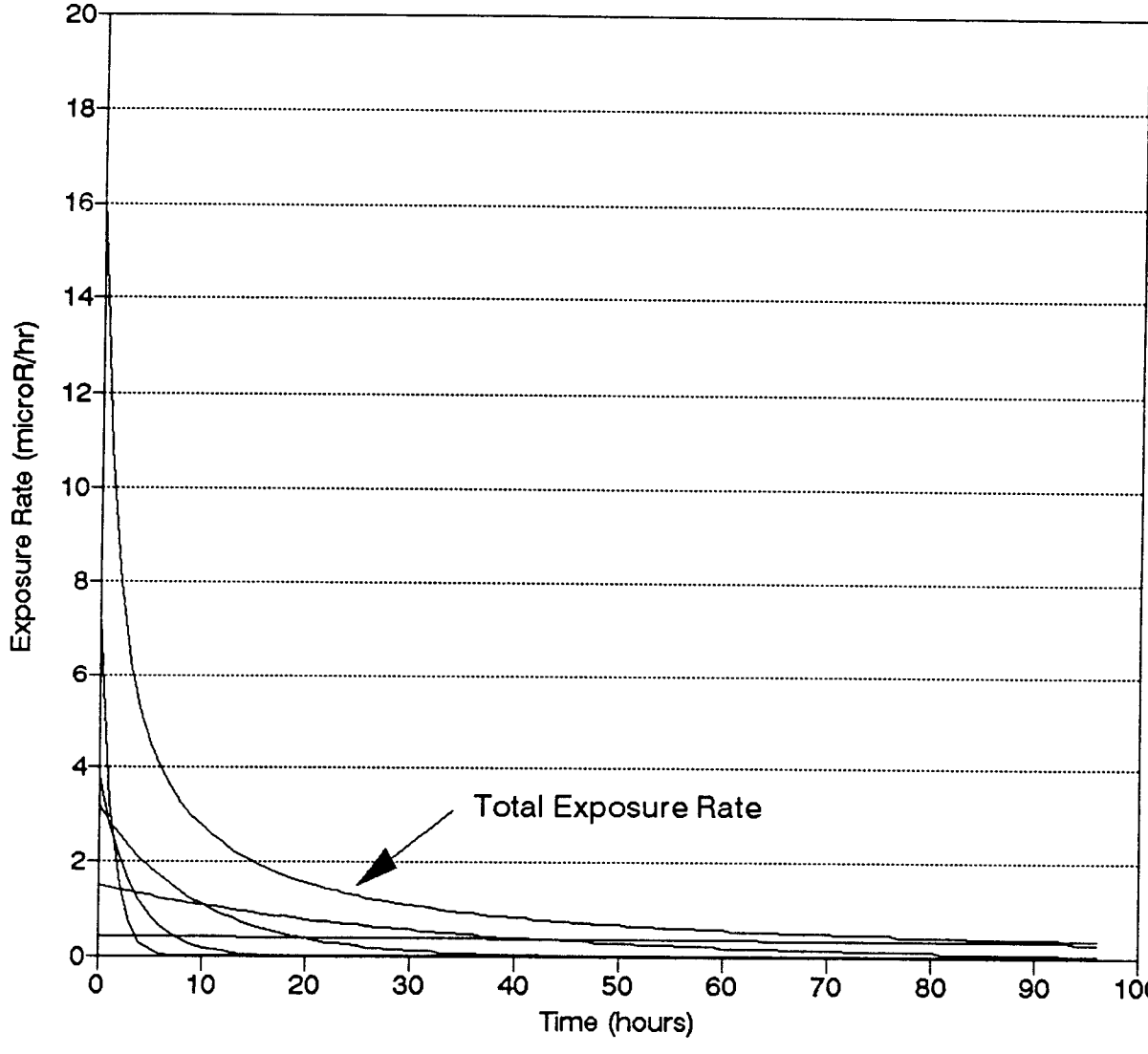

Figure 3-1 Exposure Rate Verses Time for Radioiodine

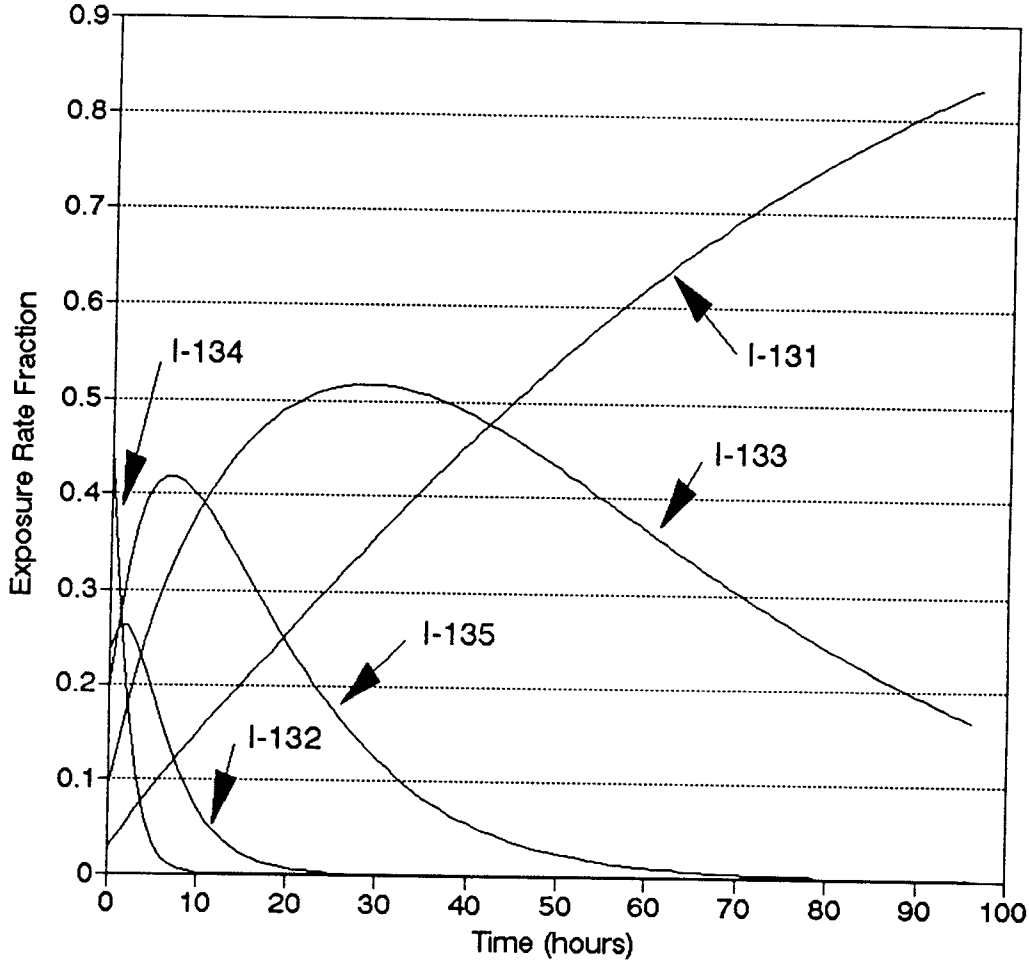

Figure 3-2 Exposure Rate Verses Time for the Different Isotopes of Radioiodine

3.3 References

1. "Plant 2 Facts", Washington Public Power Supply System, May 1985.

2. "WPPSS Nuclear Plant No. 2: Final Safety Analysis Report", Washington Public Power Supply System, Volumes 18 and 19, Chapter 15, Amended December 1985.

3. Manual Of Protective Action Guides And Protective Actions For Nuclear Incidents, Environmental Protective Agency, EPA 400-R-92-001, October 1991.

4. "RTM-92 Response Technical Manual", NUREG/BR-0150, Volume 1, Rev. 2, U. S. Nuclear Regulatory Commission. October 1982.

5. Federal Register, Volume 47, No. 205, October 22, 1982.

6. "Lessons Learned from the 1991 Trojan Nuclear Plant Post-Emergency Exercise. A new method to control food and protect the public", 2nd Edition, Oregon Department of Energy, Oregon State Health Division, and Columbia County Oregon Emergency Services. April 1993.

