A COMPARATIVE STUDY OF RADIOLOGICAL THREAT ENVIRONMENTS AND RADIATION CONTROL

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ABSTRACT

Radiation Control Programs (RCPs) differ from state to state as does their integration with public health agencies. The purpose of this study was threefold: to describe and compare across states the environmental radiological attributes of RCPs, to describe how these programs are organized structurally within state government, and to identify if RCPs differ structurally in environments of differing radiological attributes. Publicly available information from the Nuclear Regulatory Commission and state agency websites was used to determine both the environmental attributes and the different approaches states use to organize RCPs.

States were grouped based on environmental attributes by employing a principle components analysis and then a hierarchical cluster analysis. Three predominant clusters were found which included 39 of the 50 states. RCP structure was described in terms of formalization (the amount of regulation and legislation in place to guide radiation control activities), standardization (the number of operational or subprograms that are carried out within a state), and centralization (the number of state and federal agencies that control one or more of the RCP operational areas or subprograms.) To test the differences between the organizational structures of the RCPs in differing radiological environments, a Pearson's chi-square significance test was used.

The forgoing test failed to reject the null hypothesis that RCPs do not differ structurally in environments of differing radiological attributes in all but one aspect of organizational structure, formalization. Formalization was found to be significantly different across the three predominate clusters.

Keywords: Radiation Control, Organizational Structure, Preparedness, Public Health, Radiological, Accident

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Dedicated to: Corey and Clint Craft. The loves of my life.

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I would like to thank my committee for their time and commitment.
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INTRODUCTION

Since their discovery, radiological materials and their uncontrolled use and release into the environment have been shown to have immense impacts on the public's health and the environment (Glasstone, 1962; Glasstone and Jordan, 1980; Hallenbeck, 1994; EPA, 1984). Both accidental and intentional acts have been widely studied to determine the acute and chronic effects associated with radiation releases (Glasstone and Jordan, 1980; Ryan, 2001). After the World Trade Center and Anthrax terrorist events of 2001, the United States (U.S.) instituted major initiatives to prevent the malicious use of radioactive materials within its borders. Both the Congressional Research Service (CRS) and U.S. Government Accountability Office (GAO) issued multiple reports on the potential for terrorist nuclear attacks using improvised nuclear weapons and issues related to transporting radioactive materials or precursor materials needed to assemble a nuclear or radiological dispersal device across U.S. borders. Reports on the vulnerability of nuclear power plants to terrorist attacks, including air attacks, were also developed, and the Nuclear Regulatory Commission's (NRC) Design-Based Threat, used to test nuclear reactor safety and security, was revised. (Medalia, 2004; Behrens & Holt, 2005) The security of our nation's nuclear power plants has been a top priority. Other studies and programs were funded to determine how radioactive materials could be acquired, transported, and used by those wishing to cause harm to human health, the environment or the economy of our country. (Bunn, Braun, Glaser, Lyman, and Steinhausler, 2003;

NRC, 2006; U.S. GAO, 2006a; Meade & Molander, 2006) Based upon these findings, preparation, mitigation, and response initiatives began focusing on preparing and securing sites that store and use certain types of radioactive materials to prevent terrorist access to this resource, as well as border security. (Medalia, 2004; Shea, 2004; U.S. GAO, 2006a)

In 2006, a GAO report examined the ability of perpetrators to use counterfeit documents to enter the U.S. with radioactive materials. GAO investigators reported that they were able to transport enough radioactive sources across two separate U.S. borders in the trunk of their vehicle to make two radiological dispersal devices (RDDs) using counterfeit documents. These documents were fabricated using NRC logos and other information readily accessible on the internet and printed on a common laser printer. The U.S. Customs and Border Protection inspectors reportedly never questioned the authenticity of the counterfeit bill of landing or the counterfeit NRC document authorizing investigators to receive, acquire, possess, and transfer radioactive sources. (U.S. GAO, 2006b)

While the federal government has placed great importance on securing radiological materials and preventing their illicit use, another very important issue is the capacity of our nation to respond to a radiological emergency if it were to occur. Disasters themselves are defined as “disasters” only when the jurisdiction’s capacity for dealing with the incident is exceeded by the demand of the response. (Alexander, 2002) To understand when this will occur in radiological incidents, it is important to understand what response systems are available for this type incident. Essentially the response to any event is ultimately the responsibility of state and local government, an idea reinforced by the experiences of Hurricane Katrina. Without state and local capacity to respond to major crises and disasters, there will be an imbalance in the "demand-capability ratio," thereby increasing the magnitude of negative environmental and human health impacts (Quarantelli, 1982). Therefore, this study will concentrate on the ability of states to respond to radiological crises.

Immediately after 9/11, experts viewed the major radiological threat to most communities as a perpetrator's ability to use stolen or illegitimately acquired radioactive sources to devise and explode a RDD, or "dirty bomb." (Shea, 2004) An RDD could consist of something as simple as a conventional explosive and a stolen radioactive source. Because radioactive sources are used in many industrial and health care settings, the source materials needed for an RDD can be relatively simple to acquire and the device relatively simple to assemble. Therefore, because of this identified vulnerability and threat, state and local responding agencies channeled federal resources to the prevention of and preparation for RDD events. Initiatives funded by federal grants, such as the Metropolitan Medical Response System (MMRS), targeted larger metropolitan areas. MMRS funded the development of plans necessary to respond to a mass casualty incident involving Weapons of Mass Destruction (WMD), including radioactive materials. (Institute of Medicine [IOM], 2003) This funding also allowed these larger jurisdictions to conduct needed training and exercises, to acquire stockpiles of pharmaceuticals and to acquire needed personal protective and real-time monitoring equipment. Because only the larger metropolitan areas were targeted, the distribution of resources throughout the country was uneven, leaving gaps in the ability of local jurisdictions to respond.

Traditional first responders; i.e., fire, law enforcement, and emergency medical services; understand that their ability to initiate an effective, efficient response to any type of incident or crisis is inversely proportional to negative impacts that may occur as a result of the incident. A response, or the management systems that support a response, cannot be improvised. Without adequate attention to planning, management, and information flows, multiple governmental, private, and, in some cases, faith-based organizations may not be able to initiate a successful and coordinated multidisciplinary response, nor will they be able to adequately acquire and allocate resources as needed during an event. This means that there should be a concerted effort to coordinate between agencies with the authority and responsibility to respond to emergencies, crises, and disasters in an effort to reduce negative impacts — human health, environmental, and economic. (Alexander, 2002)

Statement of the Problem

On July 9, 2004, the IOM released Letter Report #6, entitled “Review of the Centers for Disease Control and Prevention's Smallpox Vaccination Program Implementation.” This report discussed the integration of public health into disaster preparedness and response and identified gaps in the area of disaster research. One of these gaps was the lack of research needed to identify planning assumptions that result in effective organizational performance. (IOM, 2004) This study will attempt to begin to fill that gap in respect to response to radiological events and will do so by focusing on one aspect of the response systems’ ability to respond to a radiological incident: the

Radiation Control Program (RCP). In doing so, a number of important contributions to public health preparedness research will result.

First, the environmental attributes of the RCP varies somewhat from state to state and region to region. As a result, preparedness and response needs can vary widely. This study maps, by state, the radiological environmental attributes which dictate the functional requirements of the RCP. In recognizing these attributes, states will be able to plan accordingly based on these attributes, as well as other identified social vulnerabilities, built environment vulnerabilities, and other hazard vulnerabilities that may exist within a given state. (Borden et al., 2008) The radiological threat environment may be described through a number of independent and dependent variables; i.e., (1) radiological system factors, such as the number of active in-state radioactive material licenses or the number of operating nuclear power reactors; and (2) man-initiated risk or event factors, such as frequency of radiological accidents/incidents or enforcement actions. This study explores radiological threat and the public health preparedness demands that are critical to insuring comprehensive and competent response capabilities by considering two classifications of radiological environmental variables: *system* and *event*. *System* variables describe what activities, processes, and independent systems exist within a given state that use, store, or process source materials, special nuclear materials (SNMs), and byproduct materials regulated by the NRC or an agreement state. *Event* variables describe factors that relate to human action, failure to act, or technical failure. This research provides an assessment of each of the 50 states. The comprehensive nature of this study allows states of varying size and composition to be compared to one another and grouped according to radiological attribute similarities.

Appendix A lists variables representing radiological environmental attributes. These variables are the dependent variables of this study and are discussed in detail in Chapter 3.

Second, this study provides an analysis of how RCPs are organized or structured. It appears that there is no consistent model of RCPs. (Conference of Radiation Control Program Directors [CRCPD], 1999) These programs may be based on historical or political considerations and hurried mandates rather than systematic analyses of the environmental radiological attributes or functional requirements of the program. The organization of RCPs in state government infrastructure may be critical to public health preparedness and response to radiological events. Structural variables that describe the RCP (see Appendix A) will be identified and are defined in detail in Chapter 3 as well as the methodology that is used to measure them. Ultimately, this assessment will allow for a comparison of RCP organization across each of the states so that similarities and differences can be identified.

Finally, each state's radiological attributes and the variables of existing RCPs will be compared to identify which organizational variables are associated with radiological environment. This analysis determines if RCPs are organized in a consistent manner depending on the radiological threat environment in which they exist.

Research Questions and Hypothesis

This study will attempt to answer the following questions:

1. How many and what proportion of each system variable exist within each state?

2. What is the level of interactive complexity for each system variable as compared to other systems?

3. How tightly coupled is each system variable as compared to other systems?

4. What is the level of the potential to impact for each system variable as compared to other systems?

5. How are states grouped based on radiological environmental attributes?

6. Where are RCPs organized within state government?

7. What functions of RCPs exist within each state?

8. What is the level of formalization and centralization of each RCP?

Further, this study explores the relationship between the radiological environmental attributes of a state and the organization structural variables (formalization, standardization of function, and centralization) of RCPs.

The following hypothesis will be tested: **RCPs will differ structurally (formalization, standardization of function, and centralization) in environments of differing radiological attributes.** Meaning, RCPs that are structured with a similar degree of formalization, standardization of function, and centralization will be found in states with similar radiological environments.

Relevance to Environmental Public Health

> "Environmental health and protection is the art and science of protecting against environmental factors that adversely impact human health or the ecologic balances to long-term human health and environmental quality, whether in the natural or human-made environment. These factors include, but are not limited to air, food, and water contaminants; radiation, toxic chemicals, wastes, disease vectors, safety hazards, and habitat alteration." (The Future of Environmental Health, 1993.)

In May 2001, the National Center for Environmental Health (NCEH) of the Centers for Disease Control and Prevention (CDC) and the American Public Health Association (APHA) issued a report entitled “Environmental Health Competency Project: Recommendations for Core Competencies for Local Environmental Health Practitioners.” This report identified 14 core competencies for local environmental health practitioners grouped into the three primary functions of an environmental health program: assessment, management and communication. One management competency focuses on “organizational knowledge and behavior” and states that environmental health practitioners should have “the capacity to function effectively within the culture of the organization and to be an effective team player.”

Emergency response to environmental impacts of radiological events will not only require that the environmental health practitioner be able to operate effectively within the public health organization, but will also require the capacity to coordinate the response operation across many governmental and non-governmental organizations with differing cultures, missions, and responsibilities, including Radiation Control. Information about the organization of state and local response resources is of paramount importance if environmental health is to meet its primary objective “to prevent death and illness from environmentally related disease and injury.” Environmental health practitioners must be able to anticipate, recognize, and respond with flexibility to environmental threats as necessary. (American Public Health Association [APHA] & National Center for Environmental Health [NCEH], CDC, 2001)

The recent radiological dispersal event that occurred in London in November 2006 reinforced the importance of the ability to respond to complex environmental health problems and how the response to these problems requires coordination, planning, and communication across multiple disciplines and organizations. Polonium-210 was used to intentionally poison Alexander Litvinenko in a public establishment. Even though only microgram quantities were involved, the British Health Protection Agency was faced with significant public health and health physics challenges, including assessing and remediating approximately 30 different venues, human exposure surveillance and assessment of potential doses of hundreds of persons exposed, and risk communication to address public concern and reduce public anxiety. (Stather, 2007) There is confusion about the organization of radiation control within the states and how these differences would affect the response to a situation such as this if it were to occur in the U.S. Therefore, this study will focus on the state's ability to respond to radiological crises, since federal resources may be delayed or, depending on the extent of the crisis, not available at all.

Federal agencies, such as the CDC's Radiation Studies Branch, are interested in the relationship of state public health agencies to the RCP in each state. This study provides precursor information on how the RCP is organized structurally so that this relationship can be further assessed. This will then potentially lead to better communication channels between federal and state organizations with responsibilities in a radiological crisis.

CHAPTER 2

LITERATURE REVIEW

Background

Radiation exists in natural background levels throughout the world from a variety of sources. These sources can be both atmospheric and terrestrial and include radiation of internally deposited radionuclides. Natural radiation is all around us, in the air and in the food and water we ingest. Exposure to natural background radiation is a fact of life. It is estimated that in the United States the average annual whole body dose equivalent from all sources of natural radiation is 3.5 millisieverts (mSv) or 0.35 Röntgen equivalent man (rem). NOTE: 1 Sv = 100 rem. (Hallenbeck, 1994)

It was not until the late nineteenth century that we became aware of radiation and radioactivity. Wilhelm Conrad Röntgen, a German physicist, discovered x rays in 1895. One year later, Antoine-Henri Becquerel's landmark research and discovery that uranium gives off radiation similar to x rays laid the foundation for radiation science. These discoveries led to many scientific advances of the early 20th century, including the discovery of many natural radioactive elements and development of man-made sources of radiation and radioactive materials. Becquerel's student, Marie Curie, later termed this phenomenon "radioactivity." In 1898, she and husband Pierre Curie discovered the naturally occurring radioactive elements polonium and radium. By the 1920s, the use of x rays in both medical and industrial applications was widespread. Biomedical and genetic researchers had begun formal study of the effects of radiation on living organisms, and physicists began to understand principles and mechanisms of spontaneous fission and radioactive decay. By the 1940's scientists had demonstrated a self-sustaining fission reaction that led to the development of nuclear reactors and atomic weapons. (Forshier, 2002) The first nuclear reactor was built at the University of Chicago as part of the Manhattan Project under the direction of Enrico Fermi and put into operation on December 2, 1942. Three years later, on December 2, 1945, Fermi had the control rods withdrawn from the reactor, marking the beginning of "the age of controlled nuclear power." (Young and Sessine, 2000) Also in 1945, J. Robert Oppenheimer developed the first nuclear weapons in Los Alamos, New Mexico. Oppenheimer and his team produced, as part of the project code named Trinity, the first atomic explosion using a fission reaction. Then in August 1945, the United States dropped atomic bombs on both Nagasaki and Hiroshima, Japan. (Young and Sessine, 2000; Glasstone, 1962)

Since the end of World War II, there have been rapid developments in the uses of radioactive materials. Today, radiation and radioactive materials are used in medicine, research, industry, and for military purposes, including nuclear fuel and weapons. Nuclear reactors and the fuel-cycle facilities that supply them are responsible for generating electricity; powering nuclear ships and submarines; producing radioisotopes used in research, space, defense, and medical applications; and are used as research tools (research and test reactors) for nuclear engineers, chemist and physicists. Particle accelerators produce radioisotopes that are widely used in research for studying the structure of atoms. The radiopharmaceutical industry produces and provides radioisotopes needed for biomedical research and nuclear medicine. X rays are widely used as a diagnostic tool in medicine and in such diverse industrial applications as oil exploration and industrial radiography (e.g., baggage scanning at airports, stress fracture detection in steel support beams in bridges, ground density gauges). (EPA, 1984) Common consumer products such as Coleman lantern mantels and luminous-dial wristwatches have been produced using radionuclides and some products, such as smoke detectors, contain radioactive sources. (Young and Sessine, 2000)

Radiation

Radiation is defined as the emission and propagation of energy, and as the emitted energy itself. Radiation can be typed as electromagnetic, acoustic, and particle; therefore it is subdivided into waves or particulates. Ionizing radiation includes highly energetic electromagnetic radiation and particulate radiation. Examples of ionizing electromagnetic radiation include x rays, gamma rays, or cosmic rays, while particulate ionizing radiation includes alpha particles, beta particles, and neutrons. Non-ionizing radiation is much less penetrating than ionizing radiation and includes ultraviolet radiation, microwaves, and high-voltage electromagnetic radiation. Ionizing and non-ionizing radiation have different mechanisms of effects on biological systems. (Young and Sessine, 2000) Ionizing radiation is describe most commonly as a form of energy emitted spontaneously by radioactive materials, high-voltage equipment, and nuclear reactions that is able to remove one or more electrons from encountered atoms, thereby leaving a positively charged ion (Glasstone and Jordan, 1980). Non-ionizing radiation causes molecular excitations. Both ionizing and non-ionizing radiation can result in altered chemical bonds in cell molecules. (Young and Sessine, 2000)

Ionizing Radiation

Some of the known elements listed on the periodic table exist in nature in two or more isotopic forms. Most of these isotopes are stable but some have nuclei that are not stable and continuously undergo changes. These unstable isotopes are said to be radioactive and this process of "change" is referred to as radioactive decay. There are 12 elements with 40 or so radioactive isotopes that exist naturally. In addition, nuclear reaction artificially produces thousands of additional radionuclides. (Glasstone and Jordan, 1980)

Ionizing radiation causes ionization of atoms due to the Compton Effect (a mid-energy phenomenon), the Photoelectric Effect (a low-energy phenomenon), or pair production (a high-energy phenomenon). The Photoelectric Effect occurs when energy from electromagnetic radiation (i.e., x-rays or visible light) is absorbed by metal and non-metal solids, liquids, or gases, resulting in the release of a photoelectron. Pair production occurs when a photon strikes the nucleus of an atom, resulting in the release of both an electron (elementary particle) and a positron (antiparticle). The Compton Effect can occur in biological materials and strips electrons away from the encountered atoms leaving them positively charged. The Compton electrons then continue to travel randomly through the material colliding with other atoms. These collisions result in a release of energy that breaks chemical bonds and causes additional ionizations. The absorbed dose of ionizing radiation is measured as the unit "gray" (Gy). One Gy is defined as one joule of energy absorbed by one kilogram of material. (Hallenbeck, 1994)

This study will focus on sources of ionizing radiation; specifically, alpha particles, beta particles, gamma rays, neutron particles, and x rays. Gamma rays and neutron particles have been identified as being produced and released in the initial intense pulse of ionizing radiation that would immediately follow the detonation of a nuclear weapon or released immediately after a nuclear power reactor explosion. These types of ionizing radiation would also be part of the residual nuclear radiation emitted after the initial intense pulse of radiation. The residual nuclear radiation from a ground-level explosion of a nuclear weapon or a nuclear reactor also will include vast quantities of alpha and beta particles that would be injected into the atmosphere, creating "fallout" at distances far from the explosion site. (NCRP, 2001; Glasstone, 1962) Three kinds of radiation associated with the more common types of radioactive decay in fission products are alpha, beta, and gamma. (Glasstone and Jordan, 1980) A nuclear explosion can also produce and release x rays. (Glasstone, 1962) Also, alpha, beta, gamma, and neutron radiation can be present after the intentional detonation of a radiological dispersal device depending on the type of source materials used. (NCRP, 2001)

Types of Ionizing Radiation. During decay, some nuclei of radionuclides spontaneously emit alpha particles. Alpha particles consist of two protons and two neutrons and have very low penetrating power; a few centimeters of air or the outer dead layer of the skin can typically stop them. (NCRP, 2005) Alpha particles generally do not constitute a hazard if generated from a source located outside of the body. (Glasstone and Jordan, 1980)

The nuclei of some types of radionuclides spontaneously emit beta particles, which are positively charged electrons. Lower-energy beta particles have low penetrating ability and can be stopped by a few millimeters of tissue, while higher-energy beta particles can be stopped by a few centimeters of tissue. (NCRP, 2005) Beta particles also generally do not constitute a hazard if generated from a source located outside of the body. (Glasstone and Jordan, 1980)

The expulsion of alpha and beta particles from the nucleus of a radioactive isotope changes the number of neutrons and protons in the nucleus. The resulting decay product, or daughter, is a different element than the original material and may or may not be radioactive itself. If it is unstable, the atom will undergo additional decays until the atom becomes stable; i.e. no longer radioactive. (Glasstone and Jordan, 1980)

Energy in excess of normal values can remain with an atom following the expulsion of alpha and beta particles. The emission of gamma rays removes this excess energy. (Glasstone and Jordan, 1980) Gamma rays are high-energy electromagnetic radiation (photons) emitted during nuclear transitions with energies particular to that transition. Gamma rays have moderate-to-high penetrating power and can penetrate deep into the human body. Up to a meter of concrete is needed to shield gamma rays. (NCRP, 2005) Unlike alpha and beta particles, because gamma rays penetrate deep distances into the body they represent a hazard from external sources. (Glasstone and Jordan, 1980)

Neutrons are uncharged particles found in the nucleus of atoms and can be energized by one of three mechanisms: spontaneous fission of nuclei, fission induced by absorption of neutrons by nuclei, and absorption of other particles by nuclei. Energetic neutrons are highly penetrating and have an enhanced ability to cause biological damage. (NCRP, 2005)

X rays are a form of electromagnetic radiation (photons) emitted in transitions of atomic orbital electrons after ionization or excitation of atoms. The deceleration of energetic charged particles (beta particles) in passing through matter can also produce x rays. (NCRP, 2005) X rays are typically of lower energy than gamma rays but still have moderate-to-high penetrating power and are able to penetrate deep within the body (Glasstone and Jordan, 1980). Several tens of centimeters of concrete are needed for shielding purposes. (NCRP, 2005)

The radioactive half-life is the time required for the activity of a particular radioactive species to decrease by half of its original value. Every species has its own characteristic half-life and rates of disintegration. (Glasstone and Jordan, 1980)

Exposure to Ionizing Radiation. Exposure to ionizing radiation such as alpha and beta particles, gamma rays, and neutrons can cause injury to living organisms directly and indirectly. Ionizing radiation can alter or destroy cell constituents that are essential to normal functioning. In addition, the products formed within the cell may be poisonous to the living tissue, causing necrosis, broken chromosomes, swelling and bursting of the nucleus or the entire cell, increased viscosity of cell fluid, increased permeability of cell membranes, and cell destruction. Exposure to ionizing radiation also results in delayed cell mitosis (process of cell division) preventing normal cell replacement.

The effects of ionizing radiation on human health depend not only on the total dose (the amount absorbed), but also on the rate of absorption and the extent and region of the body exposed. (Glasstone, 1962)

After the release of radiological materials there are many ways whereby a person in the general vicinity could be exposed. Exposure can occur both externally and internally. External exposure can occur if radionuclide(s) are dispersed in air (submersion), deposited on the ground, or in the water when one takes a bath or goes swimming (immersion) (Glasstone and Jordan, 1980). External exposures can also occur when a sealed source or a material within some type of container directly exposes a person to radiation (NCRP, 2005). Internal exposure can occur by inhalation of contaminated air or by ingestion of contaminated food and water. This is exacerbated by the disposition of airborne materials to crops that are directly ingested by humans or the disposition of airborne materials to grass that are ingested by food stock animals. Disposition can also contaminate water supplies. The uptake of the radionuclides from contaminated water by aquatic life which serve as a food source can increase exposure risks to humans. (Glasstone and Jordan, 1980)

Non-ionizing Radiation

Ultraviolet radiation, microwaves, and high-voltage electromagnetic radiation are all types of non-ionizing radiation that have been shown to have effects on biological systems.

Ultraviolet (UV) radiation can only penetrate several layers of cells; therefore, the effects of exposure to humans are seen in the skin and eyes. UV radiation is classified into one of three groups based on wavelength; UV-A, UV-B, or UV-C. UV-C includes UV radiation with wavelengths that range from 200-280 nanometers (nm). UV-B includes UV radiation with wavelengths of 280-320 nm and UV-A with wavelengths of 320-400 nm. The most biologically damaging type of UV radiation is UV-C, with UV-A being the least damaging. The atmosphere contains both UV-B and UV-A, which is part of the background radiation we receive most every day. Acute effects of overexposure include thermal burns or sunburns. Repeated overexposures to UV-B can lead to damage to the DNA in skin cells and, ultimately, skin cancer.

Microwaves are a type of electromagnetic radiation. Microwaves are released from telecommunication devices (i.e., microwave radio) and from both industrial and commercial microwave ovens. Microwaves are reflected by metals, absorbed by water, and transmitted by glass. Biological tissues are made up of different cell types with different chemical and water make-ups. Because of these differences across biological tissues, microwaves absorb unevenly, which may enhance the action of thermal heating. Microwaves can be lethal when both the power intensity and exposure time are sufficient to increase temperatures in the body beyond its capability to maintain homeostasis. Cataracts in the eyes and testicular damage in the form of reduced spermatogenesis and degeneration of the epithelial lining of the seminiferous tubules can result from non-lethal exposures to microwaves. Microwaves can also have non-thermal effects, including increased fatigue, headaches, irritability, decreased hearing acuity, and drowsiness. Cell membrane permeability can be altered due to exposures to microwaves.

Extremely low frequency electromagnetic fields (ELF) are a type of non-ionizing radiation produced by the electric and magnetic fields associated with high-voltage currents in power transmission lines. Biological effects from ELF radiation are the least understood and most controversial of the types of non-ionizing radiation. Studies have shown that there is not a clear dose-response relationship and that some biologic effects are seen only at certain frequencies and dose rates. There is no strong evidence linking ELF with either short- or long-term effects from exposure. (World Health Organization [WHO], 2001)

After a nuclear explosion, there is an emission of a non-ionizing electromagnetic pulse (EMP) from the explosion itself. This “alteration” of the electrical properties in the atmosphere can result in a disturbance of electromagnetic waves used in communications and radar technologies. These disturbances can cause blackouts of communications for several hours after an explosion. (Glasstone, 1962)

Environmental and Human Health Impacts

Whether accidental or intentional, the environmental and human health impacts associated with the release of radioactive materials are similar. The release of most radionuclides, with the exception of those with relatively short half-lives, will result in contamination that will require decontamination and remediation. Actions taken by responding organizations in the early and mid phases of a response to such releases will therefore have profound impacts on recovery operations and restorative activities. (National Council on Radiation Protection and Measurements [NCRP], 2001) This section will offer an examination of both the environmental and human health impacts of radiological releases. The NCRP Report No. 138 (2001) entitled “Management of Terrorist Events Involving Radioactive Materials” describes the likely consequences of two general categories of incidents that could have widespread radiological consequences: radiological dispersal events and nuclear detonations. The consequences from radiological dispersal events, nuclear detonation, as well as releases from nuclear reactors and nuclear fuel cycle facilities will be discussed below.

Radiological Dispersal Events

NCRP (2001) divides radiological dispersal events into two broad categories: those involving localized sources (small amounts of radioactive material or low-level materials dispersed over a localized area) and widely dispersed sources (those involving the dispersal of large amounts of radioactive materials over a very large area).

Localized source events will typically involve a single source or a few, small low-level sources used principally to cause fear and social disruption. The radioactive materials, if in solid form, could be packaged in a small container and dispersed in a public arena, could be released from a motor vehicle or aircraft, or could be dumped into the water supply. The NCRP reports that the harm from this kind of event is primarily psychosocial and that only low external or internal doses would be received, producing no immediate adverse health effects and only a small probability of long-term health effects for those exposed.

Widely dispersed source events are of greater concern. This type event could result in the dispersal of radioactive materials over large areas. This could be done with a RDD, such as a conventional explosive coupled with large amounts of radioactive materials. Therefore, a radiological dispersal event of this nature could potentially lead to life-threatening levels of exposure as well as blast and impact injuries near the point of detonation. NCRP reports that the most likely scenario would involve the use of solid radioactive materials: e.g., pellets or powder, and that the activity of the material will probably be lower as to not seriously inhibit the perpetrators from carrying out the attack. However, it is conceivable that a perpetrator (or group of perpetrators) with some technical expertise or the willingness to be detrimentally exposed could carry out a dispersal event using high-level source materials. The area of contamination from this type event would be dependent on the amount of explosives used, the energy level of the radioactive materials used, atmospheric conditions, as well as other physical properties including the extent to which the radioactive material adheres to dust or other materials dispersed by the explosion. Experts predict that initial contamination would involve only a few city blocks; however, care should be taken by responders so that contamination is not spread. Nuclear reactors, spent fuel and high-level waste storage facilities, transport vehicles, as well as facilities that process nuclear materials at any point in the nuclear fuel cycle may be potential sources of radioactive materials and/or potential targets.

Health effects seen from this type of event could be similar to those seen after Chernobyl (e.g., acute radiation poisoning) but on a much smaller scale. Responders should anticipate the possibility that victims might experience both internal and external exposure from multiple sources, including radioactive gases, liquids, and particulates. NCRP reports that the areas at risk from the dispersal of high-level radioactive materials from this type of event could extend many miles from the point of explosion due to either atmospheric conditions or survivors fleeing from the area. (NCRP, 2001)

Nuclear Detonations

The only direct information on the human health effects after an intentional detonation of a nuclear device comes from Japan. The air burst (approximately 1,850 feet above the earth’s surface) in both Hiroshima and Nagasaki with 20-kiloton energy yield nuclear devices led to three main types of physical effects: blast and shock, thermal radiation, and nuclear radiation. Casualties in both Hiroshima and Nagasaki were reported by distance from detonation or ground zero (See Table 1). According to estimates, 50 percent of the deaths in Japan were caused by thermal radiation burns, and 30 percent of those who died at Hiroshima had received a lethal dose of ionizing radiation, even though this was not always the immediate cause of death. Estimates of blast and shock injuries were impossible because many that were close enough to ground zero to suffer these type injuries were also burned. Within a half a mile of ground zero in both Hiroshima and Nagasaki, blast, burn, or nuclear radiation injury alone was lethal. For this purposes of this study, further discussion will be limited to the effects of nuclear radiation. (Glasstone, 1962)

Nuclear radiation injuries (or radiation sickness) caused by the air blasts in Japan were caused primarily by the initial ionizing radiation released from the blast, a one-time “acute” exposure. In an acute exposure, the whole radiation dose is received in a relatively short time interval, in this case within the first 24 hours. The effects seen from residual radiation (e.g., fallout and induced radioactivity) in Japan were negligible. Residual radiation exposures occurring during the first twenty-four hours after the blast were classified as “acute” exposures. Exposures to those who entered the blast area after the first twenty-four hours and remained there for extended periods were classified as chronic exposures. In a scenario where a nuclear detonation occurred at the earth’s surface; the situation would be very different, as greater effects would be seen from exposures to both initial and residual radiation, increasing the environmental contamination and the possible number of chronic exposures that could occur. (Glasstone, 1962)

Table 1: Casualties at Hiroshima and Nagasaki

Zone	*Population*	*Density* *(per square mile)*	*Killed*	*Injured*
	Hiroshima			
0 to 0.6 mile	31,200	25,800	26,700	3,000
0.6 to 1.6 miles	144,800	22,700	39,600	53,000
1.6 to 3.1 miles	80,300	3,500	1,700	20,000
Totals	256,300	8,400	68,000	76,000
Standardized Casualty Rate: 261,000 (Vulnerable area 9.36 square miles).				
	Nagasaki			
0 to 0.6 mile	30,900	25,500	27,200	1,900
0.6 to 1.6 miles	27,700	4,400	9,500	8,100
1.6 to 3.1 miles	115,200	5,100	1,300	11,000
Totals	173,800	5,700	38,000	21,000
Standardized Casualty Rate: 195,000 (Vulnerable area 7.01 square miles).				

Adapted from Glasstone, S.(Ed.). (1962). The effects of nuclear weapons.

Nuclear Reactor and Fuel Processing Plant Releases

On March 28, 1979, an accident with the potential for a core meltdown occurred at Three Mile Island Nuclear Station, Unit 2, near Harrisburg, Pennsylvania. This is the most serious accident in a commercial nuclear power plant to date in the United States.

(Glasstone and Jordan, 1980) On April 26, 1986, an accident at Chernobyl Reactor 4 outside of Kiev, Ukraine, resulted in a steam explosion and fire that released an estimated 5 percent of the graphite reactor core to the atmosphere and downwind. (World Nuclear Association [WNA], 2008) This event is the most serious nuclear power plant accident that has ever occurred. Both of the reactors, at Chernobyl and Three Mile Island, were the type of light-water reactors described as pressurized water reactors (PWR). PWRs are designed to keep water in the reactor vessel from boiling at a maximum operating temperature of 620°F by maintaining a pressure of 2250 psi. (Glasstone and Jordan, 1980) Design flaws, inadequate procedures, and operator error contributed to both accidents. (Glasstone and Jordan, 1980; WNA, 2008)

The Three Mile Island accident resulted in the pumping of contaminated water from the sump to a radioactive waste tank in an auxiliary building. Some radioactive gases escaped into the atmosphere during this process. Several days after the accident, measurements of radiation levels indicated that the risk of health effects to the general public were relatively small. (Glasstone and Jordan, 1980)

As of 2004, the Chernobyl accident resulted in 56 total fatalities. Two people died in the explosion and 28 people died in the first four months from complications associated with thermal burns or acute radiation poisoning. Approximately 209 people involved in the response and clean-up were treated for acute radiation poisoning but reportedly recovered. Of those, 19 have been confirmed to have later died from effects attributable to the accident. No one off site was reported to have suffered from acute radiation sickness, but there have been at least 9 deaths reported from thyroid cancer associated with the accident. Large areas of Belarus, Ukraine, and Russia were contaminated in varying degrees and some remain abandoned today. (WNA, 2008)

The other major known release from a nuclear power reactor occurred on October 7, 1957, north of Liverpool, England. A fire in a graphite-cooled reactor at Windscale released a large amount of radionuclides contaminating over 200 square miles.

Other accidents have occurred in facilities that process nuclear fuels. The most recent occurred on September 30, 1999, at the Tokaimura nuclear fuel processing plant located 70 miles northeast of Tokyo, Japan. This accident was caused by the improper mixing of uranium solutions by plant workers and resulted in the death of two of workers and the exposure of at least 439 other plant workers and firemen who responded to the incident. In 2000, reports indicated that upwards of 667 people had received radiation exposures from the accident. Monitoring sites outside of the plant detected gamma dose rates about 1000 times higher than normal background levels 11 hours after the accident began. Other incidents similar to the Tokaimura accident have taken place in Oak Ridge, Tennessee, in 1958, in Mayak in the Urals, in 1958, and in Wood River Junction, Rhode Island, in 1964. (Ryan, 2001)

History of Radiation Protection

Soon after the discovery of x rays and radioactivity, there were reports of the dangers and risks posed by exposure. In 1896, x ray burns were reported in the medical literature, and by 1910, it was understood that the same type of burns could be caused by exposure to radionuclides. By 1920, radium dial painters as well as medical radiologists and miners provided direct evidence of the dangers and risks associated with radiological exposure. Indirect evidence was also collected from biomedical and genetic research done with animals. In 1928, the Second International Congress of Radiology met in Stockholm, Sweden. At this meeting, the International X ray and Radium Protection Commission was created. (Forshier, 2002; Glasstone and Jordan, 1980) This was the first commission established to develop radiation protection recommendations. The commission was renamed the International Commission of Radiation Protection (ICRP) in 1950 to better reflect scientific advances and its changing role.

The International X ray and Radium Protection Commission (later the ICRP) recommended that each nation participating in the 1928 Congress of Radiology appoint national advisory committees. These national advisory committees represented their country's viewpoints in developing the recommendations and also assisted the Commission in distributing and disseminating radiation control recommendations. The U.S. advisory group was developed in 1929 and was named the Advisory Committee on X ray and Radium Protection. After several name changes and reorganizations, this U.S. advisory committee emerged in 1964 as the National Council on Radiation Protection and Measurements (NCRP). The NCRP is a congressionally chartered nongovernmental body charged with "collecting, analyzing, developing and disseminating information and recommendations about radiation protections and radiation quantities, units, and measurements." These tasks are to be performed with the interest of the public as its primary concern. (EPA, 1984)

Throughout their existence, both the ICRP and the NCRP have worked closely together to develop radiation protection recommendations that reflect current perspectives of the dangers and risk associated with exposures to ionizing radiation. The first exposure limits adopted by the ICRP and the NCRP established 0.2 roentgen per day as the “tolerance dose” for occupational exposures to x rays and the gamma rays from radium. This recommendation remained in affect until 1948 when the NCRP formulated new limits. At that point in history, the use of radioactive materials was widespread. The NCRP’s 1948 recommended limits were supported by ICRP in its 1950 recommendations and were formally issued in the U.S. in National Bureau of Standards (NBS) Handbook #54. (The NBS is now known as the National Institute of Standards and Technology and is a governmental agency within the U.S. Department of Commerce.) (National Institute of Science and Technology [NIST], 2007) These recommendations lowered the occupational dose limit to 0.3 rad per week or 15 rad per year (down from 25 rad per year). Rad is the acronym for Radiation Absorbed Dose. One rad is equal to the radiation dose that deposits 10^{-5} joules of energy per gram of absorbing material. (Martin and Harbison, 1986; Forshier, 2002) These revisions also introduced several new concepts that are still considered today when formulating new recommendations. First, weighting factors were introduced taking into consideration the various types and energies of radiation. The unit *roentgen equivalent man,* or *rem*, was developed to “express the equivalence in biological effects between radiations of differing types and energies.” Second, the recommendations introduced the concept of critical organs and tissues to assure that no tissue or organ would receive a dose in excess of a whole body dose. Third, it was suggested that no one under the age of 18 should receive more than one-tenth the exposure allowed by adults. Forth, the concept of a “maximum permissible dose” (expressed as dose per unit time) replaced the concept of “tolerance dose.” This change reflected the understanding that any radiation exposure might involve some risk and that the risk may be dependent on the length of time since last exposure or the total accumulated dose. (Environmental Protection Agency [EPA], 1984) Finally, the NCRP recognized that knowledge regarding the effects of radiation is inadequate and that there is a possibility that any exposure might have some potential for harm. (Glasstone and Jordan, 1980)

Scientific evidence gathered in the 1950's from studies done after exposures to radium by the dial painters, after exposures of medical radiologists in the 1930's and 1940's, and exposures of the survivors of the atomic bombs dropped on Japan in 1945, suggested that "genetic effects and long-term somatic effects" were more important than previously considered. (EPA, 1984) Again, in 1959, the NCRP and ICRP revised their recommendations after considering this new body of information. The new recommendations lowered the maximum permissible dose for whole-body exposure from 0.3 rad per week to 5 rem per year, with a quarterly limit of 3 rem.

For the first time, in 1959, recommendations were also included for some nonoccupational groups and for the general public. As a guide, the NCRP recommended that the maximum dose to an individual be limited to 0.5 rem per year, with maximum permissible body burdens of radionuclides set at one-tenth the amount allowed by radiation workers. (EPA, 1984) The genetic diversity of a population was considered in establishing these values that serve "primarily for the purpose of keeping the average dose to the whole population as low as reasonably possible, and not because of the likelihood of specific injury to the individual." (EPA, 1984)

During the 1960's the ICRP and the NCRP lowered the maximum permissible dose limits again to reflect the considerable scientific data on the effects to exposure to ionizing radiation. They felt that there was still inconclusive evidence of the dose-response relationship at low levels of exposure. Therefore, both the ICRP and the NCRP stressed the need to keep all exposures to the lowest possible levels.

In 1977, the ICRP “abandoned the critical organ concept in favor of the weighted whole-body dose equivalent concept to limit occupational exposures.” (EPA, 1984) ICRP Publication 26 recommended that the annual limit on effective dose equivalent for workers be at 5 rem (50 mSv) per year and the dose limit for the public at 500 mrem (0.5 rem) per year, “provided that the lifetime average annual effective dose equivalent does not exceed 100 mrem.” (Martin and Harbison, 1986; Forshier, 2002)

In 1991, the ICRP further reduced the recommended occupational exposure limit to 2 rem (20 mSv) per year. The United States has not adopted this recommendation to date. (Forshier, 2002)

Regulatory Authority

In the United States, the NCRP functions as an advisory body. Its recommendations are not binding. Therefore, in 1959, the Federal Radiation Council (FRC) was established by executive order as the official governmental entity responsible for formulating radiation protection criteria. The FRC’s major responsibility was to “advise the President with respect to radiation matters, directly or indirectly affecting health, including guidance for all Federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with the states.” (EPA, 1984) In 1960, the first standards for Federal agencies were approved by the President. NCRP and ICRP recommendations served as the basis for these standards, establishing limits for occupational exposures. The FRC also established exposure limits for the members of the public. These limits were set at 0.5 rem per year whole body dose for an individual, and 5 rem in 30 years per capita. The 0.5 rem per year whole body dose for an individual was considered what an individual received from natural background exposures. The FRC established an operational basis for determining compliance by identifying a "suitable sample of the population" to monitor. FRC, in addition to the formal exposure limits, established Federal policy "that there should be no radiation exposure without an expectation of benefit" and that "every effort should be made to encourage the maintenance of radiation doses as far below this guide as practical." (EPA, 1984)

Because of epidemiological evidence showing a higher incidence of lung cancer in adult males who worked in uranium mines, the FRC issued guidance for the control of radiation hazards in uranium mining and milling operations in 1967. This guidance established specific exposure limits for miners and advised that all exposures be kept "as far below the guide limits as possible." FRC functions were transferred to the U.S. EPA upon its establishment in 1970. (EPA, 1984)

Environmental Protection Agency

In addition to EPA's statutory responsibility to provide guidance on radiation protection, the EPA has several other statutory authorities and responsibilities regarding the regulation of radiation exposure, including the establishment of environmental standards for exposure to radionuclides. The EPA also has authority to issue standards to limit exposures due to operations of some types of nuclear reactors involved in the nuclear fuel cycle and limit the annual dose equivalent to any member of the public from these activities to 25 mrem (whole body), 75 mrem (thyroid), and 25 mrem (to other organs). In addition, to protect against build up of long-lived radionuclides with half-lives that exceed one year, the EPA sets normalized limits for emission. EPA also has regulatory authority and has standards for disposal of spent fuel, high-level wastes, and transuranic elements. The Safe Drinking Water Act gives the EPA regulatory authority to limit levels of radium, gross alpha, manmade beta, and photon-emitting contaminants in community water systems. The EPA designated radionuclides as hazardous air pollutants under the Clean Air Act and has set National Emissions Standards for radionuclides from selected sources. (EPA, 1984)

Nuclear Regulatory Commission

The Nuclear Regulatory Commission (NRC) was established by the Energy Reorganization Act of 1974. Under the authority of the Atomic Energy Act of 1954, as amended in NUREG-0980, the NRC is responsible for licensing and regulating the use of source material (uranium and thorium), special nuclear material (enriched uranium and plutonium), and byproduct material (material made radioactive in a reactor and residues from the milling of uranium and thorium). The NRC is also responsible for assuring that all licensed activities are conducted in a manner that protects the health and safety of the public. (NRC, 2007a) Initially, the Atomic Energy Act of 1954 gave a single agency, the Atomic Energy Commission, the responsibility for the development and production of nuclear weapons and for both the development and the safety regulation of the civilian use of nuclear materials. The Energy Reorganization Act of 1974 split these functions.

The responsibility for the development and production of nuclear weapons and promotion of nuclear power was give to the Department of Energy (DOE). The NRC was assigned the regulatory work, which does not include the regulation of defense nuclear facilities. (EPA, 1984) In January 1994, the NRC set dose equivalents based on NCRP Report 91. These dose equivalents include 5 rem per year for occupational exposure and 0.1 rem or 100 mrem for frequent exposures per year for the public. Infrequent annual exposure of the public is set at 0.5 rem or 500 mrem annually. (Forshier, 2002) The EPA's regulations apply directly to NRC-licensed activities and, therefore, the NRC must assure that none of the operations it licenses exposes individuals of the public to more that 0.5 rem per year.

The NRC is responsible for regulating commercial nuclear power reactors used to generate electricity and non-power reactors used mostly in research and testing in academia. There are two types of commercial nuclear power reactors in operation in the United States: pressurized water reactors (PWR) and boiling water reactors (BWR). There over a hundred licensed commercial nuclear power reactors in operation. Sixty-nine (69) are PWRs and 35 are BWRs. The NRC's Office of Reactor Regulation (ORR) has oversight and licensing responsibility for the non-power reactors also called "research and testing reactors". The NRC regulates approximately 50 research and testing reactors, only about two thirds of which are operational. The other third are either awaiting decommissioning or in the process of decommissioning (removing radioactive materials). Sites undergoing or awaiting decommissioning have licenses that allow them to possess residual radioactive materials, but not to operate the reactor. (NRC, 2007b)

Again, NRC is also responsible for regulating the use of source material, special nuclear material, and byproduct material. (NRC, 2007c; NRC, 2007d, NRC, 2008a) However, the Atomic Energy Act (AEA) permits the NRC to make agreements with the governors of states to turn over regulatory authority for these materials to the state if certain conditions are met. States that meet NRC's requirements and conditions are called "agreement states." (NRC, 2008b)

Source Materials. The NRC regulates source materials under 10 CRF Parts 20, 40, 75, and 76. States that are participants in the Agreement State Program maintain authority of licensing and regulating the use of source materials within their borders. (NRC, 2007c)

> "Source material means either the element thorium or the element uranium, provided that the uranium has not been enriched in the isotope uranium-235. Source material also includes any combination of thorium and uranium, in any physical or chemical form, or ores that contain by weight one-twentieth of one percent (0.05 percent) or more of uranium, thorium, or any combination thereof. Depleted uranium (left over from uranium enrichment) is considered source material." (NRC, 2007c)

Uranium exists in relatively low concentrations in ore. The source material then results from the concentration of uranium from this ore and other ores mined specifically for precious metals.

Special Nuclear Materials. Title I of the Atomic Energy Act of 1954 defines plutonium, uranium-233, or uranium enriched in the isotopes uranium-233 or uranium-235 as special nuclear materials. The definition includes any other material that the NRC determines to be special nuclear material but does not include source material.

NRC regulates special nuclear materials under 10 CFR Parts 10, 70, 73, 74, 75, and 76. States that are participants in the Agreement State Program maintain authority of licensing and regulating all but “formula quantities” of strategic special nuclear materials such as uranium-235 that can be enriched and used in an atomic weapon. The NRC maintains authority over these strategic special nuclear materials even in agreement states. (NRC, 2007d)

Byproduct Materials. The NRC defines byproduct materials according to the 2005 Energy Policy Act (EPAct). Sections 11e(1-4) of the EPAct are specific to byproduct materials. Section 11e(1) defines byproduct material as”radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or using special nuclear material” and Section 11e(2) continues the definition to included “the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content.” Section 11e(3) and Section 11e(4) defines byproduct materials as follows:

> “any discrete source of radium-226 that is produced, extracted, or converted after extraction, before, on, or after the date of enactment of the EPAct for use in a commercial, medical, or research activity; or any material that has been made radioactive by use of a particle accelerator and is produced, extracted, or converted after extraction, before, on, or after the date of enactment of the EPAct for use for a commercial, medical, or research activity.” (NRC, 2008a)

It also includes:

> “any discrete source of naturally occurring radioactive material, other than source material, that the Commission, in consultation with the Administrator of the Environmental Protection Agency (EPA), the Secretary of the Department of Energy (DOE), the Secretary of the Department of Homeland Security (DHS), and the head of any other appropriate Federal agency, determines would pose a

> threat similar to the threat posed by a discrete source of radium-226 to the public health and safety or the common defense and security; and is extracted or converted after extraction before, on, or after the date of enactment of the EPAct for use in a commercial, medical, or research activity." (NRC, 2008a)

The NRC regulates byproduct materials under 10 CFR Part 30 and those states who participate in the Agreement State Program maintain authority over byproduct materials within their borders. (NRC, 2008a)

Department of Energy

The DOE operates facilities that are not licensed by the NRC and therefore will not be included in this study. The facilities include national laboratories and weapons facilities. The DOE is responsible under the Atomic Energy Act, as amended in 1978, for assuring that the operations of these facilities do not jeopardize the public's health and safety. These facilities support weapons production and numerous research and development programs for the Department of Defense (DOD), including research on health effects of radiological exposures, environmental and safety aspects of nuclear energy, and nuclear waste processing. DOE facilities the following:

- Argonne National Laboratory,
- Brookhaven National Laboratory,
- Idaho National Laboratory,
- Los Alamos National Laboratory,
- Lawrence Berkeley National Laboratory,
- Lawrence Livermore National Laboratory,
- Oak Ridge National Laboratory,
- Pacific Northwest National Laboratory,

- Sandia National Laboratory, and the
- Nevada Test Site.

Also included is the decommissioned Hanford nuclear production complex in Washington State. (EPA, 1984; National Research Council, 2008) The DOE is also working to establish a high-level radioactive waste geologic repository at a Yucca Mountain site in Nye County, Nevada. Spent fuel produced at nuclear power reactors is currently stored on site. The Yucca Mountain repository could possibly receive spent fuel waste from nuclear reactors as well as high-level waste generated while reprocessing spent fuels at nuclear fuel cycle facilities. (The Yucca Mountain Project, 2009)

Department of Defense

The NRC does not regulate DOD facilities; therefore, they will not be included in this study. These facilities include the Armed Forces Radiobiology Research Institute located on the grounds of the National Naval Medical Center in Bethesda, Maryland, as well as a number of U.S. Army facilities and U.S. Naval Shipyards. The U.S. Army operates two nuclear reactors; one located at the Aberdeen Proving Ground in Maryland, the other at White Sands Missile Range in New Mexico. The U.S. Navy's nuclear fleet is based from a number of shipyards where construction, overhaul, refueling, and maintenance take place. (EPA, 1984)

State-Level Radiation Control Programs

Through the NRC's Agreement State Program, a state can assume portions of NRC's regulatory authority to license and regulate byproduct materials, source materials and certain quantities of special nuclear materials. This includes both inspection and enforcement responsibilities and gives them the authority to protect the public from the hazards associated with ionizing radiation. As of January 2010, 37 states are NRC agreement states; one other state, Michigan, has signed a letter of intent to become a NRC agreement state; and the 12 remaining states and the District of Columbia are non-agreement (See Table 2). In NRC non-agreement states, and in the District of Columbia, NRC Regional Offices have regulatory authority for all source, byproduct, and special nuclear materials.

All states, whether NRC agreement or non-agreement states, have the authority to regulate exposures to electronic sources of radiation; i.e., x rays. In addition, all states retain the authority to regulate the use of naturally occurring radioactive materials (NORM) and accelerator-produced radioactive materials. Some states have also started regulating the use of non-ionizing types of radiation, such as the use of tanning beds. (NRC, 2008c)

In some states, the regulating authorities and responsibilities are split between two or more state agencies. The organization and functions of state level programs with the authority to regulate the use of radioactive materials and radiation varies from state to state. Radiation Control Programs (RCP) may be located in the environmental management agency in one state and in public health, emergency management, or as a stand-alone agency in another. Looking across states it is obvious there are many differences in how RCPs are organized and the functions of these programs.