4.0 APPLICATION TO HANFORD STORAGE TANKS

4.1 Site Characteristics

The US Corp of Engineers selected an area of approximately 600 square miles, located in eastern Washington State, for production of nuclear materials, mainly plutonium in support of the US effort in World War II. The Hanford site was chosen because it met the criteria established by the Du Pont Company and the US Army Corp of Engineers. The site selected had to meet the following criteria [1]:

- a large and remote piece of land,
- no town of 1000 or more population closer than 20 miles,
- no main highway, railroad, or employee village closer than 10 miles
- an abundant clean water supply,
- a large electrical supply and
- ground that could bear heavy loads.

Since selection of the site in early 1943, nine reactors were built on the site [2]. Companion fuel fabrication plants, chemical processing plants, and waste management facilities were constructed and operated [2]. The irradiated uranium discharged from the reactors was processed to recover uranium and plutonium. This recovery process has resulted in the accumulation of a wide variety of radioactive and chemical wastes which are stored in 177 waste tanks.

4.2 Release Pathways

A number of the tanks at the Hanford Site facilities and equipment at the tank farms are 40 to 50 years old and have not been well maintained. The Hanford tank farms consist of 177 waste tanks, of which 149 are single-shell tanks (SSTs) and 28 are double-shell tanks (DSTs) [3]. Approximately sixty-one million gallons (230,000 m^3) of caustic liquids, slurries, saltcakes, and sludges have been accumulated in these tanks [3]. The SSTs contain mostly solid wastes and the DSTs contain liquid and suspended solids [3]. There are a few scenarios which could result in an explosive rupture of a tank which would result in a contamination event similar to what occurred at Tomsk.

Currently there are a number of safety issues concerning the waste tanks at the Hanford site. There is a flammable hydrogen gas concentration existing in twenty-five SSTs and DSTs. The most serious problem is in tank 241-SY-101 where high levels of hydrogen gas are being generated and released. The levels of hydrogen released have been high enough that the lower flammability limit was exceeded in the tank head space for several minutes prior to being removed by the ventilation system. To mitigate the problem a pump was installed to periodically mix the waste to remove the hydrogen that was trapped in the sludge. Preliminary results show that the concentration of hydrogen gas in the tank head space have been lowered to levels below the lower flammability level.

Another potentially explosive mixture is sodium nickel ferrocyanide and sodium nitrate in twenty tanks. At certain concentrations these chemicals are known

to react exothermically at high temperatures. Temperature measurements and computer modelling have shown that the probability for such an occurrence is very unlikely.

There is the potential for an exothermic nitrate-nitrite organic chemical reaction in nine SSTs. These tanks contain organic material, that in certain concentrations, may react with nitrate or nitrite under high temperature conditions. The tank of greatest concern is 241-C-103. Current analysis is being performed on the vapor space, the organic layer, and the liquid waste in the tank. Preliminary data indicates the waste consists mainly of tributyl phosphate with a small concentration of natural paraffin hydrocarbons. The temperature in the tank is well below the flashpoint of such a mixture.

There is a high heat load in SST 241-C-106 requiring periodic addition of water to provide evaporative cooling. The liquid cannot be removed from this tank because the tank would over heat and potentially damage the structural integrity of the tank.

4.3 Source Terms

The source term for the Hanford tanks is more complex then for the WNP-2 scenario. There are a number of different radioactive isotopes present in the waste tanks. The radioactive isotopes of concern in this thesis are cesium, strontium, and plutonium.

At the time of the writing of this thesis the yield of plutonium isotopes from weapons production is still classified information. For the purpose of the calculations that are forth coming in this thesis the concentrations of plutonium yield are from a mixed oxide fuel. A mixed oxide fuel is similar to the fuel used in weapons production plants. MOX fuel is made up of recycled uranium (UO_2) and plutonium [4]. The assumptions for the plutonium isotopic concentrations in the mixed oxide fuel are [5]:

1. The fuel was burned to 33,000 MWD/MTHH
2. The fuel is reprocessed after three years of operation
3. The fuel is stored for two years following reprocessing.

The plutonium isotope with the largest relative concentration, of 58.3%, is ^{239}Pu. The isotope with the smallest relative concentration, 1.8%, is ^{238}Pu. The relative concentrations of the plutonium isotopes are shown in Table 4.1.