Table 2: Agreement and non-agreement states

	Agreement States		Non-Agreement States
1	Alabama	1	Alaska
2	Arizona	2	Connecticut
3	Arkansas	3	Delaware
4	California	4	Idaho
5	Colorado	5	Indiana
6	Florida	6	Michigan (Letter of Intent)
7	Georgia	7	Missouri
8	Illinois	8	Montana
9	Iowa	9	South Dakota
10	Kansas	10	Vermont
11	Kentucky	11	Hawaii
12	Louisiana	12	West Virginia
13	Maine	13	Wyoming
14	Maryland		
15	Massachusetts		District of Columbia (Note: Excluded from study)
16	Minnesota		
17	Mississippi		
18	Nebraska		
19	Nevada		
20	New Hampshire		
21	New Jersey		
22	New Mexico		
23	New York		
24	North Carolina		
25	North Dakota		
26	Ohio		
27	Oklahoma		
28	Oregon		
29	Pennsylvania		
30	Rhode Island		
31	South Carolina		
32	Tennessee		
33	Texas		
34	Utah		
35	Virginia		
36	Washington		
37	Wisconsin		

Radiation Control Programs

In April of 1999, the Conference of Radiation Control Program Directors, Inc. (CRCPD) issued a publication, *Criteria for an Adequate Radiation Control Program.*

This publication provided a means of standardization of RCPs and provided the managers of these programs a tool for evaluating program activities that represent the “hallmarks of an adequately functioning radiation control operation.” (CRCPD, 1999) This document incorporated five previously published criteria documents released by the CRCPD and responded to a need to update previous criteria and to add the new program areas addressing low-level waste and non-reactor emergency response. CRCPD defines seven operational areas or subprograms of the RCP: Electronic product radiation – ionizing (x ray); electronic product radiation – non-ionizing; radioactive materials; radon; environmental radiation surveillance and monitoring; low-level radioactive waste; and non-reactor radiological emergency response. CRCPD assumes that all seven of these subprograms would be located within one agency but recognized that some states apportion radiation control functions among two or more agencies. CRCPD also recognizes that all subprogram areas may not be applicable to every state. Some states, such as Alabama, do not have legislation in place that authorizes the regulation of non-ionizing electronic product radiation. Following is a brief description of the scope of each of the seven subprogram areas.

Electronic Product Radiation – X rays

This operational area or subprogram of the RCP contains activities that address all uses of x ray producing equipment; therapeutic medical use of particle accelerators; and industrial, academic, and government uses of x ray and fluoroscopy, including analytical x ray equipment, security equipment, and particle accelerators. X ray producing equipment is used in diagnostic and therapeutic medicine, including chiropractic, podiatric, dental, and veterinary x ray and includes fluoroscopy and mammography. The CRCPD states that this program area should cover activities associated with these functions in the following areas: facility registration, service registration, inspection, reporting, and quality assurance. This subprogram must confirm or issue operator certification and provide educational and training programs in the area of regulatory requirements and procedures, radiological health risk, methods to reduce patient and worker doses, and other topics of interest within this component.

Electronic Product Radiation – Non-ionizing

Regulatory activities in this area, source registration and inspection, should address the use of industrial radiofrequency (RF) heaters, industrial microwave ovens, fixed-laser light shows, and industrial and medical laser installations. The RCP should establish educational programs and user assistance programs that address UV exposure from mercury vapor lamps, exposure from commercial tanning beds, ultrasound devices, magnetic resonance imaging (MRI) systems, RF communications systems, and other areas as identified.

Radioactive Materials

RCPs located in states that are participants in the NRC Agreement State Program should address under this subprogram the regulation, licensing, inspection, and use of all radioactive materials within its jurisdiction. RCPs located in states that are not participants in the NRC Agreement State Program should address under this subprogram the use of naturally occurring (NORM) and accelerator-produced radioactive materials

(NARM) not otherwise regulated by the AEA. This provision provides authority to regulate the following: the diagnostic and therapeutic uses of radioactive materials in the healing arts and veterinary medicine; the use of radioactive materials in governmental, academic, or industrial applications or research; the manufacture and sale of radioactive sources and kits or devices containing radioactive sources; uses of devices with radioactive sources; and other activity involving radioactive materials specified by state regulation.

Radon

Under this subprogram, the RCP should license, certify and/or register radon measurement and mitigation contractors. The RCP should also conduct surveys to locate areas of elevated radon. RCPs should provide guidance and pubic information regarding radon exposure. RCPs should also have the capability to provide radon measurement and mitigation in schools and other public buildings.

Environmental Radiation Surveillance

Activities under this subprogram should include three components: field sampling and measurement, laboratory analysis, and data analysis. These activities should characterize ambient background levels (ambient monitoring), monitor major facilities (source-oriented monitoring), and monitor emergency response for unplanned or unusual radiation exposures or releases of radioactive materials. Both field and laboratory procedure manuals should be developed and used to collect samples, operate field monitoring equipment, acquire and interpret data, and record analytical results. (CRCPD, 1999)

Low-level Radioactive Waste (LLW)

LLW includes items that have become contaminated with radioactive material or have become radioactive through exposure to neutron radiation. This waste typically consists of contaminated protective shoe covers and clothing, wiping rags, mops, filters, reactor water treatment residues, equipments and tools, luminous dials, medical tubes, swabs, injection needles, syringes, and laboratory animal carcasses and tissues. The radioactivity can range from just above background levels found in nature to very highly radioactive in certain cases (e.g., parts from inside the reactor vessel in a nuclear power plant). Licensees typically store LLW on-site, either until it has decayed away and can be disposed of as ordinary trash, or until amounts are large enough for shipment to a LLW disposal site in containers approved by the Department of Transportation. LLW disposal occurs at commercially operated LLW disposal facilities that must be licensed by either NRC or the Agreement State. (NRC, 2007e)

LLW is classified by NRC based on the potential hazards they pose. This classification can be complex, but basically there are three general classes of LLW: Class A, Class B, and Class C. Class A LLW generally contains lower concentrations of long half-lived radioactive materials than Class B and C LLW.

Sites containing LLW are also classified into four categories. Activities of this subprogram in the RCP will be dependent on this classification. Category 1 LLW sites have no LLW and are not expecting LLW. Category 2 LLW sites are preparing to generate or accept LLW. Category 3 LLW sites are active sites that contain LLW. Category 4 LLW sites are closed (not accepting LLW) but currently store LLW. (CRCPD, 1999) As of June 4, 2008, there are three Category 3 sites licensed by the NRC. Each is located in and regulated by the agreement states in which they reside: South Carolina, Utah, and Washington. (NRC, 2007e)

Non-reactor Emergency Response

All RCPs should maintain "a capability for responding to accidents and incidents involving radioactive materials in transport or at sites other than nuclear reactors." The RCP should be the lead in assessing the extent of the radiation hazard. The RCP should also be able to recommend protective actions to responders and clean-up contractors and to supervise decontamination efforts and source stabilization/recovery. Most importantly, the RCP should be able to communicate and coordinate with various local, state, and federal agencies and task forces involved in response and recovery operations.

RCPs also have roles and responsibilities in responding to nuclear reactor incidents. Numerous NRC, EPA, and Federal Emergency Management Agency (FEMA) documents detail these roles and responsibilities. (CRCPD, 1999)

Identifying Radiological Threat

Fundamental terms central to hazard and vulnerability research are threat, hazard, risk, vulnerability, and consequence. As adopted by Borden, Schmidtlein, Emrich, Piegorsch, and Cutter (2008) from Mileti (1999), and Cutter (2001), the following broad conceptualizations will be used. "A *hazard* represents the potential *threat* from an environmental process." "*Risk* is a measure of the probability a hazard event will occur and adversely affect a population." Finally, "*vulnerability* broadly defines the susceptibility to harm from the risk posed by hazard events at a particular location as well as the potential for social disruption from such events." (Borden et al., 2008) The Merriam-Webster dictionary defines *threat* as "the indication of something impending." In assessing terrorism risk, Willis (2007) goes further to define *consequence* as the magnitude and type of damage resulting. Willis (2007) conceptualizes risk as the intersection of threat, vulnerability, and consequence. This study will focus on the threat posed by radiological attributes across each of the 50 states and the consequences of that hazard as measured by a radiological systems potential to have negative impacts on human health, environment, and economy.

Theoretical Framework

A number of empirical studies have been published that focus on urban vulnerability to hazards and disasters. However, most focus on a particular place and type of hazard such as Platt's (1999) study focusing on the Oakland wildfires and Solecki's (1999) focusing on Miami after Hurricane Andrew. Borden et al (2008) developed a comparative metric for assessing the relative vulnerability of multiple cities across the U.S. to natural hazards and disasters using a standardized methodology. They achieved this measure by categorizing their data into three sub-groups according to the type of vulnerability represented: social, built environment, or natural hazard. (Borden et al, 2008) This study will employ a similar approach in assessing radiological threat across the 50 United States. System and Event variables will be operationalized to determine the level of threat a given state faces. Subject matter experts will be used to identify and weigh system variables. Specific variables and the methods that will be used to operationalize them will be defined in the next chapter.

Normal Accident Theory

Until 1984, a system-level explanation of why some processes are riskier than others did not exist. (Wolf, 2001) Perrow's publication "Normal Accidents: Living with High Risk Technologies" (1984) changed that by offering what is now referred to as normal accident theory. Perrow defines a normal accident as those "unintended or untoward" events that disrupt the normal output of the organization or system. (Perrow, 1999) Cooke (2003) further described normal accidents as "accidents that result from breakdown of a complex system for which no single cause can be found." "Normal accidents are failures that result as a consequence of interactions among a technical system's components that are unanticipated because of the very large number of potential interactions in complex systems." (Wolf, 2001) "Normal accident theory suggests that disasters are the unwanted, but inevitable output of complex socio-technical systems." (Cooke and Rohleder, 2006)

According to Perrow's theory, two characteristics associated with the organization determine the risk of experiencing normal accidents, system interaction, and system coupling. System interaction describes interactive complexity of the organization. According to Perrow (1999) determinates such as "tightly spaced production equipment, closely aligned production steps, common-mode interconnections, limited isolation of failed components, personnel specialization, limited ability to substitute materials and supplies, unfamiliar and unintended feedback loops, multiple control parameters with possible interactions, indirect and inferential information systems, and limited understanding of production transformations" all contribute to the interactive complexity of a system. Coupling, also according to Perrow (1999), is "determined by the degree of time dependence in a process, flexibility in process sequencing, single or multiple paths to a goal, and the availability of slack resources." The more tightly coupled a system, the more reliant the parts of the system are on one another. Wolf (2001) measured coupling in petrochemical plants and refineries based on resource availability.

Normal accidents are commonplace and, according to Wolf (2001), "recovery, for the most part, is achieved without major consequences." Normal accident theory states that when systems have high interactive complexity and are tightly coupled, recovery may become impossible. Perrow states that "accidents are inevitable and happen all of the time; serious ones are inevitable but infrequent; catastrophes are inevitable but extremely rare." (Perrow, 1999) As pointed out by Wolf (2001), this line of thinking coincides with Heinrich's 300–29–1 ratio where, of 330 similar incidents, 300 produce no injury or significant consequence, 29 result in minor injuries, and 1 will result in a major injury. (Heinrich, 1959)

Normal accident theory posits that an interactively complex technological system subject to the constraints of tight coupling is always vulnerable to normal accidents because the probability of its failure can never be equal to zero. (Wolf, 2001) Wolf (2001) concluded in his study of petrochemical plants and refineries that more complex refineries with tighter coupling experienced significantly higher rates of accidental hazardous chemical releases. Cooke (2003) demonstrated how normal accident theory is used to develop a system dynamics model to provide insights into the behavior of the complex systems in place when the Westray mine disaster occurred in May 1992, killing 26 miners. Sagan (1993) concluded that normal accident theory provides a strong base of understanding of the safety of U.S. Air Force Strategic Air Command's handling of nuclear weapons during the cold war.

These studies show that normal accident theory can provide a foundation for understanding an important aspect of radiological threat contributed by complex systems and a theoretical foundation for understanding complex system risk. By determining the risk of normal accidents of radiological systems, emergency planning assumptions can be made based on the threat posed by that system to the community in which it is located. The greater the interactive complexity and the more tightly coupled the system components, the higher the risk of normal accidents to the radiological system. The higher the risk of normal accidents to the radiological system, the greater the threat to the community in which it resides.

Process Safety Management

The Occupational Safety and Health Administration (OSHA) issued the *Process Safety Management of Highly Hazardous Chemicals* Standard (29 CFR 1910.119) in February 1992. The logic behind this standard is relevant to this discussion. The Process Safety Management (PSM) standard contains requirements for the management of hazards associated with systems and processes that used highly hazardous chemicals. A key provision of the PSM standard requires at a minimum that a Process Hazard Analysis (PHA) is completed to review what could go wrong and what safeguards should be implemented to prevent releases of hazardous chemicals. The PHA should identify the hazard threats associated with processes that use highly hazardous chemicals, evaluate the possible effects of these hazards on employees and surrounding communities, and identify controls to be implemented to prevent unexpected releases of toxic, reactive, or flammable liquids and gases. More simply, the PHA will identify weaknesses in the process system and evaluate those weaknesses. This not only provides engineers with information needed to develop engineering controls, but also provides emergency managers and planners the information they need to make appropriate emergency planning assumptions and provide employees and the response community with valuable information that may be needed if a release occurs. (U.S. Department of Labor, 2000) The study proposed here will attempt to identify the threats posed by radiological environmental attributes. As the PHA attempts to identify weaknesses in process systems that used highly hazardous chemical, this study will attempt to identify systems that are more apt to have weaknesses because of the interactive complexity and tight coupling of the system.

Radiological Threat Variability

This study explores the variability in radiological attributes found across the United States and will group states based on these attributes. Borden et al. (2008) and Piegorsch, Cutter, and Hardisty (2007) used a similar methodology to compare the vulnerability of 132 urban areas and to quantify urban vulnerability to terrorist incidents, respectively. The organizational variables of RCPs found in similar radiological environments are compared, as described in Chapter 3, to determine if similarities of structure exist. This comparison will be based on organizational contingency and configuration theories.

Organizational Theory

Both contingency and configuration theory provide appropriate paradigms for studying RCPs and the radiological environments in which they exist. Contingency theory states that “there is no one best way to structure an organization that will ensure equal effectiveness given varying risk and environmental conditions”. (Reeves, Duncan and Ginter, 2003) Contingency theory has been expanded to include the idea that “there may be many organizational designs appropriate in any environmental state.” This is referred to as the “equafinality” principle. (Reeves et al., 2003)

Organizations function as multi-dimensional constructs with countless internal and external variables. As such, any classification of organizations has to take into account these variables. The contingency theory, now the primary field of thought in organizational classification (Donaldson, 2001), serves as the foundation for most modern organizational research. The contingency theory is based primarily on the research of Burns and Stalker (1961), Chandler (1962), and Woodward (1965). According to contingency theory, the organization is contingent on conditions and variables. Contingency theorists are thus primarily concerned with identifying those characteristics required for survival of an organization given a specific set of variables. Comparisons of successful and unsuccessful organizations that exist in a similar set of variables or environments can then be completed to determine what characteristics of an organization make it more or less successful than others.

To approach this, theorists have generally assumed that while one specific way of organizing may work for any given organization, it works only due to the unique conditions and variables surrounding it, and may not work in other circumstances. (Galbraith, 1973; Donaldson, 2001; Foster, 2006) In essence, each organization must find its proper "fit" within its environment. (Donaldson, 2001) As such, organizations must adapt to their variables, matching their strengths with those unique opportunities within the external environment. (Hofer and Schendel, 1978) This runs contrary to universalistic theories of management such as the theory of specialization, the idea that any given organization can apply one successful method to itself and see positive change. (Taylor, 1947; Brech, 1957)

While no set number of variables has been pinpointed, Donaldson (2001) highlights three as particularly notable: (1), the variable of environment (Burns and Stalker, 1961); (2), the variable of organizational size (Child, 1972); and (3), the variable of organizational strategy (Chandler, 1962). In some cases, the literature distinguishes a fourth variable, performance, based on the idea that structures will be created to accommodate the highest possible level of productivity (Miller and Friesen, 1984a; Reeves et. al., 2003).

Structural contingency theory suggests that organizations align their structures to fit the qualities of environment, size, and strategy variables as a means of achieving the highest level of performance (Donaldson, 2001; Hage and Aiken, 1969; Child, 1972). Similarly, in this study, the variable of environment will be analogue to variables of radiological environmental attributes or the state's radiological threat environment (termed system and event variables). These variables will be used to group states with similar attributes. Variables to measure the structural characteristics of RCP's will then be identified and used to determine if state RCPs align their structure to fit the qualities of their specific environmental radiological attributes.

Configurational approaches use holistic methods to try to explain how all of the constituent parts contribute to the order of the organization, including a complementary combination of organizational, strategic, and operational attributes in varying hazard environments that make one system perform better than another. (Reeves, 1996)

However, it is clear from the literature that all of these variables mentioned above are closely dependent—some would say, in fact, that they irrevocably correlate (Miller, 1986). One cannot isolate strategy from environment, as both are interlocked. By observing the connections and interrelationships between these variables, a door is opened into a new form of organizational study. Miller (1986) writes:

> "…elements of strategy, structure and environment often coalesce or configure into a manageable number of common, predictably useful types that describe a large proportion of high-performing organizations. The configurations (or 'gestalts', or 'archetypes', or 'generic types') are said to be predictably useful in that they are composed of tight constellations of mutually supportive elements. The presence of certain elements can thus lead to the reliable prediction of the remaining elements."

Though contingency theory naturally supports the idea that no one plan is a guaranteed success for an organization based on its variables, the line of thought presented above, that of configuration theory (or, as Miller and Friesen [1984a] refer to it, a "quantum view"), is an offshoot that suggests that by examining the variables of successful organizations and by observing their structures, it is then possible to find "various common organizational forms" (Miller, 1986).

Though interconnected, there are significant differences in the contingency and configuration theories; the most significant is in the approach both take to examine constituent parts of the organization (Meyer, Tsui, and Hinings, 1993). The contingency theory maintains that the constituent parts of an organization can be adjusted in isolation, wherein causality is directly determined due to these linear adjustments. The configuration theory examines the constituent parts in regards to their interaction and contribution to the whole. In essence, the configuration theory maintains that constituent parts cannot be isolated as one single part separate from the whole of the organization, and causality is nonlinear, often wildly varying.

Though configuration theory accounts for the wild variability that most organizations face, Miller and Friesen (1984a) found that "a relatively small number of these configurations or types are believed to encompass quite a large fraction of the population of organizations." Throughout the literature many attempts have been made to construct basic archetypes for these configurations (Miller and Friesen, 1984a; Miller and Friesen, 1984b; Miller, 1986; Miller and Friesen, 1986; Ulrich and McKelvey, 1990; Reeves et. al., 2003). However, Miller and Friesen (1984a) concede that it is an oversimplification to assume that the "same relationships exist among variables in different types of organizations." All configurations are multidimensional, encompassing complex levels of interrelated variables (Miller and Friesen, 1984a), and therefore it would be fallacious to assume any basic archetype applied to several different organizations would imply an exact match of all variables.

This study focuses on the structural variables associated with RCPs to identify what organizational designs exist. Zinn and Mor (1998) defined structural variables in terms of formalization, specialization, standardization, complexity, and centralization. Formalization depicts the amount of written documentation held by an organization. This includes standard operating procedures, job descriptions, regulations, and policy manuals. Specialization describes the degree to which the tasks of organization are subdivided into jobs. Standardization is the extent to which similar work is performed in a uniform manner. Complexity illustrates the number of discrete units and their arrangement in the organization. And finally, centralization describes the hierarchical level with the authority to make decisions.

This study uses this theoretical base to describe the organizational structure of RCPs. This allows the structural variables of RCPs found in similar environments to be compared to determine if similarities in structure exist.

CHAPTER 3

METHODS

This study tests how the organizational structure of RCPs is associated with the radiological environmental attributes found across the 50 United States. The study was carried out in multiple phases. First, an assessment of the radiological environmental attributes (system and event variables) by state was completed. Second, an assessment to identify organizational structural variables of the RCPs was conducted, identifying the similarities and differences that describe the organization. And finally, the variables produced in those research areas were used to determine if RCPs structured with a similar degree of formalization, standardization of function, and centralization are found in states with similar radiological environments.

This chapter is divided into five major sections. The first provides a description of the sample. The second, third, and fourth sections address each of the study phases: assessing radiological environmental attributes, the radiation control programs, and the association between the organizational variables of radiation control programs and radiological environmental attributes. The final section presents the limitations of the study.

Sample Description

The sample is composed of information collected concerning radiological environmental attributes and RCPs in the 50 United States. United States territories are omitted because of the varying degree of federal involvement in their programs and the use of non-English languages in many of their documents. The District of Columbia was also omitted because it represents just one city and has extensive federal oversight.

Assessing Radiological Environmental Attributes

Einarsson and Rausand (1998) used the vulnerability concept to characterize a system's lack of robustness and resilience with respect to various threats internal and external to a system. This study will focus on one aspect of a state's vulnerability: those posed by radiological threats. Any radiological system may be vulnerable to many different types of threats. These threats can be classified through vulnerability to such factors as technical failures, human errors, failure to act, and criminal acts. (Einarsson and Rausand, 1998) Any system that exists in the modern world "is rife with danger and an almost infinite number of perils." (Powers, 1996) Therefore, this study will first attempt to identify and define variables of radiological attributes that may increase a state's vulnerability. The methodology for rating these variables will be presented, as well as the methodology that will be employed to determine how states that have similar radiological environmental attributes can be grouped.

Radiological Environmental Attributes

The radiological attributes of any state can be challenging to quantify because of its dynamic nature. Therefore, it has been necessary to consult multiple subject matter experts – representing state and federal regulatory agencies, radiological emergency response, and public health – to guide the development of these variables. For the purpose of this study, the data that will represent radiological environmental attributes are categorized into two sub-groups according to the type of variable represented: *System* and *Event. System* variables describe what activities, processes, and independent systems exist within a given state that use, store, or process source materials, special nuclear materials, and byproduct materials regulated by the NRC or an agreement state. *Event* variables describe factors that relate to human action or technical failure. These variables are then used to compare and group states based on radiological environmental attributes.

System Variables

System variables are used to quantify the number of regulated systems using ionizing radioactive materials in a given state, the degree to which each is susceptible to normal accidents, and the potential of each system to impact human health, environment, or the economy due to a catastrophic event.

System variables include:

1. Operating nuclear power reactors – Pressurized water reactors (PWRs)
2. Operating nuclear power reactors – Boiling water reactors (BWRs)
3. Nuclear power reactors undergoing decommissioning
4. Non-power (research and test) nuclear reactors
5. Non-power (research and test) nuclear reactors undergoing decommissioning
6. Independent spent fuel storage installations – Spent fuel pools
7. Independent spent fuel storage installations – Dry cask storage
8. Nuclear material facilities – Uranium milling facilities
9. Nuclear material facilities – Fuel cycle facilities

10. Low-level waste disposal sites
11. Transuranic waste sites
12. Active in-state licensees (including both specific source licensees as well as broad byproduct licensees)

System variables are considered to be independent systems and were assessed via an electronic survey by subject matter experts (SMEs) for system attributes based on Normal Accident Theory (system interaction and system coupling) and potential impact due to system failure. (See Appendix A.) A definition of each construct is provided in the following section.

Defining System Variables. Each of the following system variables will be assessed in each state. Information about the number of each of these systems by state is publicly available. The first two variables listed below describe the two types of commercial nuclear power reactors in operation in the United States: PWRs and BWRs. (NRC, 2008d)

1. *Operating nuclear power reactors – PWRs.* PWRs are designed to keep water in the reactor vessel from boiling at a maximum operating temperature of 620°F by maintaining a pressure of 2250 psi. (Glasstone and Jordan, 1980) NRC describes PWRs as pressurized light-water reactors. These type reactors have a primary and secondary loop system. The reactor core creates heat that is carried to a steam generator by the pressurized water in the primary coolant loop. In the steam generator, the heat from the primary loop vaporizes water that is contained

in the secondary loop. This steam drives the turbine to produce electricity. (NRC, 2008d)

2. Operating nuclear power reactors – BWRs. BWRs are designed in a single closed-loop system where water is heated by the reactor core, generating steam that is delivered to the turbines that generate electricity and then returns to the reactor core in a liquid state. The water is force-circulated by electrical pumps. Emergency cooling water is provided by other pumps that can run off of diesel generators or some other type of backup power source. (NRC, 2008d)

3. Nuclear power reactors undergoing decommissioning. Nuclear power reactors that are undergoing decontamination and decommissioning are regulated by the NRC or the agreement state with the ultimate goal of terminating the license. During this process the facility or site is removed from service, and the residual radioactivity is reduced to a level that will allow the property to be released for either restricted or unrestricted use. (NRC, 2008e) A list of power reactor sites undergoing decommissioning can be found at http://www.nrc.gov/info-finder/decommissioning/power-reactor/.

4. *Non-power (research and test) nuclear reactors.* This variable will represent Class I, II, and III research and test reactors licensed by the NRC to operate in the United States. Research and test reactors – also called "non-power" reactors – are nuclear reactors primarily used for research, training, and development. These reactors contribute to almost every field of science, including physics, chemistry, biology, medicine, geology, archeology, and environmental sciences. The radiation produced by research reactors is the key output, not the very little

amount of energy produced. The most common use of this radiation is for experiments. Primarily, two types of radiation are used from research reactors: neutrons and gamma rays. Some experiments require more of one type radiation than the other. The amount and types of radiation may be controlled by placing different types of "filters" between the reactor and the experiment, or positioning the experiment at different locations relative to the radioactive fuel in the core. (NRC, 2008f)

5. Non-power (research and test) nuclear reactors undergoing decommissioning. According to http://www.nrc.gov/info-finder/decommissioning/research-test/, there are 11 research and test reactor sites undergoing decommissioning as of January 13, 2010. This variable will quantify the number of sites undergoing decommissioning in each state. Again, the goal of decommissioning is to reduce levels of residual radioactivity to levels that will allow the property to be released for either restricted or unrestricted use. (NRC, 2009)

6. High-level waste disposal site – Independent spent fuel storage installations – Spent fuel pools. Spent fuel refers to "uranium-bearing fuel elements that have been used at commercial nuclear reactors and that are no longer producing enough energy to sustain a nuclear reaction." (NRC, 2008g) One-fourth to one-third of the fuel load is removed from the reactor core every 12 to 18 months. After its removal from the reactor core, it can be stored via one of two methods that are approved by the NRC: spent fuel pools and dry cask storage. Spent fuel pools are designed to store spent fuel rods under at least 20 feet of water in order to provide adequate shielding for anyone who nears the pool. (NRC, 2007f) This variable will quantify the number of licensed spent fuel pool installations regulated by NRC in each of the 50 United States.

7. High-level waste disposal site – Independent spent fuel storage installations – Dry cask storage. Once pool capacity is reached at a facility, spent fuels that have already been cooled in the spent fuel pool for at least one year can be moved to dry cask storage. The cask is usually a steel cylinder that is either welded or bolted closed once the fuel rods are inserted and surrounded by an inert gas. The cask is then surrounded by additional steel and concrete to provide shielding for workers as well as the general public. (NRC, 2007g) This variable will quantify the number of licensed dry cask storage installations regulated by NRC in each of the 50 United States.

8. Nuclear material facilities – Uranium milling facilities. All uranium milling sites are located in the western United States because the population density is lower. (NRC, 2007h) Ore from uranium mining operations contain only a fraction (typically less than 1%) of uranium 235 (^{235}U). It is necessary then to separate it from the other minerals in the ore to produce a concentrated form of uranium called yellowcake (U_3O_8). To do this, the ore is ground and leached with an acid or base. The uranium is then separated from the other material, called tailings. (Till & Grogan, 2008) Of the active facilities, four are "in situ leach facilities," and another 11 are conventional uranium milling facilities. Of the 11conventional facilities, all but one facility(in Wyoming) is undergoing decommissioning. Each of these sites is contaminated with uranium mill tailings.

These tailings are a sandy process waste material that contains the radioactive decay products from the uranium chains and heavy metals. (NRC, 2007h)

9. Nuclear material facilities – Fuel cycle facilities. Fuel cycle facilities are facilities that enrich uranium. Several processes were developed to increase the fraction of ^{235}U above the 0.72% present naturally in ore. All enrichment processes used gaseous forms of uranium, where yellowcake is converted via diffusion, centrifugation, or electromagnetic means to uranium hexafluoride (UF_6). (Till and Grogan, 2008) There are 12 licensed fuel cycle facilities: six uranium fuel fabrication facilities, one uranium hexafluoride production (conversion) facility, two gaseous diffusion enrichment facilities, two gas centrifuge enrichment facilities, and one mixed oxide fuel fabrication facility. (NRC, 2008h) These facilities create highly enriched uranium (HEU), containing more than 20% ^{235}U, and uranium products containing lower amounts (< than 20%) of ^{235}U (LEU). HEU with levels of ^{235}U greater than 90% are used for weapons production. Various grades of LEU are used for commercial reactor fuels. The DOE has leased enrichment facilities in Ohio and Kentucky to the U.S. Enrichment Corporation to produce commercial-reactor fuel-grade LEU. Two new facilities have been proposed, one for Piketon, Ohio, the other in New Mexico, which will use centrifuge technology to enrich uranium. (Till and Grogan, 2008)

10. Low-level waste disposal site. There are three active low-level waste sites licensed by the NRC in the United States. Low-level waste includes items such as contaminated protective clothing, tools, filters, rags, medical tubes, and many other items that become contaminated during use in nuclear reactors and other applications. (NRC, 2007e)

11. Transuranic waste disposal site. High-level radioactive wastes called transuranic (TRU) waste are produced by DOE defense spent fuel reprocessing programs in DOE facilities across the country, by commercial reprocessing operations at West Valley, New York, and by nuclear power reactors. TRU wastes account for most of the radioactive hazard remaining in high-level waste after a thousand years. Under the amended provisions of the Nuclear Waste Policy Act the DOE is responsible for locating, building, and operating TRU waste repositories, but the NRC has the responsibility to establish regulations that will govern the construction, operations, and closure of the repository. Because of this, TRU waste disposal sites will be considered in this study even though they are DOE sites. The Waste Isolation Pilot Plant (WIPP) located in the Chihuahuan Desert outside of Carlsbad, New Mexico, also accepts TRU waste from some of these facilities. (NRC, 2007j)

12. Active in-state licensees. RCPs located in states that are participants in the NRC Agreement State Program regulate, license, and inspect the use of all radioactive materials within its jurisdiction. The NRC Regional Offices regulate, license, and inspect the use of radioactive materials within states that are not part of the NRC Agreement State Program. This authority is based from Title 10 of the Code of Federal Regulations (CFR) 31, 32, and 33 (10 CFR 31, 10 CFR 32, and 10 CFR 33). This variable will represent the number of entities – whether industrial, medical, academic or other – that hold active licenses (either issued by the agreement state or NRC) to use, store, process, sell, or produce ionizing radioactive materials within the states' jurisdiction. This information is accessible in a U.S. NRC Federal & State Materials & Environmental Management document (FSME-07-073) dated July 25, 2008, and can be found on the NRC web site at http://nrc-stp.ornl.gov/asletters/program/sp07073.pdf. This variable includes both specific sources as well as broad byproduct licensees.

System variables will be considered independent systems and will be assessed by subject matter experts (SMEs) for system attributes based on Normal Accident Theory (system interaction and system coupling) and potential impact due to system failure. (See Appendix A.)

System Attributes. System attributes will be used to determine which system or systems pose a greater risk to the state in which it exists. The threat posed by any given system variable to the state in which it exists will be highly dependent on the system's vulnerability to system failures, as well as its potential to impact human health, environment, and the economy if there is a catastrophic system failure. It is imperative then to first determine a measure of system vulnerability and potential impact. A group of SMEs were surveyed and asked to rate each system variable for system attributes and potential impacts of system failure. SMEs were drawn from a pool of past attendees of the National Radiological Emergency Preparedness Conference. Attendees of this conference include federal personnel representing agencies such as NRC, CDC, EPA, DOD, DOE, or state and local personnel representing RCPs, emergency management, and emergency services organizations. Personnel representing private industry also attend this conference and include representatives of the nuclear power industry and many private consulting firms including SAIC. SMEs from all these type agencies and organizations will be used because of their different vantage and viewpoints. These scores will be utilized along with the numbers of each system type by state to compare states by system variable attributes.

The survey asked respondents to score each system variable for system attributes as defined by Perrow (1984) and normal accident theory. (See Appendix B for survey instrument.) Perrow classifies a system according to two basic characteristics that identifies system vulnerability to normal accidents: system interactions and system couplings. System interactions describe the complexity of the system and are determined by the number and type of interdependencies between units and subsystems. When units or subsystems functions cannot be preformed because a second unit or subsystem does not function, a system is determined to be complex. Perrow states that system interactions become more complex with the age of the system, since there is often a tendency to add new features and modify systems over time. In a linear system, subprograms or units can operate independently of one another; therefore, one unit can remain operational if another unit does not function. (Perrow, 1984) Einarsson and Rausand (1998) describe linear systems as those in which the dependencies and interactions between various system components may be described and possible consequences foreseen or predicted – and thereby potentially prevented. In complex systems that is not possible and, therefore, those systems will be more vulnerable to internal and external threats than those that are more linear in structure. (Einarsson and Rausand, 1998)

Survey respondents were asked to score each system variable on system interactions using an 11 point Likert type scale (0-10) with zero meaning “linear” and ten meaning “most complex.” They were asked to consider examples of system interactions as described by Perrow (1999) (i.e., tightly spaced production equipment, closely aligned production steps, common-mode interconnections, limited isolation of failed components, personnel specialization, limited ability to substitute materials and supplies, unfamiliar and unintended feedback loops, multiple control parameters with possible interactions, indirect and inferential information systems, and limited understanding of production transformations). For the purpose of this study, the more linear a system, the less vulnerable it may be as compared to a more complex system. The more complex a system, the more vulnerable it may be to internal and external threats, thereby making it more of a threat to surrounding populations and the state in which it resides.

Perrow’s second system attribute, system coupling, was used to gauge the slack or buffer between subsystems. According to Perrow (1984), a tightly coupled system means that what happens in one subsystem will directly affect what happens in other subsystems. The more tightly coupled systems live with a higher degree of vulnerability. Therefore, survey respondents were asked to score each system variable on system coupling using an 11 point Likert type scale (0-10) with zero meaning “loose” and ten meaning “tightly coupled.”

To further justify this approach, Perrow (1984) states that systems that have complex interactions and tight coupling cannot be adequately analyzed for system vulnerability and are, therefore, prone to “normal accidents” which he considers natural phenomenon. For the purposes of this study, systems more prone to “normal accidents,” are considered of greater threat to the surrounding community and the state in which it resides.

SMEs were also asked to score each system variable on its potential to impact human health, environment, and economy as a result of system failure. This construct will serve as a measure of consequence if system failure does occur. An 11 point Likert type scale (0-10) was used to rank the systems potential impacts resulting from system failure, with zero meaning “negligible” and ten meaning “catastrophic.”

A pilot study to test the survey instrument was conducted in March 2009 and the final survey instrument was distributed electronically to 632 past participants of the National Radiological Emergency Preparedness (NREP) Conference in November 2009. Once responses were gathered from each survey participant, a Principal Components Analysis (PCA) was initiated to identify which system attributes are predictive of system threat. Eigenvalues derived from the PCA that are zero or close to zero indicate that the attribute is linear and not predictive of threat across the system variables. Cutter (2003), Boruff, Emrich, and Cutter (2005) and Borden et al. (2007) have used PCA to reduce the complexity of multidimensional data in similar previous studies.

For the purposes of this study, a system variable rated with higher system interaction, system coupling, and potential to impact will be considered of greater threat to the state in which it exists. Again these determinates will allow differentiation between system variables based on these attributes and will be used to determine which states have higher systematic threats due to the number of each system variable in its borders as well as the system interactions, system coupling, and potential to impact of each variable.

Pilot Study. A pilot study was conducted in March 2009. The purpose of the pilot was to test the constructs used to assess radiological system variables and the reliability (extent to which an experiment, test, or any measuring procedure yields the same result on repeated trials) and validity (the degree to which a study accurately reflects or assesses the specific concept that the researcher is attempting to measure) of the survey instrument. (Schwab, 1999)

Institutional Review Board (IRB) approval for both the pilot and the study survey was gained from UAB's Office of Institutional Review Board for Human Use on February 20, 2009 (Protocol Number: X090219004). (See Appendix C)

Fifty random attendees of past National Radiological Emergency Preparedness (NREP) conferences were chosen for inclusion in the pilot study. The attendee lists of the 2007 and 2008 conference were merged into one spread sheet and duplicates removed, retaining the most current contact information available for each participant (N=692). Utilizing Microsoft Excel's random number generator, 50 random numbers where generated and used to determined the positions of the pilot study participants on the spread sheet. Those selected for participation in the pilot survey included representatives from governmental agencies at the federal, state, and local levels, as well as private industry.

The pilot survey was constructed using Drupal software and was administered electronically via the UAB School of Public Health website. This survey instrument is based from previous work done by Einarsson and Rausand (1998) in analyzing the vulnerability of complex industrial systems. Detailed instructions were provided, and a glossary was created defining all constructs (system variables and system attributes). Construct definitions were provided to respondents via links from the electronic survey instrument.

Before initiating the pilot, the survey instrument was examined by SMEs to insure construct validity and reliability. A measure is considered construct valid if there is a close association between the numerical values (scores) and the investigated characteristic (or the researchers' mental representation of the investigated characteristic). Construct validity cannot be accessed directly, but content and test construction validity can be assessed by SMEs and the face validity by the pilot participants. Items are considered content valid when they are judged by SMEs to accurately reflect the domain of the construct as defined conceptually. (Schwab, 1999) Therefore, two groups of SMEs were asked to examine the pilot instrument. First, SMEs experienced in survey design and construction were asked to examine the instrument for test construction validity. Feedback on survey test construction was gained, including Likert scaling, in order to increase the survey's construct validity and reliability by reducing the possibility of systematic errors. SMEs also suggested adding demographic items to the survey that could be used to describe respondents. Items 16-21 on the electronic survey include asking respondents to identify the state in which they work, their total years of work experience, their years in current position, the type of organization for which they work, their primary job role, and whether their organization is federal, state, local, tribal, or private. It was also recommended that a pilot participant feedback form be constructed to assess face validity. Face validity is when a measure appears to be construct valid by the individuals participating in the study. (Schwab, 1999) A pilot feedback form was created, and again SMEs were asked to examine and comment. Changes based on these comments were made to the pilot feedback form before the pilot survey was administered. The final pilot participant feedback form can be found at www.soph.uab.edu/radsurvey/pilot and in Appendix C of this proposal. A second group of SMEs, all of which have extensive experience with radiological systems, provided feedback on survey constructs and construct definitions to insure content validity.

The email used to solicit participation can be found in Appendix E of this proposal. After the initial email was sent to the pilot study sample, response rates were monitored. Responses were received on days 1, 2, and 3. No responses were received on day 4. On day 5, a reminder email was sent to the pilot study sample thanking those that had already responded and asking those that had not yet responded to please consider doing so. Again, response rates were monitored, and a second reminder was sent on day 8 to the entire group. The survey was left open until the end of day fourteen.

Pilot Study Results. A response rate of 20% was achieved (N=10). Table 3 presents demographics of the respondent group. Table 4 presents the descriptive statistics of responses to each of the system domains.

A PCA was used to identify the combinations of variables that will allow a reduction in the number of variables and to identify collinearities or combinations of variables that are predictive. This is a data reduction technique that represents the directions in space that identify the most variability. All the variation can be described in a minimal set of variables that are orthogonal or stochastically independent of each other.

When used as predictor variables, the resulting regression coefficients are easily transformed into coefficients for the original variables.

PCAs were run on all 12 system domains. It was found that an average of 95% of the variation in the data was described by 2 principle components for each of the 12 system domains, allowing the number of variables to be reduced from 36 to 24. The first principle component was dominated by system interaction and system coupling. The second principle component is dominated by potential to impact. Table 5 presents the PCA results for boiling water nuclear reactors. The eigenvalues are the variances of the new variables and indicate the level of dispersion. Variables which have small dispersion (eigenvalues < 1) are generally not good predictor variables. As you can see, the eigenvalue of principle component 3 is 0.11793327, which indicated that it would not be predictive. Also note the cumulative proportion of the variation explained by each component. The first principle component explains 62.72% of the variation. The second principle component explains another 33.35% of the variation. Between the first and second principle components the cumulative proportion of the variation explained is greater than 96%, meaning that only less than 4% of the variation is not explained. The eigenvectors values (See Table 6) can be viewed as weights assigned to each original variable in the principle component. As you can see, system interactions and system coupling are equally weighted (0.707) in first principle component, while the weight of potential to impact (.007) is negligible. This infers that system interactions and system coupling dominate the first principle component. Following the same logic, the second principle component is dominated by potential to impact which has an eigenvector of 0.999. The third principle component is essentially the difference between system

Table 3: Pilot study respondent demographics

	N	*Min (yrs)*	*Max(yrs)*	*Mean (yrs)*	*Std. Dev.*
Years of work experience	10	2	33	20.75	9.373
Years in current position	10	1	21	6.35	6.174

	N (%)
State	
AL	1 (10%)
AZ	1 (10%)
CA	1 (10%)
LA	1 (10%)
MI	1 (10%)
MS	1 (10%)
NC	1 (10%)
NE	1 (10%)
SD	1 (10%)
No Response	1 (10%)
Organization	
Emergency management	3 (30%)
Nuclear Power industry	3 (30%)
Radiation control	3 (30%)
Public health	1 (10%)
Job role	
Emergency planner	3 (30%)
Health physicist	2 (20%)
Radiation control	2 (20%)
Management	1 (10%)
Operations	1 (10%)
Emergency Preparedness	1 (10%)
Organization type	
Private	3 (30%)
State	7 (70%)

Table 4: Pilot Study descriptive statistics of test constructs

	N	*Mean*	*Std. Dev.*
Pressure water reactors			
System Interaction	10	7.00	2.108
System Coupling	10	6.80	2.616
Potential to Impact	10	5.70	3.234
Boiling water reactors			
System Interaction	10	6.80	2.394
System Coupling	10	7.00	2.000
Potential to Impact	10	5.70	3.164
Nuclear Power Reactors Undergoing Decommissioning			
System Interaction	10	4.20	2.658
System Coupling	10	2.60	1.265
Potential to Impact	10	2.20	1.989
Operating non-power reactors			
System Interaction	10	5.00	1.333
System Coupling	10	4.30	.823
Potential to Impact	10	2.10	1.524
Non-power reactors undergoing decommissioning			
System Interaction	10	2.70	1.337
System Coupling	10	2.50	1.650
Potential to Impact	10	1.20	1.229
Spent fuel ponds			
System Interaction	10	3.80	1.989
System Coupling	10	4.50	2.635
Potential to Impact	10	2.80	2.741
Dry cask storage			
System Interaction	10	2.30	1.703
System Coupling	10	2.60	2.171
Potential to Impact	10	2.20	1.874
Uranium milling facilities			
System Interaction	10	4.10	2.183
System Coupling	10	4.00	2.261
Potential to Impact	10	2.30	1.418
Fuel cycle facilities			
System Interaction	10	6.00	2.828
System Coupling	10	4.90	2.558
Potential to Impact	10	2.90	1.449
Low-level waste disposal site			
System Interaction	8	2.75	2.188
System Coupling	8	2.25	1.581
Potential to Impact	8	1.38	.916
TRU waste site			
System Interaction	8	4.38	1.996
System Coupling	8	3.88	1.642
Potential to Impact	8	2.25	2.315
Active in-state licenses			
System Interaction	8	3.88	2.232
System Coupling	8	3.13	2.295
Potential to Impact	8	2.50	1.690

Table 5: Principle components analysis of boiling water reactor

Correlation Matrix

Boiling Water Reactor	*System Interaction*	*System Coupling*	*Potential to Impact*
System Interaction	1.0000	0.8817	-.0088
System Coupling	0.8817	1.0000	0.0176
Potential to Impact	-.0088	0.0176	1.0000

Eigenvalues of the Correlation Matrix

Principle Component (PC)	*Eigenvalue*	*Difference*	*Proportion*	*Cumulative*
1	1.88171642	0.88136611	0.6272	**0.6272**
2	1.00035031	0.88241705	0.3335	**0.9607**
3	0.11793327		0.0393	1.0000

Table 6: Eigenvectors of the PCA – Boiling water reactors

Eigenvectors

Boiling Water Reactor	*PC 1*	*PC 2*	*PC3*
System Interaction	**0.707037**	-0.019906	0.706897
System Coupling	**0.707142**	0.009970	-0.707001
Potential to Impact	0.007026	**0.999752**	0.021126

interactions and system coupling but, as described above, only explains less than 4% of the dispersion in the variables and is not predictive.

To increase interrater reliability, detailed instructions to pilot survey participants were provided as well as detailed construct definitions. By using intraclass correlation coefficient, it is possible to determine the amount of agreement among raters (Cronbach's alpha) and the significance of the correlation. (Macaluso, Delzell, Rose, Perkins, and Oestenstad, 1993) The raters had an alpha of .835. Cronbach's alpha equals 0 when the true score is not measured at all and there is only an error component. Alpha equals 1.0 when all items measure only the true score and there is no error component. Pedhazur and Pedhazur Schmelkin (1991) point out examples that show that adequate explanatory power falls between the .5 for exploratory research and .7 where high amounts of agreement are required. Therefore, the alpha of .835 is adequate for the purpose of this study, which is largely exploratory. The intraclass correlation is used to measure interrater reliability for two or more raters and can be used when sample size is small (<15). The ICC approaches 1.0 when there is no variance due to the raters and no residual variance to explain. The average intraclass correlation coefficient is .733. The F statistic for the average intraclass correlation was significant at p = .001.

Pilot Survey Participant Feedback. Six out of 10 pilot participants completed the survey feedback form. When asked if instructions and items were clearly stated and understandable, 100% of the respondents stated "yes." One respondent stated that "it took me a while before I understood where to find the definitions." No recommendations for changes to the instructions or items were given, but due to the comment, the instructions to the links in the survey were made clearer and more obvious. When asked if there were items on the survey that they felt are of no value, 100% of the respondents stated "no." When asked if the survey included system variables that it should not or if there were other variables that should be included, 100% of the respondents stated "no" or "N/A." When asked how useful was the glossary information used to define the constructs all responded positively (helpful, useful, very useful, absolutely necessary for the valid completion of this survey, necessary, I would have not known what you meant by system interaction or coupling…feel like I learned something). No changes were recommended to the glossary.

Study Survey. An electronic survey was administered to subject matter experts, and they were asked to rate each systems attribute (system interaction, system coupling, and potential to impact), for each of the 12 system types on an 11 point Likert scale. The study survey population consisted of past attendees of the 2007, 2008, and 2009 National Radiological Emergency Preparedness (NREP) conferences. The attendee lists of the 2007, 2008, and 2009 conference were merged into one spread sheet and duplicates were removed, retaining the most current contact information available for each participant.

Again, Institutional Review Board (IRB) approval for both the pilot and the study survey was gained from UAB's Office of Institutional Review Board for Human Use on February 20, 2009, and extended on February 19, 2010 (Protocol Number: X090219004). (See Appendix C.)

The final survey was administered electronically in November 2009. The survey can be accessed from www.soph.uab.edu/radsurvey or found in Appendix B. The survey was administered via email to the 632 past participants of NREP. The email used to solicit participation can be found in Appendix E of this proposal. After the initial email was sent to the study sample, response rates were monitored. Responses were received on days one, two, and three. No responses were received on day four. On day five, a reminder email was sent to the study sample thanking those that had already responded and asking those that had not yet responded to please consider doing so.

Event Variables

Event variables describe factors that relate to human action or technical failure. Event variables are categorized into two sub-groups according to the type of variable represented: *Reportable Event* and *Enforcement Action.*

Reportable Event. Reportable event variables represent events reported by licensees to the NRC or agreement states as required by Title 10 of the Code of Federal Regulations (10 CFR Part 20, Subpart M; 10 CFR 30.50; 10 CFR 40.60; 10 CFR 50.72; 10 CFR 70.50; 10 CFR 70.74; 10 CFR 73.71; 10 CFR 76.120, which can be found at http://www.nrc.gov/reading-rm/doc-collections/cfr/) or comparable state legislation in agreement states. In addition, nuclear power reactors have specific event notification requirements (NUREG-1022), which can be found on the NRC website at http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1022/. These requirements are binding on all persons and organizations who receive a license from the NRC or an agreement state to use source materials, special nuclear materials, and byproduct materials, or operate nuclear facilities. Examples of reportable events include the loss or theft of radioactive sources, loss of control events, incidents, accidents, medical events, and contamination events. Once events are reported, each is classified according to the NRC's emergency classification system as a *non-emergency event, unusual event, alert, site area emergency*, or a *general emergency*. A *non-emergency* event is the least critical event type while a *general emergency* is the most critical.

Most recently available archival data over a five-year period will be assessed (2003-2007) and can be found at http://www.nrc.gov/reading-rm/doc-collections/event-status/event/. From these data, numbers of reportable events by state will be determined for each emergency classification.

For the purposes of this study the following will be considered: the number of events within each emergency classification occurring within a state and the severity of the event classification. These variables will be considered when comparing across each of the states and when grouping states according to similar radiological environmental attributes.

Enforcement Actions. Enforcement action variables describe the number of enforcement actions initiated by the NRC within each state. These enforcement actions include notices of violation (NOVs) without civil penalties; NOVs with civil penalties; orders to modify, suspend, or revoke a license; and orders with civil penalties. Enforcement actions are issued by the NRC's Office of Enforcement and used as a deterrent to emphasize the importance of compliance with regulatory requirements and to encourage prompt identification and correction of violations. Enforcement authority is drawn from the AEA of 1954 and the Energy Reorganization Act (ERA) of 1974. These acts authorize the NRC to conduct inspections and investigations, to issue orders, to revoke licenses under certain circumstances, and to impose civil penalties. Following are the principle parts of Title 10 governing enforcement:

- Part 2.201 - procedures for issuing Notices of Violation
- Part 2.202 - procedures for issuing orders
- Part 2.203 - procedures for settlement and compromise
- Part 2.204 - procedures for issuing demands for information
- Part 2.205 - procedures for issuing civil penalties
- Part 2.206 - procedures for members of the public to request enforcement action under this subpart (NRC, 2007i)

The source of data will be the NRC's Office of Enforcement Annual Reports available at http://www.nrc.gov/reading-rm/doc-collections/enforcement/annual-rpts/. From this data, the number of enforcement actions (EA) by state and type will be determined over a five-year period (2003-2007).

For the purposes of this study, the greater the number of NRC significant enforcement actions issued within a state and the greater the severity of the enforcement action, the higher the radiological threat to that state. The following were considered: the number of enforcement actions issued within a state and the severity of the enforcement action. These variables were used in comparing across each of the states and in grouping states according to similar radiological environmental attributes.

The regulatory climate is similar from state to state because a common set of enforcement regulations exist and the regulatory enforcement authority is overseen by NRC's Office of Enforcement. Because regulation is time-consuming and expensive, the assumption is made that the NRC is not unfairly regulating one state versus another. This supports the appropriateness of this variable as a measure that will be included in the overall measure of radiological threat.