Table 4.1 Plutonium Isotope Relative Concentrations

Isotope	Percentage (%)
^{238}Pu	1.8
^{239}Pu	58.3
^{240}Pu	23.3
^{241}Pu	11.0
^{242}Pu	5.6

4.4 Calculations

The calculations performed in this section are used to find the 1-meter exposure rates from a release from the Hanford tanks. The exposure rates for all the isotopes are normalized to a ^{137}Cs ground deposition of 3.0 $\mu Ci/m^2$, excluding ^{90}Sr, which is the minimum concentration at which protective actions are implemented. ^{90}Sr has a protective action minimum of 0.5 $\mu Ci/m^2$. The exposure rates are calculated for the next fifty years, with the initial start time beginning in 1994.

The activity concentrations of the isotopes in the Hanford tanks are taken from Final Environmental Impact Statement for the disposal of high level and transuranic wastes from the Hanford tanks [2]. The isotope with the largest activity concentration is ^{137}Cs-^{137m}Ba. The ^{137}Cs-^{137m}Ba activity concentration is 6.44E+07 curies. The other isotopes in the Hanford tanks have much smaller activities than the ^{137}Cs-^{137m}Ba. The isotopic activities of ^{137}Cs-^{137m}Ba, ^{90}Sr, ^{90}Y, and the plutonium isotopes are shown in table 4.2.

Table 4.2 Isotopic Activity for the Hanford Tanks

Isotope	Activity (Curies)
^{90}Sr	7.31E+05
^{90}Y	183.72
^{137}Cs-^{137m}Ba	6.44E+07
^{238}Pu	3.17
^{239}Pu	105.06
^{240}Pu	41.98
^{241}Pu	17.16
^{242}Pu	10.09

The half lives, decay constants, dose rate conversions, and exposure rate conversions for the Hanford Tanks are calculated in the same manner as was used in the WNP-2 calculations. These values can be found in Table 4.3.

Table 4.3 Various Parameters for the Hanford Waste Tank Isotopes

Isotope	Half-life (years)	Lambda ($years^{-1}$)	Dose Rate Conversion (rem/hr/ $\mu Ci/m^2$)	Dose Rate Conversion (mrem/yr/ $\mu Ci/m^2$)	Exposure Rate Conversion ($\mu R/hr/ \mu Ci/m^2$)
^{90}Sr	29.1	0.02	0	0	0
^{90}Y	7.31E-03	94.8	0	0	0
^{137}Cs-^{137m}Ba	30.17	0.02	3.49	30.61	4.99
^{238}Pu	87.7	7.90E-03	4.9E-03	0.04	7.0E-03
^{239}Pu	2.41E+04	2.88E-05	2.16E-03	0.02	3.1E-03
^{240}Pu	6.56E+03	1.06E-04	4.68E-03	0.04	6.7E-03
^{241}Pu	14.4	0.05	0	0	0
^{242}Pu	3.75E+05	1.85E-06	0.03	0.03	5.6E-03

The isotopic activities for the Hanford tanks were calculated for : 0, 10, 20, 30, 40, and 50 years since the isotopes of concern have half lives that are many years. The isotopic activities are listed in Table 4.4 where 0 years refers to the year 1994.

Table 4.4 Isotopic Activity for Hanford Waste Tanks (Curies)

Isotope	0 yrs	10 yrs	20 yrs	30 yrs	40 yrs	50 yrs
^{90}Sr	7.3E+05	5.8E+05	4.5E+05	3.6E+05	2.8E+05	2.2E+05
^{90}Y	183.7	144.8	114.1	89.9	70.9	55.9
^{137}Cs-^{137m}Ba	6.4E+07	5.1E+07	4.1E+07	3.2E+07	2.6E+07	2.0E+07
^{238}Pu	3.2	2.9	2.7	2.5	2.3	2.1
^{239}Pu	105.1	105.0	105.0	105.0	104.9	104.9
^{240}Pu	42.0	42.0	42.0	42.0	42.0	42.0
^{241}Pu	17.2	10.6	6.6	4.1	2.5	1.5
^{242}Pu	10.1	10.1	10.1	10.1	10.1	10.1
Gross	6.5E+07	5.2E+07	4.1E+07	3.3E+07	3.0E+07	2.1E+07