Creating State Clusters Based on Environmental Radiological Attributes

To group states based on environmental attributes, a principle components analysis and a hierarchical cluster analysis was employed. This clustering approach produces a hierarchical cluster by starting with each data point as a single cluster and merges the two closest clusters until a single cluster remains. (Aldenderfer and Blashfield, 1984) Similar studies, such as Reeves et al. (2003); Ford, Duncan, and Ginter

(2003); Piegorsch et al. (2007); and Borden et al. (2008), have utilized similar techniques. This approach allowed states to be grouped based on the similarity of their environmental attributes. The number of clusters was chosen in order to maximize the number of clusters with multiple members.

Assessing the Radiation Control Program

In assessing the RCP, this study defines and quantifies descriptive variables that describe the structural attributes that exist among RCPs. There were two phases to the research conducted to assess RCPs. First, data was gathered from RCPs in all 50 states by reviewing state agency websites. Because RCPs are either stand-alone state agencies or are part of a state agency, a large amount of raw data relating to the organization's activities is publically available. This same approach was used by Ford et al. (2003) in describing the structure of state health agencies. Therefore, information produced by the RCP or by the NRC, which has regulatory authority for certain functions of the RCP in agreement states and direct responsibility for certain functions in non-agreement states, was analyzed. Next, the RCPs were scored using the methodology derived by Miller and Friesen (1984a) and adapted by Reeves (1996) and Ford et al. (2003). Each RCP was scored utilizing a pre-developed coding sheet to insure consistency (See Appendix F).

Data Sources

Information that guided the development of structural organizational variables was collected from a review of each RCP website, or the website of the agency or agencies in which the RCP functions are housed, as well as the NRC website. NRC annual reports, Integrated Material Performance Evaluation Program (IMPEP) reviews, and organizational charts, as well as other relevant documents available were utilized. Variables such as the status of the state in the NRC Agreement State Program and the location of the RCP within state government are considered.

Structural Variables

Structural variable are described in terms of formalization, standardization, and centralization.

Formalization describes the amount of written documentation held by a RCP. This could include standard operating procedures, job descriptions, regulations, and policy manuals.

1. *Status in the NRC's Agreement State Program.* If a state is an agreement state then it has assumed portions of NRCs regulatory authority to license and regulate byproduct materials, source materials, and certain quantities of special nuclear materials. In becoming an agreement state, a state must submit supporting state legislation, regulations, and a program description to the NRC for review and approval. Because of this process, it can be assumed that all states that are members of the Agreement State Program will have a similar level of regulatory formulization. Therefore, this variable will be an indication of formalization and will be scored dichotomously. If a state is an agreement state it will be scored a one; if the state is a non-agreement state it will be scored a zero.
2. *Status of laws, policies and legislation.* A NRC Integrated Materials Performance Evaluation Program (IMPEP) reviews (NRC, 2004) each agreement state and

NRC Regional Office that regulates each non-agreement state on four-year cycles. The NRC IMPEP has developed non-common performance indicators to look at the status of state laws, policies, or legislation to determine if any are missing or lacking certain identified key areas. This variable represents the completeness of state laws, policies and legislation and is scored dichotomously, (1 = Satisfactory; 0 = Non-Satisfactory or Needs Improvement).

Standardization describes the extent to which similar work is performed in a uniform manner.

3. *Standardization of function* describes RCP operational attributes. This will define which of the CRCPD seven RCP operational areas/subprograms are carried out in the state. The seven operational areas or subprograms of the RCP include electronic product radiation – ionizing (x-ray), electronic product radiation – non-ionizing, radioactive materials, radon, environmental radiation surveillance and monitoring, low-level radioactive waste, and non-reactor radiological emergency response. The more functioning operational areas identified in the state, the higher the score on this variable.

Centralization describes how centralized or decentralized the functions of the RCP are within state government.

4. *Agency differentiation* concerns the organization of the RCP within state government. This variable allows the identification the number of state and federal agencies that control one or more of the operational areas or subprograms of the RCP. States who have programs that are spread across multiple agencies

will be classified as decentralized and scored as such on a dichotomous scale, (0 = decentralized; 1 = centralized).

RCP Variable Scoring

Variables were coded as dichotomous or continuous/discrete depending on the variable by the principle investigator. Dichotomous variables include 1) status in the NRC's Agreement State Program, 2) status of laws, policy, or regulations, and 3) agency differentiation (e.g., centralization). Continuous variables will be used to measure RCP standardization of function. To insure consistency in data collection between states a coding sheet was developed and used (See Appendix F).

Assessing the Association between RCPs

The final step of the study is to test the differences between the organizational variables of RCPs (independent variables) in differing radiological environments (dependent variables). This will be done by using the Pearson's chi-square significance test. The chi-square significance test will be used to test the null hypothesis that RCPs do not differ structurally in environments of differing radiological attributes. A chi-square probability of 0.05 or less is commonly interpreted as a justification for rejecting the null hypothesis.

CHAPTER 4

RESULTS

The results are organized along the same lines as the methods section. The information for all system variables licensed for operation in the U.S. was gathered and will be presented here. The survey of system attributes was completed, analyzed, and will be presented. All reported events and enforcement actions initiated or issued from 2003-2007 were collected and average rates calculated. These variables (system and event), representing the radiological environmental attributes of each state, were analyzed, and the states were grouped based on these attributes. Next, information on the organizational structure of RCPs from all 50 states was gathered and analyzed. Finally, an assessment of the association between states clustered by radiological environmental attributes and the RCP organizational variables is presented.

Radiological Environmental Attributes

Two types of variables were collected which describe the radiological attributes of a given state. This section will present these attributes as defined in the preceding chapter. These variables are categorized into two groups according to the type of variable represented: *System* and *Event.*

System

System variables attempt to describe what activities, processes, and independent systems exist within a given state that use, store, or process source materials, special nuclear materials, and byproduct materials regulated by the NRC or an agreement state. System variables are used to quantify the number of regulated systems utilizing ionizing radioactive materials in a given state, the degree to which each is susceptible to normal accidents, and the potential of each system to impact human health, environment, or the economy due to a catastrophic event.

Definitions of system variables included in this study can be found on starting on page 56. They include the following:

1. Operating nuclear power reactors – PWRs
2. Operating nuclear power reactors – BWRs
3. Nuclear power reactors undergoing decommissioning
4. Non-power (research and test) nuclear reactors
5. Non-power (research and test) nuclear reactors undergoing decommissioning
6. Independent spent fuel storage installations – Spent fuel pools
7. Independent spent fuel storage installations – Dry cask storage
8. Nuclear material facilities – Uranium milling facilities
9. Nuclear material facilities – Fuel cycle facilities
10. Low-level waste disposal sites
11. Transuranic waste sites
12. Active in-state licensees (including both specific source licensees as well as broad byproduct licensees)

Tables 7and 8 present the quantity (N) and the percentage (%) of the total of each system type by state.

There are total of 104 operating nuclear power reactors located in 31 states across the U.S. The 19 states that have neither an operating PWR nor a BWR include Alaska, Colorado, Delaware, Hawaii, Idaho, Indiana, Kentucky, Maine, Montana, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, Rhode Island, South Dakota, Utah, West Virginia, and Wyoming. Of the 104 operating nuclear power reactors, 69 are PWRs located in 26 states across the country. Of the 26 states with operating PWRs, South Carolina has the highest proportion (N=7 or 10.1% of the total operating PWRs in the U.S.). Florida is next with five active PWRs (7.2%), while California, Illinois, Texas, and Virginia have four (5.8%) active PWRs each. There are 35 operating BWRs in the U.S. located in 16 states. The highest concentration of BWRs can be found in Illinois (N=7 or, 20% of the total operating BWRs in the U.S.). Pennsylvania has six operating BWRs (17.1%). The next largest concentration can be found in Alabama and New York, each having 3 (8.6%) active BWRs.

There are 14 power reactors currently undergoing decommissioning. The highest concentrations of these are found in California, where there are four (28.6%) power reactors undergoing decommissioning; in Illinois, where there are three (21.4%); and in Pennsylvania, where there are two (14.3%). Five other states have one (7.1%) each: Connecticut, Maryland, Michigan, New York, and Wisconsin.

Non-power (research and test) reactors (N=32) are located in 22 states across the U.S. The highest concentration of non-power reactors can be found in California (N=4 or 12.5% of the total operating non-power reactors). Both Maryland and Texas have three

Table 7: Number of system variables by state - N (column %)

State	PWR	BWR	NPR Decom	R&T Reactor	R&T Reactor Decom	Fuel Ponds	Dry Cask
AL	2 (2.9)	3 (8.6)				5 (4.8)	2 (3.6)
AK							
AZ	3 (4.3)			1 (3.1)		3 (2.9)	1 (1.8)
AR	2 (2.9)					2 (1.9)	1 (1.8)
CA	4 (5.8)		4 (28.6)	4 (12.5)	4 (36.4)	4 (3.9)	4 (7.3)
CO				1 (3.1)			1 (1.8)
CT	2 (2.9)		1 (7.1)	1 (3.1)		2 (1.9)	2 (3.6)
DE	2 (2.9)	1 (2.9)				3 (2.9)	
FL	5 (7.2)			1 (3.1)		5 (4.8)	1 (1.8)
GA	2 (2.9)	2 (5.7)				4 (3.9)	1 (1.8)
HI							
ID				1 (3.1)			2 (3.6)
IL	4 (5.8)	7 (20.0)	3 (21.4)		1 (9.1)	11 (10.6)	3 (5.4)
IN				1 (3.1)			
IA		1 (2.9)				1 (0.9)	1 (1.8)
KS	1 (1.4)			1 (3.1)		1 (0.9)	
KY							
LA	1 (1.4)	1 (2.9)				2 (1.9)	1 (1.8)
ME							1 (1.8)
MD	2 (2.9)		1 (7.1)	3 (9.4)		2 (1.9)	1 (1.8)
MA		1 (2.9)			1 (9.1)	1 (0.9)	1 (1.8)
MI	3 (4.3)		1 (7.1)	1 (3.1)	1 (9.1)	3 (2.9)	2 (3.6)
MN	2 (2.9)	1 (2.9)				3 (2.9)	2 (3.6)
MS		1 (2.9)				1 (0.9)	1 (1.8)
MO	1 (1.4)			2 (6.3)		1 (0.9)	
MT							
NE	1 (1.4)	1 (2.9)			1 (9.1)	2 (1.9)	1 (1.8)
NV							
NH	1 (1.4)					1 (0.9)	1 (1.8)
NJ		1 (2.9)				1 (0.9)	3 (5.4)
NM				1 (3.1)			
NY	3 (4.3)	3 (8.6)	1 (7.1)	1 (3.1)	1 (9.1)	6 (5.8)	2 (3.6)
NC	3 (4.3)	2 (5.7)		1 (3.1)		5 (4.8)	1 (1.8)
ND							
OH	1 (1.4)	2 (5.7)		1 (3.1)	2 (18.2)	3 (2.9)	1 (1.8)
OK							
OR				2 (6.3)			1 (1.8)
PA	3 (4.3)	6 (17.1)	2 (14.3)	1 (3.1)		9 (8.7)	3 (5.4)
RI				2 (6.3)			
SC	7 (10.1)					7 (6.7)	5 (9.1)
SD							
TN	3 (4.3)					3 (2.9)	1 (1.8)
TX	4 (5.8)			3 (9.4)		4 (3.9)	
UT				1 (3.1)			1 (1.8)
VT		1 (2.9)				1 (0.9)	1 (1.8)
VA	4 (5.8)					4 (3.9)	4 (7.3)
WA		1 (2.9)		1 (3.1)		1 (0.9)	1 (1.8)
WV							
WI	3 (4.3)		1 (7.1)	1 (3.1)		3 (2.9)	1 (1.8)
WY							
Total	69 (100)	35 (100)	14 (100)	32 (100)	11 (100)	104 (100)	55 (100)

Table 8: Number of system variables by state (Continued) - N (column %)

State	U Milling Facility	Fuel Cycle	LLW	TRU	Number of Licensees
AL					455 (2.1)
AK					57 (0.3)
AZ					385 (1.8)
AR					254 (1.2)
CA					2077 (9.5)
CO					374 (1.7)
CT					191 (0.9)
DE					61 (0.3)
FL					1621 (7.4)
GA					541 (2.5)
HI					58 (0.3)
ID					83 (0.4)
IL		1 (8.3)			779 (3.6)
IN					277 (1.3)
IA					179 (0.8)
KS					313 (1.4)
KY		1 (8.3)			444 (2.0)
LA					560 (2.6)
ME					131 (0.6)
MD					671 (3.1)
MA					541 (2.5)
MI					538 (2.5)
MN					213 (1.0)
MS					325 (1.5)
MO					298 (1.4)
MT					78 (0.4)
NE	1 (5.0)				152 (0.7)
NV					278 (1.3)
NH					83 (0.4)
NJ					507 (2.3)
NM	5 (25.0)	1 (8.3)		1 (100)	207 (0.9)
NY					1554 (7.1)
NC		1 (8.3)			692 (3.2)
ND					71 (0.3)
OH		2 (16.7)			867 (4.0)
OK					269 (1.2)
OR					488 (2.2)
PA					698 (3.2)
RI					60 (0.3)
SC		2 (16.7)	1 (33.3)		384 (1.8)
SD					41 (0.2)
TN		1 (8.3)			624 (2.9)
TX					1673 (7.7)
UT	3 (15.0)		1 (33.3)		194 (0.9)
VT					38 (0.2)
VA		2 (16.7)			390 (1.8)
WA		1 (8.3)	1 (33.3)		446 (2.0)
WV					185 (0.8)
WI					371 (1.7)
WY	11 (55.0)				77 (0.4)
Total	20 (100)	12 (100)	3 (100)	1 (100)	21853 (100)

(9.4%) operating non-power reactors. Missouri, Oregon, and Rhode Island have two (6.3%) each. The remaining 16 states have one (3.1%) each as seen in Table 7.

Eleven non-power reactors are currently undergoing decommissioning in seven states across the country. The highest concentration can be found in California, where there are currently four (36.4%) non-power reactors undergoing decommissioning. Ohio has the next highest concentration, N=2 (18.2%), of non-power reactors undergoing decommissioning. Five states (Illinois, Massachusetts, Michigan, Nebraska, and New York), each have one (9.1%) non-power reactor undergoing decommissioning.

Independent spent-fuel storage installations classified as fuel storage ponds can be found in every state where there are operating PWRs and BWRs. Therefore there are 104 licensed fuel storage pond installations located in 32 states in the U.S. The highest concentration, (N=11, 10.6%) of these installations exist in Illinois. (Illinois has four operating PWRs and seven operating BWRs.) Pennsylvania is next with nine (8.7%) licensed fuel storage pond installations, followed by South Carolina with seven (6.7%), and New York with six (5.8%).

Once spent fuel rods are removed from fuel storage ponds, they are stored in dry casks. There are 55 licensed dry cask storage installations in 33 states across the U.S. The highest concentration of dry cask storage installations exists in South Carolina, where there are five or 9.1% of the total dry cask storage facilities in the U.S. Both California and Virginia have four (7.3%) each and Illinois, New Jersey, and Pennsylvania have three (5.4%) each.

There are 20 uranium milling facilities currently licensed by the NRC in the U.S. located in four different states. Wyoming has the highest concentration of these facilities

(N=11, 55.0%). New Mexico has five (25%) uranium milling facilities, while Utah has three (15%) and Nebraska has one (5%).

Currently, there are 12 fuel cycle facilities licensed by the NRC. These are facilities that enrich uranium. These facilities are spread across nine states. Ohio, South Carolina, and Virginia each have two (16.7%) fuel cycle facilities. Illinois, Kentucky, New Mexico, North Carolina, Tennessee, and Washington have one (8.3%) each.

There are three active low-level waste disposal sites licensed by the NRC in the U.S. They are located in South Carolina, Utah, and Washington and one active transuranic waste disposal site in the U.S. located in New Mexico. Transuranic waste is high-level radioactive waste produced by the DOE defense spent fuel reprocessing program in DOE facilities around the country, by commercial reprocessing operations in New York, and by nuclear power reactors.

All 50 states have licensees which use, store, process, or produce ionizing radioactive materials within the state's jurisdiction. This variable represents the number of both specific source and broad byproduct licensees held within each state. There are a total of 21,853 active licensees across the U.S. at the time of this study. Vermont has the lowest concentration of licensees, 38, or 0.2% of the total number of licensees in the U.S., while California has the highest, 2077 or 9.5%.

The total number of system types was calculated based on the number of system variables operating within a given state. This variable will represent the total number of system types being regulated by the state in NRC agreement states or by the NRC regional offices in non-agreement states. Table 9 presents the number of system types found in each state. The number of system types within states ranged from one in

Table 9: Number of system types operating in each state

Number of System Variable Types	Number of States	States
1	9	AK, DE, HI, MT, NV, ND, OK, SD, WV
2	5	IN, KY, ME, RI, WY
3	3	CO, ID, OR
4	9	AR, IA, KS, MS, MO, NH, NJ, TX, VT
5	11	AL, AZ, FL, GA, LA, MA, MN, NM, TN, UT, VA
6	4	CT, MD, SC, WI
7	6	CA, MI, NE, NC, PA, WA
8	3	IL, NY, OH

Alaska, Delaware, Hawaii, Montana, Nevada, North Dakota, Oklahoma, South Dakota, and West Virginia, to eight in Illinois, New York, and Ohio.

System Attributes. System attributes are used to determine which of the 12 radiological system types regulated by the NRC or the Agreement State pose a greater risk due to system vulnerability to the state in which they exists. For the purpose of this study, risk posed by any given system to the state in which it exists will be highly dependent on the system's vulnerability to normal accidents, as well as its potential to impact human health, environment and the economy if there is a catastrophic system failure.

In order to access system attributes, a survey was administered via email to the 632 past participants of NREP. The email used to solicit participation can be found in Appendix E of this proposal. After the initial email was sent to the study sample, response rates were monitored. Responses were received on days one, two, and three.

No responses were received on day four. On day five, a reminder email was sent to the study sample thanking those that had already responded and asking those that had not yet responded to please consider doing so. Again, response rates were monitored, and a second reminder was sent on day eight to the entire group. The survey was left open until the end of day sixteen.

A number of potential respondents (N=68 or 10.8% of the study population) decline the offer to participate in the survey. Reasons for declining participation included the following: 1) the potential respondent was involved directly in regulating one or more of the system types found in the survey and felt participation in survey was a conflict of interest, 2) supervisor would not approve participation in survey, and 3) respondent felt he or she did not have the knowledge or expertise required to respond to survey.

Survey Results. A response rate of 15.6% was achieved (N=99). Table 10 presents the demographics of the respondent group. As you can see, respondents had a mean work experience of 17.60 years, with a mean of 6.35 years in current position. Respondents represented 32 different states. Greater than 31% of the respondents work in emergency management organizations, 23.2% in the nuclear power industry, 19.2% in public health, and 18.2% within radiation control programs not within public health. Over 50% of respondents selected emergency planner as their primary job role in their organization. Another 20.2% selected health physicist and 11.1 % selected radiation control as their primary job roles within their organizations. Table 11 presents the descriptive statistics of responses to each of the system domains.

Table10: Study survey respondent demographics

	N	*Min (yrs)*	*Max(yrs)*	*Mean (yrs)*	*Std. Dev.*
Years of work experience	98	2	43	17.60	7.444
Years in current position	98	1	21	6.35	5.537

	N (%)
State	
Number of States with one or more respondents	32
No Response	1
Organization	
Emergency management	31 (31.3)
Nuclear Power industry	23 (23.2)
Public Health	19 (19.2)
Radiation control	18 (18.2)
NRC	4 (4.0)
Homeland Security	2 (2.0)
University	2 (2.0)
Job role	
Emergency planner	50 (50.5)
Health physicist	20 (20.2)
Radiation control	11 (11.1)
Administration	10 (10.1)
Engineering	2 (2.0)
Researcher	2 (2.0)
Operations	1 (1.0)
Educator	1 (1.0)
Laboratory	1 (1.0)
Regulatory Compliance	1 (1.0)
Organization type	
State	42 (42.4)
Private	26 (26.3)
Federal	17 (17.2)
County	8 (8.1)
Local	5 (5.0)
Tribal	1 (1.0)

Table 11: Descriptive statistics of survey test constructs

	N	*Mean*	*Std. Dev.*
Pressure water reactors			
System Interaction	99	7.41	2.299
System Coupling	99	6.93	2.135
Potential to Impact	99	6.81	2.940
Boiling water reactors			
System Interaction	99	7.40	2.325
System Coupling	99	6.97	2.197
Potential to Impact	99	6.71	2.918
Nuclear Power Reactors Undergoing Decommissioning			
System Interaction	99	5.21	2.529
System Coupling	99	4.97	2.501
Potential to Impact	99	3.74	2.376
Operating non-power reactors			
System Interaction	99	6.03	2.229
System Coupling	99	5.74	2.038
Potential to Impact	99	4.72	2.540
Non-power reactors undergoing decommissioning			
System Interaction	99	4.18	2.401
System Coupling	99	4.19	2.337
Potential to Impact	99	3.44	2.366
Spent fuel ponds installations			
System Interaction	99	5.06	1.878
System Coupling	99	4.82	2.017
Potential to Impact	99	4.80	2.347
Dry cask storage installations			
System Interaction	99	4.24	2.162
System Coupling	99	4.33	2.424
Potential to Impact	99	3.94	2.398
Uranium milling facilities			
System Interaction	99	4.65	2.116
System Coupling	99	4.43	2.056
Potential to Impact	99	4.09	2.186
Fuel cycle facilities			
System Interaction	99	6.34	1.933
System Coupling	99	6.05	1.763
Potential to Impact	99	5.36	2.206
Low-level waste disposal site			
System Interaction	97	3.51	1.974
System Coupling	97	3.49	2.323
Potential to Impact	97	2.78	2.152
TRU waste site			
System Interaction	97	4.96	2.136
System Coupling	97	4.54	2.250
Potential to Impact	97	3.82	2.458
Active in-state licenses			
System Interaction	97	4.59	1.754
System Coupling	97	4.11	1.898
Potential to Impact	97	4.03	2.084

The goal was to create a metric of system vulnerability to allow a comparison of systems across system types. The data for each system type was standardized for each component of system attributes (system interaction, system coupling, and potential to impact) by calculating standardized variates (zero means and unit variance) for each variable. A factor analysis, principle components analysis (PCA), was then applied to the standardized variables within each component. For the purposes of creating a system vulnerability index, the number of dimensions were reduced to only those provisional factors whose eigenvalues from the PCA were larger than 1.0. This is a standard variable reduction method, called Kaiser's criterion, used with PCA and is used in similar studies. (Borden, et al., 2008; Piegorsch, et al., 2007) The eigenvalues equate to the variance of the principle component. Therefore, since the data were previously standardized, those principle components with eigenvalues greater than one represent factors with large variances and greater explainability than the original values. The first principle component for each of the 12 system domains all had eigenvalues greater than one. (See Table 12.) The variation in the data was found to be typically between 68% and 77% in the first principle component for each of the 12 system domains, allowing the number of variables to be reduced from 36 to 12. The first principle component was dominated by all three system attributes: system interaction, system coupling, and potential to impact. The eigenvectors for the first principle component for each of the 12 system domains were used as weights or loading factors to calculate a system vulnerability index (SVI) using the following formula:

$$SVI_x = LF_{SI_x}\left(\frac{SI_x - \overline{SI_x}}{SD_{SI_x}}\right) + LF_{SC_x}\left(\frac{SC_x - \overline{SC_x}}{SD_{SC_x}}\right) + LF_{PI_x}\left(\frac{PI_x - \overline{PI_x}}{SD_{PI_x}}\right)$$

Table 12: Principle component of standardized variables by system type and resulting loading factors (LF)

	Principle Component 1		Eigenvectors of Principle Component 1		
System Types	**Eigenvalues**	**% Variance**	**System Interaction (LF$_{SI}$)**	**System Coupling (LF$_{SC}$)**	**Potential to Impact (LF$_{PI}$)**
Pressure Water Reactors	**2.051**	**68.35**	**.864**	**.864**	**.746**
Boiling Water Reactors	**2.077**	**69.24**	**.870**	**.867**	**.755**
Power Reactors Decommissioning	**2.299**	**76.63**	**.905**	**.914**	**.802**
Non-Power (R&T) Reactors	**2.208**	**73.60**	**.911**	**.864**	**.795**
Non-Power (R&T) Reactors Decommissioning	**2.336**	**77.88**	**.927**	**.921**	**.793**
Fuel Storage Ponds	**1.959**	**65.30**	**.883**	**.891**	**.620**
Dry Cask Storage	**2.331**	**77.71**	**.895**	**.920**	**.826**
Uranium Milling Facilities	**2.236**	**74.54**	**.863**	**.924**	**.765**
Fuel Cycle Facilities	**2.138**	**71.26**	**.882**	**.897**	**.746**
Low-level Waste	**2.174**	**72.41**	**.848**	**.872**	**.832**
Transuranic Waste	**2.394**	**79.80**	**.929**	**.904**	**.845**
No. of Active Licensees	**2.144**	**71.47**	**.903**	**.933**	**.677**

The SVI is a unitless measure and has importance for its comparative value across system domains. Those system domains with larger SVI, indicate those with greater system vulnerability to normal accidents and potential to impact. Table 13 presents system types ranked by the derived system vulnerability index. Fuel cycle facilities have the largest SVI (880.47), meaning that they have the highest degree of system vulnerability to normal accidents and potential to impact of the 12 system types studied. Low-level waste disposal facilities have the lowest SVI (489.0).