4.4.1 Isotopic Fractions

The isotopic fraction of total curies released for the Hanford tanks was calculated in the same manner as those calculations performed to find the isotopic fractions of the WNP-2 reactor. ^{137}Cs-^{137m}Ba has the largest isotopic concentration of the isotopes of concern in the Hanford tanks. ^{137}Cs-^{137m}Ba makes up 99% of the total curies released from the site. The isotopic fractions are shown in table 4.5.

The isotopic concentration in the Hanford Waste tanks is normalized to a uniform ground concentration of 3.0 $\mu Ci/m^2$ of ^{137}Cs-^{137m}Ba. ^{90}Sr and ^{90}Y are normalized to a uniform ground concentration of 0.5 $\mu Ci/m^2$ [6]. These calculations are made in the same manner as those done in the WNP-2 analysis. The isotopic normalized concentrations are shown in the Table 4.6.

Table 4.5 Isotopic Fractions of Total Curies Released for the Hanford Tanks

Isotope	0 yrs	10 yrs	20 yrs	30 yrs	40 yrs	50 yrs
^{90}Sr	0.01	0.01	0.01	0.01	0.01	0.01
^{90}Y	2.8E-06	2.8E-06	2.8E-06	2.8E-06	2.7E-07	2.7E_07
^{137}Cs-^{137m}Ba	0.99	0.99	0.99	0.99	0.99	0.99
^{238}Pu	1.5E-07	1.4E-07	1.3E-07	1.2E-07	1.1E-07	9.9E-08
^{239}Pu	4.9E-06	4.9E-06	4.9E-06	4.9E-06	4.9E-06	4.9E-06
^{240}Pu	2.0E-06	2.0E-06	2.0E-06	2.0E-06	2.0E-06	2.0E-06
^{241}Pu	8.0E-07	5.0E-07	3.1E-07	1.9E-07	1.2E-07	7.2E-08
^{242}Pu	4.7E-07	4.7E-07	4.7E-07	4.7E-07	4.7E-07	4.7E-07

Table 4.6 Isotopic Concentration Normalized to Cs-137 Concentration of 3.0 ($\mu Ci/m^2$) for the Hanford Tanks

Isotope	0 yrs	10 yrs	20 yrs	30 yrs	40 yrs	50 yrs
^{90}Sr	0.50	0.39	0.31	0.24	0.19	0.15
^{90}Y	0.50	0.39	0.31	0.24	0.19	0.15
^{137}Cs-^{137m}Ba	3.00	2.38	1.89	1.51	1.12	0.95
^{238}Pu	1.48E-07	1.36E-07	1.26E-07	1.16E-07	1.08E-07	9.94E-08
^{239}Pu	4.89E-06	4.89E-06	4.89E-06	4.89E-06	4.89E-06	4.89E-06
^{240}Pu	1.96E-06	1.95E-06	1.95E-06	1.95E-06	1.95E-06	1.95E-06
^{241}Pu	7.99E-07	4.94E-07	3.05E-07	1.89E-07	1.17E-07	7.21E-08
^{242}Pu	4.70E-07	4.70E-07	4.70E-07	4.70E-07	4.70E-07	4.70E-07

4.4.2 1-Meter Exposure Rates

The isotopic exposure rate from the Hanford Tanks is calculated in the same manner as was used for the WNP-2 scenario. The isotope with the greatest 1-meter exposure rate is ^{137}Cs-^{137m}Ba which has an exposure rate of 14.97 μR/hr at 0 years and an exposure rate of 4.75 μR/hr at 50 years. The isotopic 1-meter exposure rates are shown in Table 4.7.

The isotopic exposure rate fractions for the Hanford Waste tanks are calculated in the same manner as was used in the WNP-2 scenario. The isotope with the greatest exposure rate fraction is ^{137}Cs-^{137m}Ba which is 1. The ^{137}Cs-^{137m}Ba isotope accounts for approximately 100% of the gamma ray exposure from a Hanford tank release.