To increase interrater reliability, detailed instructions were provided to survey participants, as well as detailed construct definitions. By using an intraclass correlation coefficient (ICC), it is possible to determine the amount of agreement among raters (Cronbach's alpha) and the significance of the correlation. (Macaluso, et al., 1993) The raters had an alpha of .956. Cronbach's alpha equals 0 when the true score is not measured at all and there is only an error component. Alpha

Table 13: System types ranked by system vulnerability index (SVI)

System Type	*System Interaction*	*System Coupling*	*Potential to Impact*	*System Vulnerability Index*	*Percent Variance Explained*
Fuel Cycle Facilities	**323.90**	**345.67**	**210.90**	**880.47**	71.3
Pressure Water Reactors	**309.89**	**314.47**	**194.16**	**818.52**	68.4
Boiling Water Reactors	**308.19**	**308.22**	**195.42**	**811.83**	69.2
Non-Power (R&T) Reactors	**281.58**	**279.91**	**175.36**	**736.86**	73.6
Fuel Storage Ponds	**281.79**	**249.61**	**150.10**	**681.50**	65.3
No. of Active Radioactive Material Licensees	**285.33**	**233.55**	**156.90**	**675.77**	71.5
Uranium Milling Facilities	**241.63**	**231.75**	**174.60**	**647.98**	74.5
Transuranic Waste Facilities	**248.79**	**213.53**	**159.23**	**621.55**	79.8
Power Reactors Decommissioning	**220.02**	**211.70**	**156.71**	**588.42**	76.6
Dry Cask Storage Installation	**218.62**	**192.98**	**166.74**	**578.34**	77.7
Non-Power Reactors Decommissioning	**196.06**	**200.52**	**145.98**	**542.57**	77.9
Low-level Waste Disposal Facility	**191.05**	**157.52**	**140.43**	**489.00**	72.4

equals 1.0 when all items measure only the true score and there is no error component. Pedhazur and Pedhazur Schmelkin (1991) point out examples that show that adequate explanatory power falls between the .5 for exploratory research and .7 where high amounts of agreement are required. Therefore, the alpha of .956 is adequate for the purpose of this study, which is largely exploratory. The intraclass correlation is used to measure interrater reliability for two or more. The ICC approaches 1.0 when there is no variance due to the raters and no residual variance to explain. The average ICC is .955. The F statistic for the average intraclass correlation was significant at p = <.001.

Events

Event variables describe factors that relate to human action, inaction, or technical failure and include both reportable events and enforcement actions that occurred in each state from 2003 through 2007.

Reportable Events. All events reported to the NRC are classified according to the NRC's emergency classification system. From FY 2003 through FY 2007, there were 5,976 events reported to the NRC. (See Table 14.) Of those, 5,776 were classified as non-emergency events, 171 were classified as unusual events, 26 were classified as alerts, and 3 were classified as site area emergencies. No events classified as general emergencies were reported during this time period. A breakdown of these events by state can be found in Table 14. All 50 states had non-emergency events reported. The number of non-emergency events ranges from 5 (0.09% of the total number of non-emergency events) in South Dakota to 360 (6.23%) in Pennsylvania.

Twenty six states reported events classified as unusual events ranging from one (0.58%) in four states, (Iowa, Indiana, Texas, West Virginia), to 29 (16.96%) in Florida.

Fourteen states reported events classified as alerts ranging from one (3.85 %) in seven states, (Alabama, Connecticut, Missouri, Nebraska, New Jersey, New York, South Carolina), to three (11.54%) in five states, (Michigan, Ohio, Pennsylvania, Virginia, Wisconsin).

During the study period, there were only three (N=3) site area emergencies reported, and all three (100%) were reported in Illinois.

Table 14: Reportable events summary by state

State	Non-Emergency Event	Unusual Events	Alerts	Site Area Emergency	Total No. of Events	Rate of Events
Alabama	126		1		127	0.279
Alaska	10				10	0.175
Arizona	154	4			158	0.410
Arkansas	58		2		60	0.236
California	348	9			357	0.172
Colorado	72				72	0.193
Connecticut	82	8	1		91	0.476
Delaware	8				8	0.131
Florida	304	29			333	0.205
Georgia	141	9			150	0.277
Hawaii	7				7	0.121
Idaho	18				18	0.217
Illinois	316	9		3	328	0.421
Indiana	54	1			55	0.199
Iowa	73	1			74	0.413
Kansas	67				67	0.214
Kentucky	120				120	0.270
Louisiana	220	4			224	0.400
Maine	12				12	0.092
Maryland	86	3			89	0.133
Massachusetts	154				154	0.285
Michigan	166	9	3		178	0.331
Minnesota	127				127	0.596
Mississippi	73				73	0.225
Missouri	121	3	1		125	0.419
Montana	8				8	0.103
Nebraska	166	5	1		172	1.132
Nevada	43				43	0.155
New Hampshire	38	2			40	0.482
New Jersey	220	4	1		225	0.444
New Mexico	30				30	0.145
New York	245	16	1		262	0.169
North Carolina	212	8			220	0.318
North Dakota	6				6	0.085
Ohio	207	7	3		217	0.250
Oklahoma	49				49	0.182
Oregon	23				23	0.047
Pennsylvania	360	12	3		375	0.537
Rhode Island	10				10	0.167
South Carolina	215	8	1		224	0.583
South Dakota	5				5	0.122
Tennessee	78				78	0.125
Texas	353	1			354	0.212
Utah	27				27	0.139
Vermont	34	3			37	0.974
Virginia	150	3	3		156	0.400
Washington	165	4	2		171	0.383
West Virginia	15	1			16	0.086
Wisconsin	193	8	3		204	0.550
Wyoming	7				7	0.091
Total	**5776**	**171**	**26**	**3**	**5976**	

Of the total number of events reported across all emergency classifications (N=5,976), South Dakota had the minimum (N = 5 or 0.08% of the total reported events from 2003-2007), and Pennsylvania had the largest number, (N=375 or 6.28% of the total reported events from 2003-2007).

In states with high system activity and a large number of radioactive material licensees, you would expect the number of events to be higher than in states with low system activity and lower numbers of radioactive material licensees. In order to compare reportable events across states, it was first necessary to calculate a rate of events. This was done by dividing the total number of events per state by the total number of radioactive material licensees. Table 14 presents the rate of events by state. Oregon is the state with the lowest rate of reportable events (0.047), while Nebraska had the highest (1.132). Nebraska is the only state that had more reportable events (N=172) than licensees (N=152).

Enforcement Actions. The number of enforcement actions by type initiated and issued by the NRC's Office of Enforcement was determined by state from 2003 to 2007. During this time period, there were 447 total enforcement actions issued by the NRC's Office of Enforcement. These included 278 notice of violations (NOVs), 98 NOVs which imposed civil penalties, 58 orders to modify, suspend or revoke a license, and 13 orders imposing civil penalties. A breakdown of these actions by state can be found in Table 15. Forty-two states had one or more NOV's issued ranging from one (0.36%) in nine states, (Arkansas, Colorado, Connecticut, Kansas, Maine, Mississippi, North Dakota, South Dakota, Utah), to 35 (12.59%) in Pennsylvania.

Thirty (N=30) states had one or more NOV's imposing civil penalties issued ranging from one (1.02%) in ten states (Arizona, Colorado, Connecticut, Georgia, Idaho, Kentucky, Massachusetts, Minnesota, South Dakota, Utah) to nine (9.18%) in two states (Ohio, Texas).

There were 58 orders issued in 22 states. The numbers of orders issued ranged from one (1.72%) in ten states (Alabama, Florida, Illinois, Louisiana, Maine, Massachusetts, Minnesota, Oregon, Texas, Wisconsin) to eleven (18.97%) in Ohio.

Eleven states had one or more order imposing civil penalties issued. Nine states had one (7.69%) each (Alaska, California, Florida, Illinois, Kentucky, Michigan, Missouri, Texas, Virginia), and two states had two (15.38%) each (Ohio, Pennsylvania).

There were no enforcement actions initiated or issued in six states during the study period (Montana, Nevada, New Hampshire, New Mexico, Oklahoma, and Rhode Island). Of the total number of enforcement actions issued (N=447), five states, (Arkansas, Kansas, Mississippi, North Dakota, Oregon) had the lowest concentration of enforcement actions, N=1 (0.22%), and Pennsylvania had the highest, N=54 (12.08%).

In states with high system activity and a large number of radioactive material licensees, you would expect the number of enforcement actions to be higher than in states with low system activity and lower numbers of radioactive material licensees. In order to compare enforcement actions across states, it was first necessary to calculate a rate of enforcement action. This was done by dividing the total number of enforcement actions per state by the total number of radioactive material licensees. Table 15 presents the rate of enforcement actions by state. Six states (Montana, Nevada, New Hampshire, New

Table 15: Enforcement actions summary by state

State	Notice of Violation (NOV)	NOV w/Civil Penalty	Orders	Orders Imposing Civil Penalty	Total No. Enforcement Actions	Rate of Enforcement Action
Alabama	3		1		4	0.009
Alaska	3	4	2	1	10	0.175
Arizona	3	1	2		6	0.016
Arkansas	1				1	0.004
California	4	2	4	1	11	0.005
Colorado	1	1			2	0.005
Connecticut	1	1			2	0.010
Delaware	3				3	0.049
Florida	4	2	1	1	8	0.005
Georgia	4	1	2		7	0.013
Hawaii	5	2			7	0.121
Idaho	2	1			3	0.036
Illinois	16	5	1	1	23	0.030
Indiana	5	2			7	0.025
Iowa	4				4	0.022
Kansas	1				1	0.003
Kentucky		1		1	2	0.005
Louisiana	6	5	1		12	0.021
Maine	1		1		2	0.015
Maryland	4		4		8	0.012
Massachusetts	4	1	1		6	0.011
Michigan	19	6	2	1	28	0.052
Minnesota	5	1	1		7	0.033
Mississippi	1				1	0.003
Missouri	12	3	2	1	18	0.060
Montana						
Nebraska	5				5	0.033
Nevada						
New Hampshire						
New Jersey	18	7	2		27	0.053
New Mexico						
New York	15	2	5		22	0.014
North Carolina	3	3			6	0.009
North Dakota	1				1	0.014
Ohio	14	9	11	2	36	0.042
Oklahoma						
Oregon			1		1	0.002
Pennsylvania	35	7	10	2	54	0.077
Rhode Island						
South Carolina	12	3			15	0.039
South Dakota	1	1			2	0.049
Tennessee	4				4	0.006
Texas	6	9	1	1	17	0.010
Utah	1	1	2		4	0.021
Vermont	4				4	0.105
Virginia	23	6		1	30	0.077
Washington	2				2	0.004
West Virginia	7	4			11	0.059
Wisconsin	11	4	1		16	0.043
Wyoming	4	3			7	0.091
Total	**278**	**98**	**58**	**13**	**447**	

Mexico, Oklahoma, Rhode Island) had no enforcement actions occurring from 2003-2007 and therefore had enforcement rates of 0.0, while Alaska had the highest average enforcement rate (0.175).

Clustering of States by Radiological Environmental Attributes

Descriptive statistics for each system and event variable across all 50 states can be found in Table 16. Before clustering states by radiological environmental attributes, a PCA was applied to identify the combinations of variables that will allow a reduction in the number of variables and to identify collinearities or combinations of variables that will be most predictive. Table 16 shows us that not all variable types exist within all states. Therefore, it was decided that the variables representing 1) total number of active radioactive material licensees, 2) total system types, 3) total reportable events, and 4) total enforcement actions would be used initially in the PCA. This decision is based either on the fact that each state has at least one of these variable types (number of licensees, total system types, total reportable events), or because the variable represents the maximum number of the variable type across the 50 states (total enforcement actions). Once applied, the PCA allowed the reduction of the data that represented the directions in space that identified the most variability. All the variation can then be described in a minimal set of variables that are orthogonal or stochastically independent of each other. When used as predictor variables, the resulting regression coefficients are easily transformed into coefficients for the original variables and comparable to all system and event variables.

Table 16: Radiological environmental attributes: Descriptive statistics of U.S. totals

Variable Type		Variable	U.S. Mean	Std Dev	Minimum	Maximum	N*
System							
		Pressure Water Reactors	1.38	1.689	0	7	50
		Boiling Water Reactors	0.70	1.432	0	7	50
		Power Reactors Decommissioning	0.28	0.784	0	4	50
		Non-Power (R&T) Reactors	0.64	0.921	0	4	50
		Non-Power Reactors Decommissioning	0.20	0.670	0	4	50
		Fuel Storage Pond Installations	2.08	2.481	0	11	50
		Dry Cask Storage Installations	1.10	1.182	0	5	50
		Uranium Milling Facilities	0.40	1.738	0	11	50
		Fuel Cycle Facilities	0.24	0.556	0	2	50
		LLW Disposal Sites	0.06	0.240	0	1	50
		Transuranic Waste Site	0.02	0.141	0	1	50
	**	No. of Active Licensees	437.06	444.480	38	2077	50
	**	**Total System Types**	4.18	2.173	1	8	50
Reportable Events							
		Non-Emergency Events	115.52	102.880	5	360	50
		Unusual Events	3.42	5.380	0	29	50
		Alerts	0.52	0.974	0	3	50
		Site Area Emergencies	0.06	0.424	0	3	50
	**	**Total Reportable Events**	119.52	107.155	5	375	50
Enforcement Actions							
		Notice of Violations (NOV)	5.56	7.008	0	35	50
		NOV w/ Civil Penalties	1.96	2.491	0	9	50
		Orders	1.16	2.253	0	11	50
		Orders w/ Civil Penalties	0.26	0.527	0	2	50
	**	**Total Enforcement Actions**	8.94	10.931	0	54	50

* N = Number of States　　** Variables used in PCA

Table 17 presents the results of the principle components analysis. The eigenvalues equate to the variances of the principal components. Also shown is the proportion of the variability explained by each principle component and the cumulative variation explained. As you can see, principle component one has an eigenvalue of 2.82 and explains 70.58% of the variability across the original variables. Principle component two has an eigenvalue of 0.63 and explains an additional 15.64% of the variability across the original variables. The third principle component has an eigenvalue of 0.45 and explains an additional 11.23% of the original variables. Principle component four, with an eigenvalue of 0.10, accounts for another 2.55% of the variability across the original variables. Note the cumulative proportion of the variation explained by each component. Again, the first principle component explains 70.58% of the variation. The second principle component explains another 15.64% of the variation. Between the first and second principle components the cumulative proportion of the variation explained is greater than 86%, meaning that only less than 14% of the variation is not explained. The third principle component explains another 11.23 % of the variation. Between the first, second, and third principle component, the cumulative proportion of the variation explained is greater than 97%, meaning that only less than 3% of the variation is not explained. The eigenvectors (See Table 17) can be viewed as weights or loading factors assigned to each original variable in the principle component. As you can see, all four variables (number of licensees, total system types, total reportable events, and total enforcement actions) are closely weighted in first principle component. This infers that all four variables dominate the first principle component. The second principle component is essentially the difference between the sum of total enforcement actions and total system types and the sum of number of licensees and total reportable events. Following the same logic, the third principle component is essentially the difference between total number of system types and the sum of number of licensees, total enforcement actions, and total events. Principle component four only explains less than 3% of the dispersion in the variables and is not predictive.

Table 17: Principle component analysis of radiological environmental attributes

Correlation Matrix

	No. of Licensees	*Total System Types*	*Total Events*	*Total Enforcement Actions*
No. of Licensees	1.0000	0.5235	0.8102	0.3857
Total System Types	0.5235	1.0000	0.7186	0.5039
Total Events	0.8102	0.7186	1.0000	0.6610
Total Enforcement Actions	0.3857	0.5039	0.6610	1.0000

Eigenvalues of the Correlation Matrix

Principle Component (PC)	*Eigenvalue*	*Difference*	*Proportion*	*Cumulative*
1	2.82300650	2.19735651	0.7058	**0.7058**
2	0.62564999	0.17635008	0.1564	**0.8622**
3	0.44929992	0.34725632	0.1123	**0.9745**
4	0.10204359		0.0255	**1.0000**

Eigenvectors

	PC 1	*PC 2*	*PC3*	*PC4*
No. of Licensees	**0.487941**	-0.624952	0.362489	0.489847
Total System Types	**0.488076**	0.055249	-0.845383	0.209897
Total Events	**0.570627**	-0.113706	0.122385	-0.804039
Total Enforcement Actions	**0.445062**	0.770360	0.372761	0.263657

Next, a centroid hierarchical cluster analysis was run on the eigenvalues of the covariance matrix for 1) principle component one, 2) principle components one and two, 3) principle components one, two, and three and, lastly, 4) principle components one, two, three, and four. This was done so that the resulting clusters could be compared not only by distance between cluster centroids but also by the number of principle components, i.e., the cumulative variability explained in the original data. This allows us to maximize how the variation in the data is used in defining the clusters, not throwing away any of the important data. The cluster analyses produced cluster trees for 1) clustering around principle component one, 2) clustering on principle components one and two, 3) clustering on principle components one, two and three, and 4) clustering on principle components one, two, three and four. From these trees, distances of 0.3 – 0.6 between cluster centroids were compared so to maximize the variation in the data and to identify a workable number of clusters with the most explainability. From these comparisons, it was decided to use the cluster analysis of principle components one, two, and three (cumulative variation of 97.45%) at a distance of 0.4 between centroid clusters. This resulted in three distinct clusters of states. These three clusters included 39 of the 50 states. Three other small clusters were indentified as well as four outlier states that did not fit in any particular cluster. Table 18 presents the descriptive statistics of the clusters, cluster names, and comparative information for outlier states. Figure 1 presents the U.S. map coded for clusters. Clusters were named based on environmental attributes that will be presented in Tables 19-24.

Table 19 presents a view of the system variables for the first cluster. This cluster is made up of 14 states that have between 152 and 692 active radioactive material licensees (mean = 444.7). Between five and seven of the 12 system types included in this study (mean = 5.7) are regulated in each state. Total reportable events in this cluster range from 78 to 224 (mean = 156.4), and total enforcement actions range from 2 to 16 (mean = 7.1). The average event rate for this cluster is 0.425, which is relatively high. Table 23 presents clusters and outlier states sorted by average event rate. Average enforcement rate for this cluster is 0.019. From Table 24, you can see this is one of the lower enforcement action rates. Because of the quantity and system vulnerability of system types regulated by states in this cluster, and its high events rate and low enforcement rate, the cluster was named *Clear and Present Danger*.

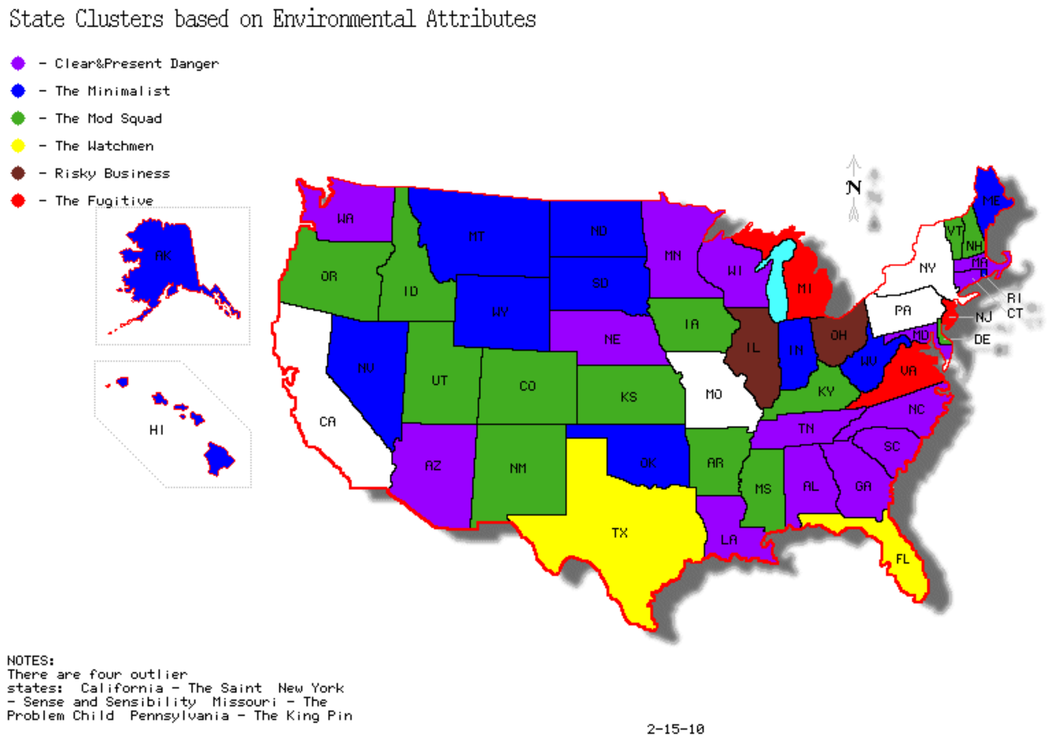
Table 18: Descriptive statistics of state clusters based on PCA of environmental attributes*

Cluster	Variable	Mean	Std Dev	Minimum	Maximum	N*
Cluster one: Clear and Present Danger						
	No. of Active Licensees	444.7	173.8	152	692	14
	Total System Types	5.7	0.8	5	7	14
	Total Reportable Events	156.4	50.1	78	224	14
	Total Enforcement Actions	7.1	4.4	2	16	14
Cluster two: The Minimalist						
	No. of Active Licensees	126.4	94.5	41	278	13
	Total System Types	1.3	0.5	1	2	13
	Total Reportable Events	18.2	18.0	5	55	13
	Total Enforcement Actions	3.8	4.0	0	11	13
Cluster three: The Mod Squad						
	No. of Active Licensees	248.5	147.9	38	488	12
	Total System Types	3.8	0.8	2	5	12
	Total Reportable Events	53.4	29.7	18	120	12
	Total Enforcement Actions	1.9	1.5	0	4	12
Cluster four: The Watchmen (FL & TX)						
	No. of Active Licensees	1647.0	36.8	1621	1673	2
	Total System Types	4.5	0.7	4	5	2
	Total Reportable Events	343.5	14.9	333	354	2
	Total Enforcement Actions	12.5	6.4	8	17	2
Cluster five: Risky Business (Il & OH)						
	No. of Active Licensees	823.0	62.2	779	867	2
	Total System Types	8.0	0.0	8	8	2
	Total Reportable Events	272.5	74.5	217	328	2
	Total Enforcement Actions	29.5	9.2	23	36	2
Cluster six: The Fugitives (MI, NJ, VA)						
	No. of Active Licensees	478.3	78.1	390	538	3
	Total System Types	5.7	1.5	4	7	3
	Total Reportable Events	186.3	35.3	156	225	3
	Total Enforcement Actions	28.3	1.5	27	30	3

	No. of Active Licensees	Total System Types	Total Reportable Events	Total Enforcement Actions
The Saint (CA)	2077	7	357	11
Sense and Sensibility (NY)	1554	8	262	22
Problem Child (MO)	298	4	125	18
King Pin (PA)	698	7	375	54

* Cluster Analysis was done on three principle components and clusters based a distance of 0.4 from cluster centroids.

Figure 1: State clusters based on environmental attributes



State Clusters based on Environmental Attributes

NOTES:
There are four outlier states: California - The Saint New York - Sense and Sensibility Missouri - The Problem Child Pennsylvania - The King Pin

2-15-10

Table 19: Cluster one – Clear and Present Danger

State	PWR*	BWR**	Power Reactor Decom	N-P (R&T) Reactor	N-P Reactor Decom	Fuel Storage Pond	Dry Cask Storage	Uranium Milling Facility	Fuel Cycle Facility	Low-Level Waste	TRU***	No. of Active Licensees	Total System Types
Alabama	2	3				5	2					455	5
Arizona	3			1		3	1					385	5
Tennessee	3					3	1		1			624	5
Georgia	2	2				4	1					541	5
Maryland	2		1	3		2	1					671	6
Massachusetts		1			1	1	1					541	5
Minnesota	2	1				3	2					213	5
Connecticut	2		1	1		2	2					191	6
Nebraska	1	1			1	2	1	1				152	7
Washington		1		1		1	1		1	1		446	7
Louisiana	1	1				2	1					560	5
South Carolina	7					7	5		2	1		384	6
Wisconsin	3		1	1		3	1					371	6
North Carolina	3	2		1		5	1		1			692	7

*Pressure Water Reactors
**Boiling Water Reactors
***Transuranic Waste Disposal Site

Avg. Rate of Events = 0.425
Avg. Rate of Enforcement Actions = 0.019

Table 20 presents a view of the system variables for the second cluster. This cluster is made up of 13 states that have between 41 and 278 active radioactive material licensees each (mean = 126.4). These states regulate one or two different system types (mean = 1.3). Total reportable events range from 5 to 55 (mean = 18.2), while enforcement actions ranged from 0 to 11 (mean = 3.8). The average event rate for this cluster is 0.131 which is the lowest of all clusters. The average enforcement action rate for this cluster is 0.046, which is relatively high. Because of the minimal system activity in the states that make up this cluster and the minimal event rate, this cluster was named *The Minimalist*.

Table 21 presents a view of the system variables for the third cluster. This cluster is made up of 12 states. Each state has between 38 and 488 active radioactive material licenses (mean = 248.5). These state regulate from 2 to 5 different systems (mean = 3.8). Total reportable events range from 18 to 120 (mean = 53.4), and total enforcement actions range from 0 to 4 (mean = 2.0). The average events rate for this cluster is 0.296, and the average rate of enforcement actions is 0.017. Because of this cluster's system activity as compared to the other clusters and because its average rates of event and enforcement actions both fall in the middle of the pack, this cluster was named *The Mod Squad* for its moderate standing.

Table 22 presents a view of the three remaining clusters and the four outlier states (California, New York, Missouri, and Pennsylvania).