Table 4.7 Isotopic Exposure Rate at 1-Meter for the Hanford Tanks (μR/hr)

Isotope	0 yrs	10 yrs	20 yrs	30 yrs	40 yrs	50 yrs
^{90}Sr	0	0	0	0	0	0
^{90}Y	0	0	0	0	0	0
^{137}Cs-^{137m}Ba	14.97	11.90	9.45	7.51	5.97	4.75
^{238}Pu	1.03E-09	9.55E-10	8.83E-10	8.16E-10	7.54E-10	6.96E-10
^{239}Pu	1.51E-08	1.51E-08	1.51E-08	1.51E-08	1.51E-08	1.51E-08
^{240}Pu	1.31E-08	1.31E-08	1.31E-08	1.31E-08	1.31E-08	1.31E-08
^{241}Pu	0	0	0	0	0	0
^{242}Pu	2.61E-09	2.61E-09	2.61E-09	2.61E-09	2.61E-09	2.61E-09
Gross	14.97	11.90	9.45	7.51	5.97	4.75

4.5 Analysis of Results

From Table 4.7 it can be seen that ^{137}Cs-^{137m}Ba is the dominant isotope for the Hanford tanks exposure rate. These values are easily measured for the first twenty years, then following this time laboratory analysis will be necessary to confirm contamination. The other isotopes are negligible compared to ^{137}Cs-^{137m}Ba. Figure 4.1 shows the exposure rates verses time for the individual isotopes. The figure shows that the exposure rate for ^{137}Cs-^{137m}Ba is ten orders of magnitude greater than any of the other isotopes. Figure 4.2 shows the exposure rate of ^{137}Cs-^{137m}Ba verses time which is the dominant isotope for the time period in which these calculations were performed.