The fourth cluster is made up of two states: Florida and Texas. Florida has 1621 active radioactive material licensees, while Texas has 1673 (mean = 1647.0). Both regulate four or five system types. Both states have four or five PWRs

Table 20: Cluster two – The Minimalist

State	PWR*	BWR**	Power Reactor Decom	R&T Reactor	R& T Reactor Decom	Fuel Storage Pond	Dry Cask Storage	Uranium Milling Facility	Fuel Cycle Facility	Low-Level Waste	TRU***	No. of Active Licensees	Total System Types
Alaska												57	1
Hawaii												58	1
West Virginia												185	1
Wyoming								11				77	2
Indiana				1								277	2
Maine							1					131	2
Rhode Island				2								60	2
Montana												78	1
North Dakota												71	1
South Dakota												41	1
Nevada												278	1
Delaware												61	1
Oklahoma												269	1

*Pressure Water Reactors
**Boiling Water Reactors
***Transuranic Waste Disposal Site

Avg. Rate of Events = 0.131
Avg. Rate of Enforcement Actions = 0.046

Table 21: Cluster three – The Mod Squad

State	PWR*	BWR**	Power Reactor Decom	R&T Reactor	R& T Reactor Decom	Fuel Storage Pond	Dry Cask Storage	Uranium Milling Facility	Fuel Cycle Facility	Low-Level Waste	TRU***	No. of Active Licensees	Total System Types
Arkansas	2					2	1					254	4
Kansas	1			1		1						313	4
Mississippi		1				1	1					325	4
Iowa		1				1	1					179	4
New Mexico				1				5	1		1	207	5
Utah				1			1	3		1		194	5
Vermont		1				1	1					38	4
New Hampshire	1					1	1					83	4
Idaho				1			2					83	3
Colorado				1					1			374	3
Oregon				2			1					488	3
Kentucky									1			444	2

*Pressure Water Reactors
**Boiling Water Reactors
***Transuranic Waste Disposal Site

Avg. Rate of Events = 0.296
Avg. Rate of Enforcement Actions = 0.017

Table 22: Clusters four, five, six and outlier states

Cluster	States	PWR*	BWR**	Power Reactor Decom	R&T Reactor	R& T Reactor Decom	Fuel Storage Pond	Dry Cask Storage	Uranium Milling Facility	Fuel Cycle Facility	LLW	TRU	No. of Active Lic.	Total System Types	Avg. Rate of Event	Avg. Rate of Enf. Action
Cluster 4 – The Watchmen															0.209	0.008
	Florida	5			1		5	1					1621	5		
	Texas	4			3		4						1673	4		
Cluster 5 – Risky Business															0.336	0.036
	Illinois	4	7	3		1	11	3		1			779	8		
	Ohio	1	2		1	2	3	1		2			867	8		
Cluster 6 – The Fugitive															0.392	0.061
	Michigan	3		1	1	1	3	2					538	7		
	New Jersey	2	2				4	3					507	5		
	Virginia	4					4	4		2			390	5		
The Saint																
	California	4		4	4	4	4	4					2077	7	0.172	0.005
Sense and Sensibility																
	New York	3	3	1	1	1	6	2					1554	8	0.169	0.014
Problem Child																
	Missouri	1			2		1						298	4	0.419	0.060
King Pin																
	Pennsylvania	3	6	2	1		9	3					698	7	0.537	0.077

*Pressure Water Reactors
**Boiling Water Reactors
***Transuranic Waste Disposal Site

and fuel storage ponds. Both states have non-power (R&T) reactors. Looking across the system variables, Florida and Texas look very similar. The average rate of events for this cluster is 0.209. The average rate of enforcement actions is 0.008, which is comparably low. Because of the large amount of system activity within these states, but the relative low rate of events and enforcement actions, this cluster has been named *The Watchmen*.

The fifth cluster is also made up of two states: Illinois and Ohio. Looking at the number and types of systems regulated, as seen in Table 22, you can see that they appear very similar. Both states have pressure and boiling water reactors with fuel storage pond installations. Both have dry cask storage installations. Both have fuel cycle facilities. Illinois has 779 active radioactive material licensees, while Ohio has 867 (mean = 823.0). Both states regulate 8 of the 12 system types included in this study. The average rate of events for this cluster is 0.336, and the average rate of enforcement actions is 0.036. Because of the high number of systems regulated in these states (eight system types in each state), the large number of nuclear power reactors (Illinois = 11, Ohio = 3), the relatively high number of radioactive material licensees comparably (mean = 823.0), and its moderate average rates of events and enforcement actions, this cluster has been named *Risky Business*.

The sixth cluster includes three states: Michigan, New Jersey, and Virginia. These states have between 390 and 538 active radioactive material licensees (mean = 478.3), and each state regulates been 5 and 7 system types (mean = 5.7). Looking at Table 22 there are some obvious system similarities. Rates of events and enforcement actions are also very similar (See Tables 14 & 15.) For the cluster, the average rate of events is 0.392, and the average rate of enforcement actions is 0.061. This cluster has one of the highest average rates of enforcement; therefore this cluster was named *The Fugitive*.

California has the highest number of active radioactive material licensees (N=2077) and regulated seven different system types in the state. System activity is high, four PWRs, four power reactors undergoing decommissioning, four non-power (R&T) reactors, four non-power reactors undergoing decommissioning, four fuel storage pond installations, and four dry cask storage installations. California's rate of events is 0.172, and its rate of enforcement actions is 0.005. Because of the high system activity but low event and enforcement rates, this state was named *The Saint*.

New York also has high system activity. Within New York there are three pressure water reactors, three boiling water reactors, one power reactor undergoing decommissioning, one non-power (R&T) reactor, one R&T reactor undergoing decommissioning, six fuel storage pond installations, two dry cask storage installation, and 1554 active radioactive material licensees. New York's rate of events is one of the lowest, 0.169, as is its rate of enforcement actions, 0.014. New York does not have as many radioactive material licensees as does California, but New York regulates one more system type than does California. Because of this and its relatively sensible rates of events and enforcement actions, the state was named *Sense and Sensibility*.

Missouri has low system activity as compared to the other outlier states. Missouri has only 298 active radioactive material licensees and only four system types, which include one PWR and one R&T reactor. However, Missouri's rate of events (0.419) and enforcement actions (0.060) are some of the highest. Therefore, Missouri was named *The Problem Child*.

Pennsylvania has relative high system activity, but only 698 active radioactive material licensees. Pennsylvania does have nine total nuclear power reactors, two others that are undergoing decommissioning at the present time, and one active non-power reactor in the state. What is interesting is Pennsylvania's rate of events (0.537) and enforcement actions (0.077). They are the highest as compared across the clusters and outlier states. Therefore, Pennsylvania was named *The King Pin*.

Table 23 presents each of the clusters and outlier states described above sorted by average rate of events. Table 24 presents the same clusters and outlier states sorted by average rate of enforcement action.

The Radiation Control Program

A review of each state's RCP and the NRC website was conducted. In some cases, state agency websites were reviewed also. Using the coding sheet found in Appendix F, variables representing the organization structure in terms of formalization, standardization of function, and centralization were collected.

Formalization

Two variables were collected that represent the formalization of the RCP: Status of the state in the NRC's Agreement State Program and status of regulations and legislation as reported on each agreement states IMPEP review. Both were coded dichotomously and a breakdown by state can be found in Figures 2 and 3. There are 37 agreement states and 13 non-agreement states. Agreement states were assigned the value of one while non-agreement states were assigned a value of zero. Of the 37

Table 23: Sorted by average rate of events

Cluster	Average Rate of Events	Average Rate of Enforcement
The Minimalist	0.131	0.046
Sense & Sensibility – NY	0.169	0.014
The Saint – CA	0.172	0.005
The Watchman – FL, TX	0.209	0.008
The Mod Squad	0.296	0.017
Risky Business – IL, OH	0.336	0.036
The Fugitive – MI, NJ, VA	0.392	0.061
Problem Child – MO	0.419	0.060
Clear & Present Danger	0.425	0.019
King Pin – PA	0.537	0.077

Table 24: Sorted by average rate of enforcement actions

Cluster	Average Rate of Events	Average Rate of Enforcement
The Saint – CA	0.172	0.005
The Watchmen – FL, TX	0.209	0.008
Sense & Sensibility – NY	0.169	0.014
The Mod Squad	0.296	0.017
Clear & Present Danger	0.425	0.019
Risky Business – IL, OH	0.336	0.036
The Minimalist	0.131	0.046
Problem Child – MO	0.419	0.060
The Fugitive – MI, NJ, VA	0.392	0.061
King Pin – PA	0.537	0.077

agreement states, 28 received a satisfactory review of the non-common performance indicator status of state laws, policies, and regulations on its last IMPEP review as of 2009. Nine agreement states received a non-satisfactory or needs improvement on the review. If an agreement state had a satisfactory IMPEP review they were assigned a value of one. If an agreement state did not get a satisfactory review or if the state is a non-agreement state, it was assigned a value of zero.

Figure 2: Agreement state status

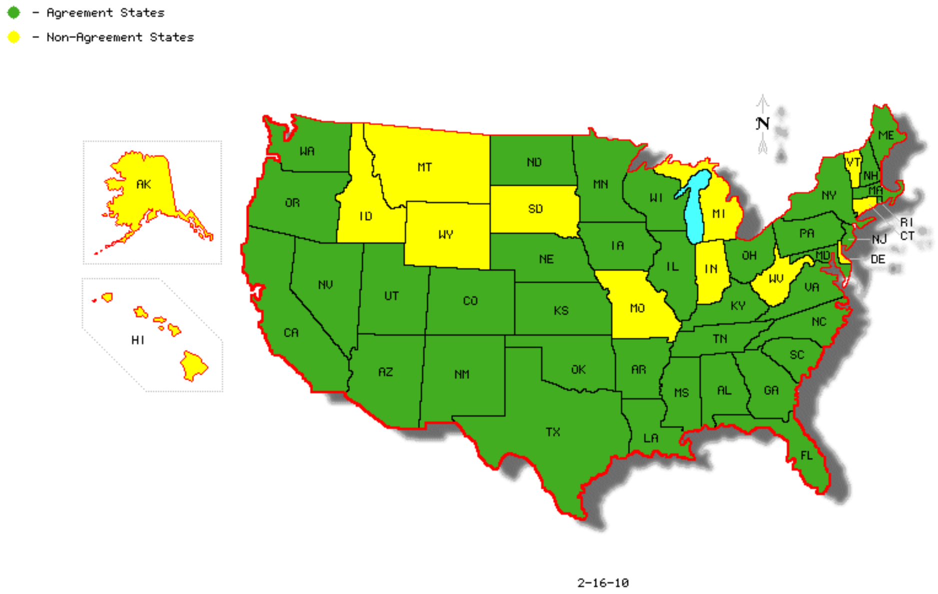
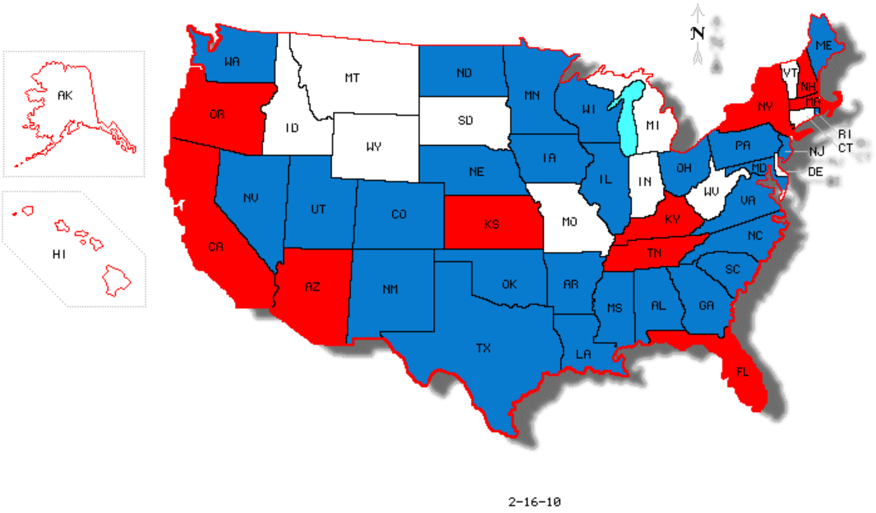


Figure 3: Status of laws, policies, and legislation

Blue = Agreement State - Satisfactory
Red = Agreement State - Not Satisfactory
White = Non-agreement State

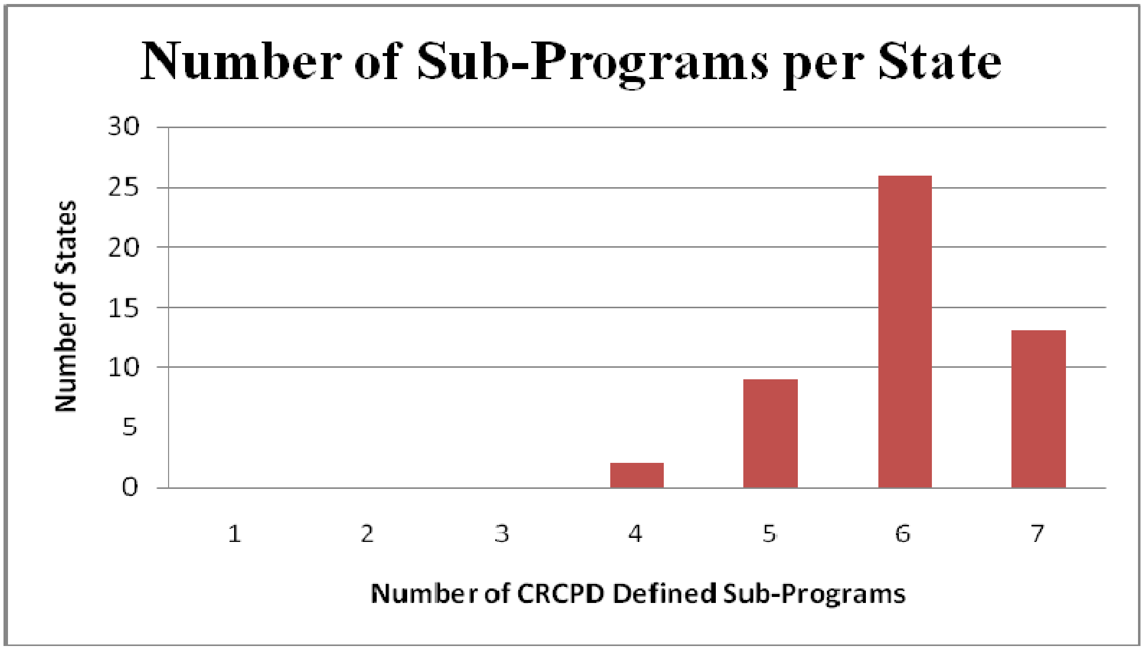


Standardization of Function

Standardization of function describes the extent to which similar work is performed in a uniform manner. This variable defines which of the CRCPD seven RCP operational subprograms/functions are carried out in each state. Appendix G provides a breakdown of which functions are available in each state, if the function is housed within a single agency or split between two or more agencies, and what agencies are involved in each RCP function. For example, if you look at Alabama, there are six of the seven RCP operational functions or subprograms carried out in the state. Of those, four are housed completely within the Alabama Department of Public Health (ADPH) (i.e., EPR-Ionizing, Radioactive Materials, Radon, Environmental Surveillance and Monitoring), and two are split between agencies (i.e., Low-level Waste is split between the ADPH and the Alabama Department of Economic and Community Affairs, Energy Division; Non-reactor Emergency Response is split between the ADPH and the Alabama Emergency Management Agency). This breakdown can be found for all 50 states in Appendix G. Figure 4 shows us that states have between four and seven of the radiation control subprograms. Table 25 provides a summary of function availability. Table 26 provides a summary of where each of these functions are housed within state agency structure. Definitions for each of the operational functions of the RCP can be found in Chapter 2.

Electronic Product Radiation (EPR) – Ionizing. Forty-nine (49) states have active EPR-ionizing (x-ray) subprograms. In 48 of these states, this operational subprogram is housed within a single agency (i.e., 37 states housed within state public health agency,

Figure 4: Number of CRCPD-defined RCP subprograms found per state



nine states in state environmental agency, one state in state emergency management agency, and one state in a standalone state agency for radiation control). In New York, the EPR-ionizing subprogram is housed partly within the state public health agency and partly within a city public health agency.

Electronic Product Radiation (EPR) – Non-ionizing. EPR – Non-ionizing subprograms exist within 18 states across the country. All 18 of these subprograms are housed within a single agency, nine of those within the state public health agency. Of the remaining nine, four are housed within the state environmental agency, one within the state emergency management agency, one within a standalone state agency for radiation control, and three within other agency types (i.e., Departments of Agriculture-Wyoming, Labor-New York and Consumer Affairs-California).

Table 25: Number of states with availability of each radiation control function

Radiation Control Functions	(Number of States)	Availability	Function within single agency
	1 – Electronic Product Radiation – Ionizing (x- ray)	49	48
	2 – Electronic Product Radiation - Non-ionizing	18	18
	3 - Radioactive Materials	50	36
	4 - Radon	49	49
	5 – Environmental Radiation Surveillance and Monitoring	38	38
	6 - Low-level Radioactive Waste	48	43
	7 – Non-reactor Radiological Emergency Response	47	40

Radioactive Material. The Radioactive Material subprogram can be found in all 50 states. In 36 states, this subprogram is housed within a single agency. Of those housed within a single agency, 24 are completely within the state public health agency, while an additional 10 states have the program partially within the state public health agency. Ten states house the Radioactive Materials subprogram completely within the environmental quality/management agency, while three additional states have the program only partially within the environmental agency. One state houses this subprogram completely with the emergency management agency and one completely within its standalone state agency for radiation control.

Radon. Forty-nine states have active radon subprograms. All 49 of these subprograms are housed within a single state agency. In 32 states, these subprograms are

Table 26: Number of states with radiation control functions within each type agency

		Agency								
	(Numbers of States)	**Public Health**	**ENV**	**EMA**	**Stand-Alone State Agency**	**Other**	**Split with Public Health**	**Split with ENV**	**Split Other**	**Total**
FUNCTIONS	**1 – Electronic Product Radiation - Ionizing**	37	9	1	1	0	1	0	0	**49**
	2 – Electronic Product Radiation - Non-ionizing	9	4	1	1	3	0	0	0	**18**
	3 - Radioactive Materials	24	10	1	1	0	10	3	1	**50**
	4 – Radon	32	12	1	1	3	0	0	0	**49**
	5 - Environmental Radiation Surveillance and Monitoring	22	14	1	1	0	0	0	0	**38**
	6 - Low-level Radioactive Waste	14	23	1	1	4	4	1	0	**48**
	7 – Non-reactor Radiological Emergency Response	22	13	2	1	2	5	2	0	**47**

housed within the state public health agency. Of the remaining states, 12 states house their radon subprogram within the state environmental agency, one within emergency management, and one within a standalone agency for radiation control. The three remaining states housed their programs within other entities, such as the state's Department of Community Affairs (Georgia) and within public universities (Arkansas & Kansas).

Environmental Radiation Surveillance and Monitoring. Thirty-eight states have formal environmental radiation surveillance and monitoring subprograms. All 38 are housed within a single agency, with 22 of those being within the state public health agency, 14 within the state environmental agency, one within emergency management, and one within its states standalone agency for radiation control.

Low-level Radioactive Waste (LLW). Forty-eight states have formal LLW subprograms. Forty-three of these subprograms are housed within a single agency, 14 within the state public health agency, 23 within the state environmental agency, one within emergency management, and one within a standalone state agency for radiation control. Four other LLW subprograms are housed completely within other agency types, such as the Minnesota Pollution Control Agency, the Oregon Department of Energy, the Washington Department of Ecology, and the Wisconsin Department of Administration. Five other states have LLW subprograms that are split between agencies. Four are partly housed within the state public health agency and one is partly housed within the state environmental agency.

Non-reactor Radiological Emergency Response. Forty-seven states have some type of subprogram addressing non-reactor emergency response. Of these, 40 states have this subprogram housed within a single agency (i.e., 22 within the state public health agency, 13 within the state environmental agency, two within the state emergency management agency, one within the state standalone agency for radiation control, and two within other agency types such as the Maine Department of Public Safety and the New Jersey Department of Laws and Public Safety. Of the seven states that split this subprogram, Alabama, Massachusetts, Ohio, and Virginia have their subprogram split between the state public health agency and the state emergency management agency; Oregon splits its subprogram between the state public health agency and the state department of energy; Georgia splits it subprogram between the state environmental agency and the state emergency management agency; and Michigan between its state environmental agency and the Michigan State Police.

Centralization

Centralization concerns the organization of the RCP within state government. This variable differentiates between RCP programs that are centralized versus those that are decentralized. For the purpose of this study, a centralized agency was defined as one in which only one state agency is involved in the RCP functions or as one in which only two agencies are involved in the RCP functions and no one function is shared or split between agencies. Table 27 provides a summary.

There are 24 states whose RCPs meet the above definition of centralization. Of those, 15 states have only one state agency involved in the RCP (state highlighted gray on

Table 27: Number of radiation control functions by state

State	Number of Radiation Control Functions Available	Number of Functions W/in a Single Agency	Number of Functions Split Between Agencies	Number of Functions located completely or partially within Primary Agency	Primary Agency	Number of Agencies/Orgs Involved with Radiation Control Functions
Alabama	6	4	2	6	Public Health	3
Alaska	6	5	1	3	Public Health	4
Arizona	7	7	0	7	ARRA*	1
Arkansas	5	4	1	5	Public Health	2
California	7	7	0	7	Public Health	1
Colorado	6	6	0	6	Public Health	1
Connecticut	6	4	2	5	Environmental	3
Delaware	5	4	1	4	Public Health	3
Florida	7	7	0	7	Public Health	1
Georgia	6	5	1	4	Environmental	4
Hawaii	6	5	1	6	Public Health	2
Idaho	6	5	1	4	Environmental	3
Illinois	7	7	0	7	Emergency Mgmt	1
Indiana	6	5	1	5	Public Health	3
Iowa	7	7	0	6	Public Health	2
Kansas	6	6	0	5	Public Health	2
Kentucky	6	6	0	6	Public Health	1
Louisiana	6	6	0	6	Environmental	1
Maine	7	7	0	6	Public Health	2
Maryland	5	5	0	5	Environmental	1
Massachusetts	6	5	1	6	Public Health	2
Michigan	6	4	2	5	Environmental	4
Minnesota	6	6	0	5	Public Health	2
Mississippi	7	7	0	6	Public Health	2
Missouri	6	5	1	4	Public Health	3
Montana	4	3	1	3	Public Health	3
Nebraska	6	5	1	6	Public Health	2
Nevada	6	6	0	5	Public Health	2
New Hampshire	5	5	0	4	Public Health	2
New Jersey	7	6	1	6	Environmental	3
New Mexico	6	6	0	6	Environmental	1
New York	7	5	2	4	Public Health	4
North Carolina	7	7	0	7	Environmental	1
North Dakota	6	6	0	6	Public Health	1
Ohio	6	5	1	6	Public Health	2
Oklahoma	7	6	1	7	Environmental	2
Oregon	5	4	1	4	Public Health	2
Pennsylvania	6	6	0	6	Environmental	1
Rhode Island	5	4	1	5	Public Health	2
South Carolina	6	6	0	6	Public Health	1
South Dakota	5	4	1	2	Public Health	2
Tennessee	6	6	0	6	Environmental	1
Texas	7	6	1	5	Public Health	3
Utah	6	6	0	6	Environmental	1
Vermont	5	4	1	4	Public Health	3
Virginia	6	5	1	5	Public Health	3
Washington	6	6	0	5	Public Health	2
West Virginia	5	4	1	5	Public Health	2
Wisconsin	7	7	0	6	Public Health	2
Wyoming	4	3	1	1	Homeland Security	5
Average	6	5.4	0.6	5.24		2.14

*Arizona Radiation Regulatory Agency

Centralized	One Agency involved in radiation control functions
Centralized	Two Agencies involved in radiation control functions and no functions shared or split
Decentralized	Two Agencies involved in radiation control functions with one or more function housed within two or more agencies or three or more agencies involved in radiation control functions

Table 27). The other nine states have two state agencies involved in the RCP, but none of the functions of the RCP are split between those agencies (state highlighted blue on Table 27). The other 26 states RCP's were coded as decentralized.

Assessing the Association between RCPs

The final step of the study is to test the differences between the organizational variables of RCPs (independent variables) in differing radiological environments (dependent variables). A chi-square significance test was used to test the null hypothesis that RCPs do not differ structurally in environments of differing radiological attributes. Table 28 presents the cluster averages of agreement state status; law, policy and legislation status; standardization of function; and centralization for each of the three predominate clusters, as well as the three smaller clusters and outlier state.

A chi-square significance test were completed across each of the organizational structural variable domains for the three dominate clusters: Clear and Present Danger (N=14), The Minimalist (N=12), and The Mod Squad (N=13). Because the remaining clusters all have small N values, they were omitted from this analysis.

Table 29 presents the chi-square test for the variable Agreement State Status which, for the purposes of this study, is a measure of formalization. As you can see, the chi-square test completed across all three clusters shows a significant difference (p=.014). When the clusters were compared pairwise, there were significant differences between Clear and Present Danger and The Minimalist (p=.005), but not between Clear and Present Danger and The Mod Squad (p=.244), or between The Minimalist and The Mod Squad (p=.072).