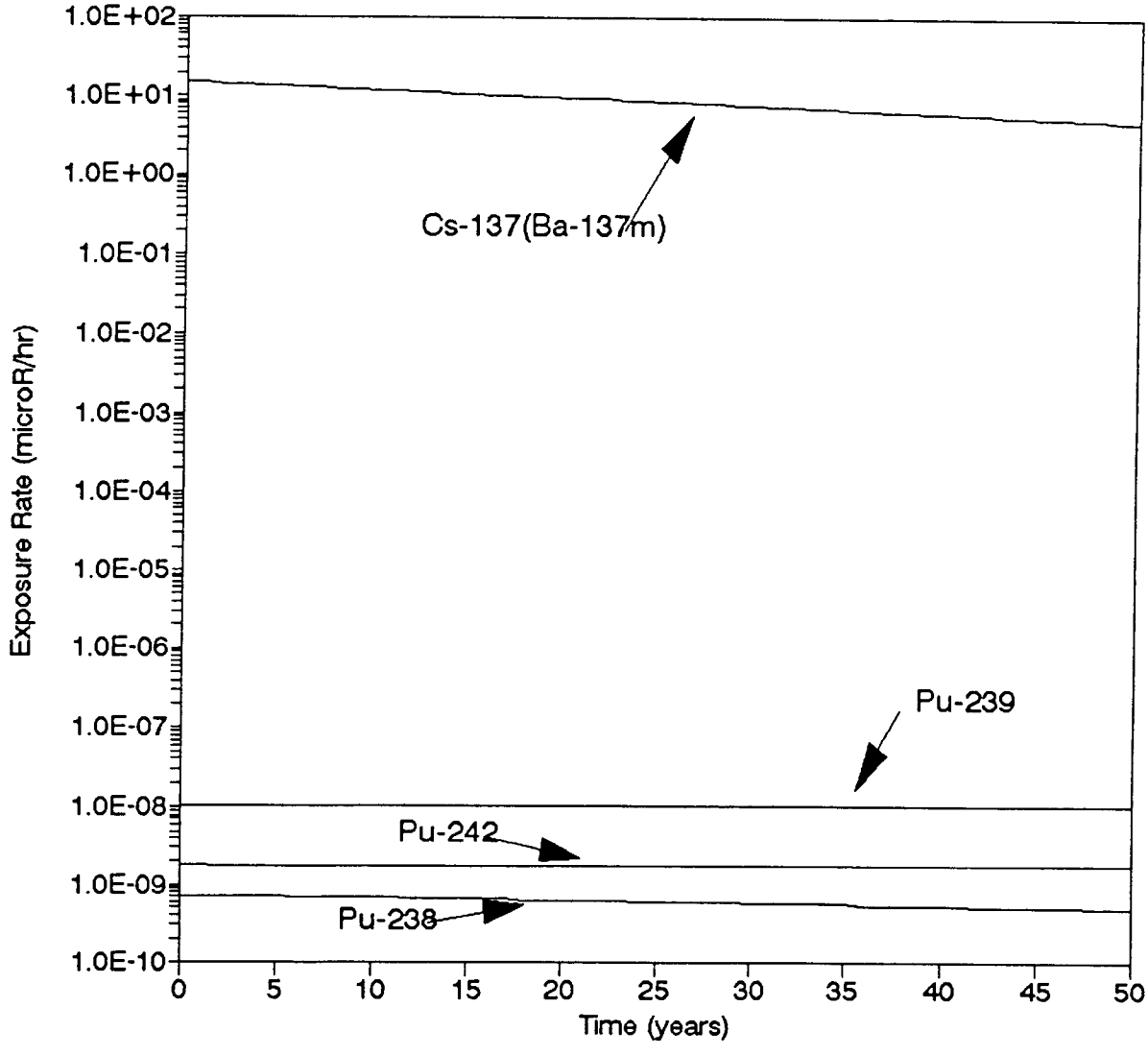

Figure 4-1 Exposure Rate Verses Time for a Release from the Hanford Tanks

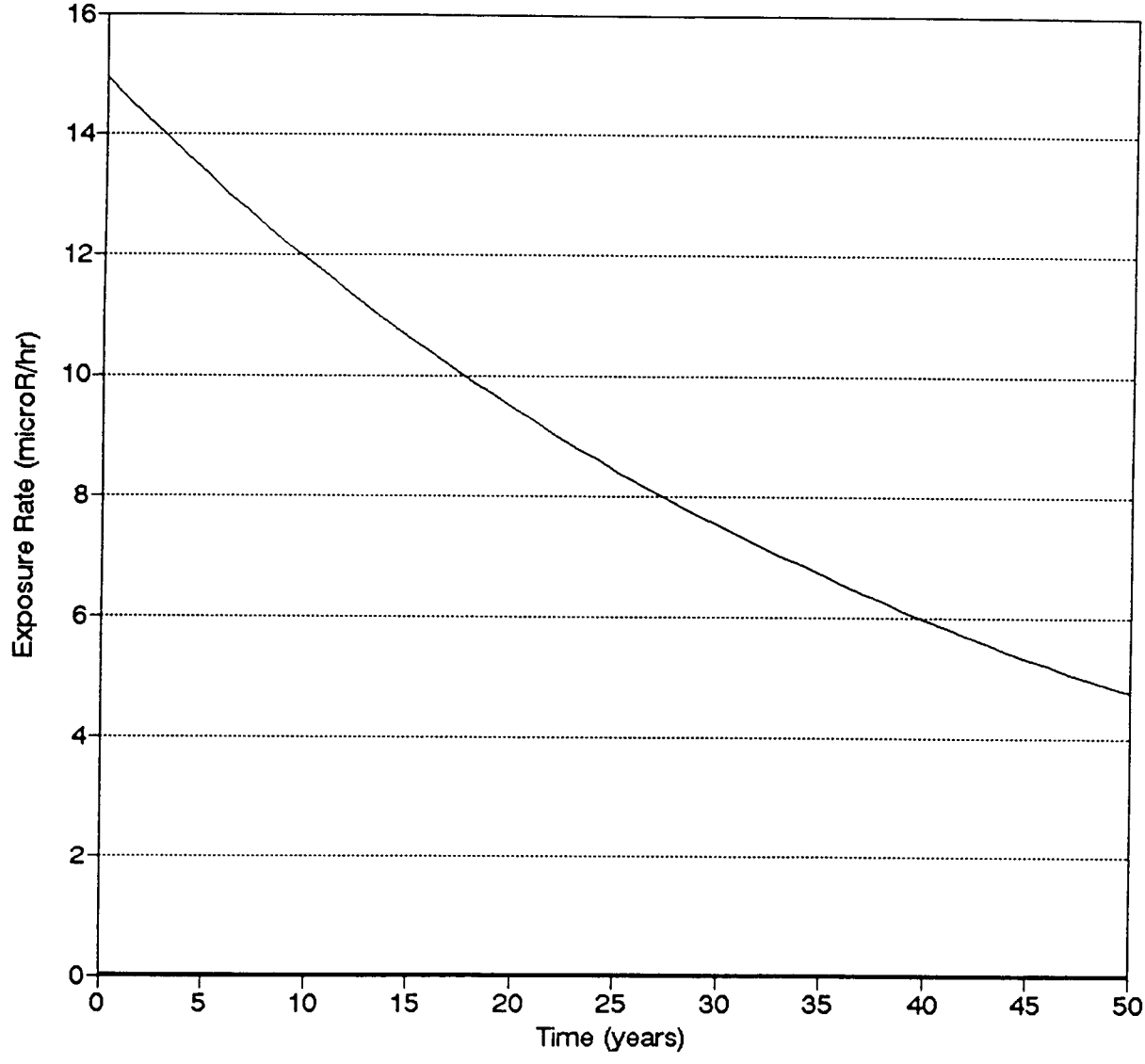

Figure 4-2 Exposure Rate Verses Time for ^{137}Cs-^{137m}Ba

4.6 References

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5.0 SUMMARY AND FUTURE RESEARCH

This chapter consists of a brief explanation of future plans for the 1-meter exposure rate calculations, as well as a general summary of the WNP-2 and Hanford waste tank calculations.

5.1 Summary

When TMI occurred the nuclear power industry in the United States was not adequately prepared to confront the situation. Following TMI a number of changes were made in the management of nuclear accidents. The major changes were pre-establishment of emergency operations facilities and centers, as well as specification of the plume exposure zone and the ingestion exposure zone.

The calculations in this thesis provide an approach to addressing immediate post-plume concerns. This method is based on measured data. It does not allow for time delay of data collection to significantly delay the development of PARs. Agencies are able to make prompt decisions to restrict access to areas of high radiation and to identify and hold potentially contaminated food, before sampling results are available, without conflicting with federal guidelines.

Two accident scenarios were calculated. The first was a radioiodine release from the WNP-2 nuclear power plant and the second was a cesium, strontium, and plutonium release from the waste tanks located on the Hanford site. Ground depositions of the gamma emitting isotopes was assumed to be 0.13 $\mu Ci/m^2$ for ^{131}I

and 3.0 $\mu Ci/m^2$ for ^{137}Cs-^{137m}Ba. These values are the minimum level for PAGs to be implemented. In each case a 1-meter exposure rate was calculated from the initial time of the event to a time later. The WNP-2 scenario had 1-meter exposure rates calculated for the first 96 hours of the accident because of the short half lifes of the isotopes involved. The Hanford tank scenario has the 1-meter exposure rates for the next fifty years calculated, beginning in 1994, because of its long half life.

The 1-meter exposure rate for the WNP-2 scenario is 1.32 $\mu Ci/hr$. This exposure rate is not readily measured, therefore the food control boundary needs to be calculated using the methods found in chapter 2 of this thesis. The 1-meter exposure rate is different than that calculated for the Trojan nuclear plant because a different dose conversion factor was used.

The 1-meter exposure rate from the Hanford tanks is easily measured for the next twenty years. The isotope that dominates the exposure is the ^{137}Cs-^{137m}Ba decay chain. ^{90}Sr and the plutonium isotopes are not significant in the exposure calculations.

5.2 Future Research

The results of the calculations show that ^{131}I is not the dominant isotope of radioiodine exposure rates. ^{131}I does not become the dominant isotope until approximately 36 hours after the release. The other isotopes of radioiodine need to be evaluated to determine there effects during a nuclear event.

The Hanford tanks showed that ^{137}Cs-^{137m}Ba decay chain was by far the most dominant isotope for the exposure rates. These calculations need to be modified in the future when the tank inventories are known.

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