Table 28: Descriptive statistics of organizational variables by cluster and outlier states

	Within Cluster Averages				
Clusters and Outlier States	*Agreement State Status*	*Law/Regulation Status*	*Standardization of Function*	*Centralization*	*No. of Agencies*
Clear & Present Danger	**0.93**	**0.71**	**6.14**	**0.57**	**1.86**
The Minimalist	**0.42**	**0.42**	**5.58**	**0.25**	**2.5**
The Mod Squad	**0.77**	**0.46**	**5.77**	**0.62**	**1.92**
The Watchmen – FL, TX	**1.00**	**0.50**	**7.00**	**0.50**	**2.00**
Risky Business- IL, OH	**1.00**	**1.00**	**6.50**	**0.50**	**1.50**
The Fugitive – MI, NJ, VA	**0.67**	**0.67**	**6.33**	**0.00**	**3.33**
The Saint – CA	**1.00**	**0.00**	**7.00**	**1.00**	**1.00**
Sense and Sensibility – NY	**1.00**	**0.00**	**7.00**	**0.00**	**4.00**
The Problem Child – MO	**0.00**	**0.00**	**6.00**	**0.00**	**3.00**
King Pin - PA	**1.00**	**1.00**	**6.00**	**1.00**	**1.00**

Table 29: Agreement state status – Chi-Square significance test

Cluster	**Non-Agreement State**	**Agreement State**
Clear and Present Danger		
Frequency	1	13
Row Percent	7.14	92.86
The Minimalist		
Frequency	7	5
Row Percent	58.33	41.67
The Mod Squad		
Frequency	3	10
Row Percent	23.08	76.92
Total Number of States	**11**	**28**

Statistic	**DF**	**Value**	**Probability**
Chi-Square	2	8.6149	**0.0135**

Pairwise Comparisons Between:	**Statistic**	**DF**	**Value**	**Probability**
Clear and Present Danger **The Minimalist**	Chi-Square	1	1.3561	**0.0048**
Clear and Present Danger **The Mod Squad**	Chi-Square	1	7.9487	**0.2442**
The Minimalist **The Mod Squad**	Chi-Square	1	3.2318	**0.0722**

A chi-square test for the Status of Laws, Policies, and Legislation showed no significant difference over the three clusters (p=.251). (See Table 30.) When compared pairwise, no significant differences were seen (Clear and Present Danger and The Minimalist [p=.126], Clear and Present Danger and The Mod Squad [p=.182], The Minimalist and The Mod Squad [p=.821]).

Table 30: Regulatory status – Chi-Square significance test

Cluster	Unsatisfactory	Satisfactory
Clear and Present Danger		
Frequency	4	10
Row Percent	28.57	71.43
The Minimalist		
Frequency	7	5
Row Percent	58.33	41.67
The Mod Squad		
Frequency	7	6
Row Percent	53.85	46.15
Total Number of States	**18**	**21**

Statistic	DF	Value	Probability
Chi-Square	2	2.7673	**0.2507**

Pairwise Comparisons Between:	Statistic	DF	Value	Probability
Clear and Present Danger **The Minimalist**	Chi-Square	1	2.3449	**0.1257**
Clear and Present Danger **The Mod Squad**	Chi-Square	1	1.7836	**0.1817**
The Minimalist **The Mod Squad**	Chi-Square	1	0.0510	**0.8213**

Next, a chi-square test were completed over the three clusters for Standardization of Function and presented in Table 31. Standardization of Function tells us how many of the seven CRCPD radiation control subprograms are available within the states. No significant difference was see over the three clusters (p=.183) or for any comparisons made pairwise, (Clear and Present Danger and The Minimalist [p=.192], Clear and Present Danger and The Mod Squad [p=.147], The Minimalist and The Mod Squad [p=.465]).

Table 31: Standardization of function – Chi-Square significance test

Cluster	4	5	6	7
Clear and Present Danger				
Frequency	0	1	10	3
Row Percent	0.00	7.14	71.43	21.43
The Minimalist				
Frequency	2	3	5	2
Row Percent	16.67	25.00	41.67	16.67
The Mod Squad				
Frequency	0	5	6	2
Row Percent	0.00	38.46	46.15	15.38
Total Number of States	2	9	21	7

Statistic	DF	Value	Probability
Chi-Square	6	8.8231	**0.1838**

Pairwise Comparisons Between:	Statistic	DF	Value	Probability
Clear and Present Danger **The Minimalist**	Chi-Square	3	4.7409	**0.1918**
Clear and Present Danger **The Mod Squad**	Chi-Square	2	3.8349	**0.1470**
The Minimalist **The Mod Squad**	Chi-Square	3	2.5550	**0.4654**

Table 32 presents the chi-square analysis for variables of Centralization. This variable concerns the organization of the RCP within state government and allows for the identification of the number of state and federal agencies involved in one or more of the operational areas or subprograms of the RCP. There were no significant differences seen for the chi-square test over the three clusters (p=0.138). Pairwise comparisons also show no significant differences (Clear and Present Danger and The Minimalist [p=.098], Clear and Present Danger and The Mod Squad [p=.816], The Minimalist and The Mod Squad [p=.066]).

Table 32: Centralization – Chi-Square significance test

Cluster	Decentralization	Centralization
Clear and Present Danger		
Frequency	6	8
Row Percent	42.86	57.14
The Minimalist		
Frequency	9	3
Row Percent	75.00	25.00
The Mod Squad		
Frequency	5	8
Row Percent	38.46	61.54
Total Number of States	20	19

Statistic	DF	Value	Probability
Chi-Square	2	3.9550	**0.1384**

Pairwise Comparisons Between:	Statistic	DF	Value	Probability
Clear and Present Danger **The Minimalist**	Chi-Square	1	2.7351	**0.0982**
Clear and Present Danger **The Mod Squad**	Chi-Square	1	0.0539	**0.8163**
The Minimalist **The Mod Squad**	Chi-Square	1	3.3810	**0.0660**

And finally, a chi-square test was completed for the number of agencies involved in the RCP functions across the three largest clusters and are presented in Table 33. Again, no significant difference was seen (p=0.530). No significant differences were seen in the pairwise comparisons (Clear and Present Danger and The Minimalist [p=.311], Clear and Present Danger and The Mod Squad [p=.530], The Minimalist and The Mod Squad [p=.400]).

Table 33: Number of Agencies Involved in RCP – Chi-Square Significance Test

Cluster	**1**	**2**	**3**	**4**	**5**
Clear and Present Danger					
Frequency	6	5	2	1	0
Row Percent	42.86	35.71	14.29	7.14	0.00
The Minimalist					
Frequency	1	7	2	1	1
Row Percent	8.33	58.33	16.67	8.33	8.33
The Mod Squad					
Frequency	4	6	3	0	0
Row Percent	30.77	46.15	23.08	0.00	0.00
Total Number of States	11	18	7	2	1

Statistic	**DF**	**Value**	**Probability**
Chi-Square	8	7.0662	**0.5295**

Pairwise Comparisons Between:	**Statistic**	**DF**	**Value**	**Probability**
Clear and Present Danger **The Minimalist**	Chi-Square	4	4.7792	**0.3107**
Clear and Present Danger **The Mod Squad**	Chi-Square	3	7.0662	**0.5295**
The Minimalist **The Mod Squad**	Chi-Square	4	4.0434	**0.4002**

CHAPTER 5

CONCLUSIONS, IMPLICATIONS, AND LIMITATIONS

The primary objective of this study was to test the hypothesis that state RCPs differ structurally in environments of differing radiological attributes. This study was exploratory in nature, and data was limited to what is available in the public domain.

The first stage of this research involved collecting information on the types and numbers of radiological systems regulated by the NRC or an agreement state (See Tables 7 and 8). Following Normal Accident Theory, systems were classified based on system vulnerability to normal accidents and their potential to impact human health, environment, and economy if a system failure were to occur. Table 13 presents the levels of system interactive complexity, system coupling, and potential to impact for each of the twelve system variables. Fuel cycle facilities ranked highest for all three system attributes as well as for overall system vulnerability. Information was also collected that categorized reportable events and enforcement actions that occurred in each state from 2003 through 2007.

The second stage of this research then grouped states according to these attributes and represented the environmental variables of the RCP. Three predominate clusters were identified along with three smaller clusters and four outlier states. Each cluster and outlier was described by its system and event attributes.

In the third stage, information on the formalization, standardization of function and centralization of state RCPs was collected. There are 37 Agreement States and 13 Non-agreement States. Twenty-seven states were determined to have satisfactory status of laws, policies, and regulations. There were between four and seven subprograms of radiation control active within each of the 50 states, and 24 of the states were determined to have centralized RCP programs.

Finally, differences between the organizational variables of RCPs (independent variables) in differing radiological environments (dependent variables) were determined to test the core hypothesis. Chi-square significant testing was completed across the three larger clusters. Included in these clusters were 39 out of the 50 states. The results of the forgoing test failed to reject the null hypothesis that RCPs do not differ structurally in environments of differing radiological attributes in all but one aspect of organizational structure, formalization. Formalization, the amount of regulation and legislation in place to guide radiation control activities, was found to be significantly different across the three predominate clusters. States with higher system and event activity have higher levels of formalization. Higher system and event activity may not, however, indicate RCP levels of centralization or standardization of function. When looking at the pairwise comparisons made between clusters, it should be noted that there are trends between *The Minimalist* and the other two clusters, *Clear and Present Danger* and *The Mod Squad*, that suggest that there are differences not only in Agreement State Status but also in centralization. Though these differences are not considered statistically significant when compared to a p value of 0.05, they are less than 0.1. Because of the lack of power in the study, these trends are important and should be discussed. Failure to reject the null hypothesis might well be attributable not only to lack of power, but also to a number of limitations in both the availability of data and the constraints this imposed on the research executed. Therefore, we must be careful not to accept the null hypothesis as true.

The methodology used in this study is new to researching a division of a larger organization, although it has been frequently used in general and health services organizational studies. However, it is apparent from the work done here that the methodology can provide insights into understanding the structure and environment of unique programs within a larger agency. These insights can then lead to clearer planning assumptions for all states, potentially reducing duplication of efforts and increasing program coordination between states with similar radiological environmental attributes.

Conclusions and Implications

This study provides new information about state-level organizational structure of radiation control programs in the U.S., identifies the environmental attributes of these programs, and examines the relationship between the structure of these programs and the environmental attributes. Thirty-nine states were included in the final analysis in assessing this relationship. The other 11 states have one or more unique environmental characteristic (e.g., high system activity and high or low event rates) that precluded their classification into one of the three predominant clusters or models of environmental attributes.

This study also provides insights into the system vulnerability of radiological systems. By calculating the system vulnerability index (SVI), a comparison across system types was made and radiological systems ranked by system vulnerability to normal accidents and potential to impact. It was found that fuel cycle facilities, PWR, and BWR have the highest levels of system vulnerability followed closely by non-power reactors. By determining each system's relation to others, emergency managers can make important assumptions in planning for the response to and recovery from radiological events. In states where a larger number of system types exists, this will be important in guiding future preparedness activities and resource allocation which, in turn, could reduce human health and environmental impacts when a radiological accident does occur.

It is clear from comparing across clusters that states face differing threats posed by radiological systems and events. Therefore you would expect to see differences between RCP that exist in differing radiological threat environments. This study looked at various approaches states have taken to organize radiation control. Every state has its own unique approach to structuring their radiation control programs. Each state has a high degree of autonomy to decide how the RCP will be organized within its state agency structure, the formality of the program, and what subprograms of RCP will be funded within the state. This autonomy, however, causes confusion and ambiguity when coordinating programs across state lines and/or with federal levels of government. When disasters or events occur, this fact is exacerbated if prior plans and methods of coordination and communication have not been put in to place. This is particularly important for radiological accidents and the public health response to these type events because the resources and expertise to handle these type events is relatively finite. And when these finite expertise and resources are spread over multiple agencies, confusion can occur even when an event is confined within one state. The National Incident Management System (NIMS) has established incident command protocols to lessen the problems of coordination and communication in an emergency, but day-to-day operations may still remain complex.

This study shows there is increased formalization in states where there is higher system activity with higher system vulnerability. A certain level of formalization is needed in order to provide the necessary legal and regulatory foundation needed to regulate and control radiological systems. So it is expected that states would have more formalized programs in higher risk environments. The disaster life cycle highlights a focus on prevention and mitigation of disaster events. Formalization, a sound legal framework, is a necessary preventive tool in the area of radiation control and is needed in order to control the uses of radioactive materials and prevent the misuse or mishandling of these materials. Therefore, states with strong laws and regulations in place for these purposes are actually mitigating or reducing the chances of these type events occurring. High levels of formalization also lead to legislative authority for providing funding and support to these types of programs, which in turn may enhance program expertise and resources. Over time, as a state becomes more engaged in new technologies, you would expect to see an increase in formalization.

This study found no significant differences in the centralization and standardization of these programs. Decentralization and lack of standardization have many possible implications to the operation and functionality of RCP. Decentralization of RCPs leads to the resources and expertise of the RCP being split between agencies with differing missions and priorities. During a radiological event, these agencies may be left to compete against each other for needed resources. This competition can lead to environments not conducive to collaboration and communication, hindering response efforts in an emergency event and potentially increasing negative outcomes. As states move towards higher risk environments, it may become necessary for a state to increase centralization and standardization of the RCP in order to adequately function. The more decentralize a program, the harder it may be to coordinate a response to a radiological event. In any situation where multiple decision makers have to be coordinated, the complexity level in solving a problem increases. This is particularly true in emergency situations when decisions need to be made quickly and resources committed in a timely manner in order to lessen both the human health and environmental impacts of a radiological incident. Furthermore, the level of complexity of responding increases when a radiological event crosses state lines and requires further coordination among other RCPs who themselves may have varying levels of centralization. For example, Washington State is classified according to the definitions presented in this study as centralized (the radioactive material, environmental monitoring, and non-reactor emergency response subprograms fall within public health). If a large event were to occur in Washington, it would require cooperation across state lines with Oregon and Idaho, both of which are decentralized. Washington State would be required to coordinate with up to five different agencies (in Oregon, the state public health agency and possibly the Oregon DOE; in Idaho, the state environmental agency, state public health agency, and possibly the NRC Region). If you consider that Washington is a border state, a large event may also require coordination with Canada.

Again, as states become more populated, urban, and engage in new technologies, you would expect to see increased standardization. States such as Montana and Wyoming, with some of the lowest system activity and risk, have only four of the seven subprograms operational within the states. Comparatively, states such as California, Texas, Florida, Illinois, and New York, have the highest system activity and risk, have all seven subprograms active within their states. This gives those states more experts in the field and a better inventory of resources to draw upon. Standardization may also affect human and material resources available during an emergency event.

Limitations

In assessing the radiological environmental attributes across the United States, focus was placed on materials that emit ionizing radiation. In an email correspondence dated March 6, 2008, with John Wible, General Council, Alabama Department of Public Health, he explained the following issues that have become key considerations for this study.

First, the NRC regulates source materials, by-products, and SNMs. States that participate in the NRC Agreement State Program regulate all source materials and byproduct materials within their borders and all but large quantities of SNMs. Some states, such as Alabama, have regulatory authority to regulate the machines that produce or work with the source material. This authority is outside the premise of the NRC Agreement State Program and therefore was not considered in this study.

Second, some state statutes do not differentiate the source of the radioactive material; in Alabama, NORM is regulated in quantities greater than 5 pi cu / dl if moved or transferred. If the NORM material is maintained where it is, then it falls outside the regulatory authority of the state. If quantities greater than 5 pi cu / dl are transferred, then it must be transferred to someone licensed to receive it. Since NORM materials are not frequently moved, sold, or transferred and are usually relatively low-level materials, NORM materials were excluded from this study.

Third, non-ionizing sources of radiation such as home or industrial uses of microwaves, TVs, cell phones and tanning beds are not regulated through NRC or the NRC Agreement State Program or necessarily regulated by a state. In Alabama, as in most states, there is no authority for the regulation of the uses of non-ionizing radiation or sources of non-ionizing radiation including power lines and transformers. Therefore, systems utilizing only non-ionizing radiation were not considered in this study.

This study focused on ionizing radiation source materials, byproduct materials, and special nuclear materials that are regulated either by the NRC or by the state through the NRC Agreement State Program, as well as larger quantities of strategic SNM regulated by the NRC. In defining the radiological attributes of a state, there are limitations to sources of data since the development of homeland security efforts as a result of the terrorist attacks of September 2001. Specific efforts have been made to protect the nation's critical infrastructure, including those that use and store radiological materials. The DOE has a number of facilities, including national laboratories located throughout the country, that support weapons production and numerous research and development programs for the DOD. (EPA, 1984; Till & Grogan, 2008) The DOD operates a number of nuclear reactors located on U.S. Army installations and the U.S. Navy's nuclear fleet is based from a number of shipyards where construction, overhaul, refueling, and maintenance of its nuclear fleet occurs. (EPA, 1984) Data and information on the activities of DOD and DOE facilities are not publicly available. It would then be necessary to rely on historical data that may not be accurate. For example, DOD has closed a number of military installations around the country since the beginning of the decade and the locations of some of its nuclear operations has been changed. Also, state-level RCPs are not charged with regulating or responding to events occurring on either DOE or DOD sites. Because of these limitations, DOD and DOE sites are excluded from this study except for TRU waste disposal sites, where NRC is responsible for establishing regulations consistent with environmental standards established by the U.S. EPA. (NRC, 2007j)

Another limitation to the systems data is the fact that the variable for “active in-state licensees” includes both specific source licensees as well as broad byproduct licensees. “Active in-state licensees” represents the number of entities –whether industrial, medical, academic or other – that hold active licenses (either issued by the agreement state or NRC) to use, store, process, sell, or produce ionizing radioactive materials within the state’s jurisdiction. A limitation of this variable includes the fact that the type of license issued cannot be distinguished, whether specific source, broad, or general domestic. Regulations found in 10 CFR 31 (General Domestic), 10 CFR 32 (Specific), and 10 CFR 33 (Broad Byproduct) authorize the NRC or the agreement state to issue licenses for the use of radioactive materials. The type of licenses would give a more accurate picture of the types of materials a licensee holds, but since 2001 this information is not publicly available.

In assessing state radiological attributes another variable considered is that of "reportable events." This variable will include all events reported as required by Title 10 of the Code of Federal Regulation. A limiting factor of this measurement is that this will only account for those events actually reported to NRC by the licensee or agreement state. Those events that occur but not reported to the NRC as required by Title 10 are absent from the data base and therefore not included in the study.

Enforcement action variables, used to characterize each state's environmental attributes, describe the number of enforcement actions initiated by the NRC within each state. Limitations include the fact that more enforcement actions may mean better, more efficient regulation that could lead to a reduction in overall radiological threat in a particular state. However, the NRC's enforcement policies set out the general principles governing NRC's enforcement activities and provide a process for implementing the agency's enforcement authority in response to violations of NRC requirements. Additionally, the regulatory climate is similar from state to state because a common set of enforcement regulations exists and the regulatory enforcement authority is overseen by NRC's Office of Enforcement. Because regulation is time-consuming and expensive, the assumption was made that the NRC is not unfairly regulating one area versus another. This supports the appropriateness of this variable as a measure that will be included in the overall measure of radiological environmental attributes. Also, in 2006, due to national critical infrastructure protection plans, the NRC's Office of Enforcement stopped publically reporting enforcement actions due to security violations at systems that were determined to have high system vulnerability. Therefore, the actual number of enforcement actions may be underrepresented in the data available.

Another very important limitation of this study will be that it does not include information on radioactive materials that may be transported through a state. There is no publicly available reliable source of information on what is shipped, how it is shipped, and what routes are used.

In determining the standardization of radiation control program functions, this study did not consider the size, scope, or limitations of any particular subprogram area. For example, Alaska has a radioactive materials subprogram. Because Alaska is a non-agreement state, this subprogram does not license, inspect or regulate those with radioactive materials licenses within the state. That responsibility falls to the NRC Region. Alaska's radioactive material program does require those who are licensed by the NRC to register with the state of Alaska. Compare that to the state of Alabama, an agreement state, who has the responsibility within its radioactive materials subprogram to license, inspect, and regulate all of its licensees. Alabama's subprogram is much more extensive than Alaska's. Alabama has six full-time employees working within its radioactive materials subprogram and two part-time equivalents, where Alaska only has part-time equivalent.

And finally, only 39 states were included in the final analysis of RCP variables. The resulting small sample size, in turn, precluded the use of some standard statistical procedures such as conical correlation. It may have also adversely affected the results of the chi-square significance test, which failed to reject the null hypothesis. If in future research these limitations can be addressed, a better understanding of the environmental attributes and the structure of the RCP can be gained.

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APPENDIX A

RADIOLOGICAL ENVIRONMENTAL ATTRIBUTE AND RADIATION CONTROL PROGRAM (RCP) STRUCTURAL VARIABLES

Radiological Environmental Attributes (Dependent Variables)

Variable	Definition	Measurement			Justification
1. System	Describes what activities, processes, and independent systems exist within a given state that use, store, or process source materials, SNMs, and byproduct materials regulated by the NRC, agreement state, the DOE, or the DOD	**System Interactions** SMEs will be asked to weight each system variable for system interaction	**System Couplings** SMEs will be asked to weight each system variable for system couplings	**Potential to Impact** SMEs will be asked to weight each system variable for potential to impact	A system variable with higher system interaction, system coupling, and potential to impact weights will be considered of greater threat to the state in which it exists.
Operating nuclear power reactors – Pressure Water Reactors (PWRs)	Will represent the number of operating PWRs within a given state				
Operating nuclear power reactors – Boiling Water Reactors (BWRs)	Will represent the number of operating BWRs within a given state				
Nuclear power reactors undergoing decommissioning	Will represent the number of power reactors undergoing decommission within a given state				
Operating Non-power (test or research) reactors	Will represent the number of operating non-power reactors within a given state				
Non-power (test or research) reactors undergoing decommissioning	Will represent the number of non-power reactors undergoing decommissioning within a given state				
High-level waste disposal site - Independent spent fuel storage installations – Spent fuel ponds	Will represent the number of Spent fuel ponds within a given state				
High-level waste disposal site - Independent spent fuel storage installations – Dry cask storage	Will represent the number of dry cask storage within a given state				

Nuclear material facilities – Uranium milling facilities	Will represent the number of uranium milling facilities within a given state		
Nuclear material facilities – Fuel cycle facilities	Will represent the number of fuel cycle facilities within a given state		
Low-level waste disposal site	Will represent the number of low-level waste disposal sites within a given state		
Transuranic (TRU)waste disposal site	Will represent the number of TRU waste disposal sites within a given state		
Active in-state licensees	Will represent the number of active in-state licensees within a given state		
2. Event	Describe factors that relate to human action or technical failure		
Reportable Events (over a 5-year period: 2003-2007)	Reportable events variables will represent the number events reported by licensees to the NRC or Agreement State as required by Title 10 of the Code of Federal Regulations or comparable state legislation in Agreement States in each of the NRC's emergency classifications.	Reportable events are classified according to the NRC's Emergency Classification System: • Non-emergency events • Unusual events • Alert • Site area emergency • General Emergency	The greater the number of events within each emergency classification occurring within a state and the greater the weight of the event classification, the greater the radiological threat.
Enforcement Actions (over a 5-year period: 2003-2007)	Describe the number of enforcement actions initiated within each state.	Types of enforcement actions include: • Notices of violations • NOVs with civil penalties • Orders to modify, suspend, or revoke a license • Orders with civil penalties	The greater the number of NRC significant enforcement actions issued with a state and the greater the weight placed on each type of enforcement action, the higher the radiological threat to that state.

Radiation Control Program (RCP) Structural Variables (Independent Variables)

Variable	Definition	Measurement	Hypotheses
1. Formalization			
Agreement State	State has assumed NRC regulatory authority to license and regulate byproduct materials, source materials, and certain quantities of special nuclear material.	Dichotomous variable: 0 = non-agreement state; 1= agreement state *Source:* www.nrc.gov/agreement	RCPs with a high degree of formalization will be found in State's with high system threat, high numbers of reportable events, and high numbers of enforcement actions.
Status of laws, policies, and legislation to regulate radioactive materials including source materials, SNM, and byproduct materials and electronic sources of radiation that falls within of the purview of the NRC Agreement State Program.	Integrated Materials Performance Evaluation Program (IMPEP) Reviews CRCPD Suggested state regulations can be found at: http://nrc-stp.ornl.gov/ special/regs/crcpd_regs.html	Dichotomous variable: 0 = not satisfactory/needs improvement 1 = satisfactory *Source:* NRC IMPEP Reviews; SRS Data forms	
2. Standardization of Function	Number of CRCPD RCP operational areas or subprograms performed within the State	Continuous variable (0-7) representing the exact number of CRCPD operational areas or subprograms performed within the State. *Source:* State agency websites	RCPs with a high degree of standardization of function will be found in State's with high system threat, high numbers of reportable events, and high numbers of enforcement actions.
4. Centralization/ Decentralization of RCP functions	Number of agencies (organizational units) with RCP subprogram functions within a State. Centralized = one agency involved in RCP functions or two agencies involved but no one function is split. Decentralized = two or more agencies involved with one or more of the functions shared between two agencies.	Dichotomous variable: 0 = Decentralized 1 = Centralized	RCPs with a high degree of centralization will be found in State's with high system threat, high numbers of reportable events, and high numbers of enforcement actions.

APPENDIX B

RADIOLOGICAL SYSTEM ATTRIBUTE SURVEY

(Electronic version of survey can be found at www.soph.uab.edu/radsurvey)

Instructions for rating system variables

Please rate each of the following radiological system variables for system interaction, coupling, and potential to impact. The system variables listed attempt to describe what activities, processes, and independent systems exist that use, store, or process source materials, special nuclear materials, and byproduct materials regulated by the NRC or an agreement state.

In each question below, you will find links that lead you to definitions and/or descriptions of each system and system attribute (interaction, coupling, and potential to impact).

Variables are to be rated in comparison to the other types of radiological systems that exist across the U.S. Scores of 0 and 10 are anchored specifically for each scale, and a score 5 implies that this attribute of the radiological system is about average in comparison to other radiological systems.

Click the value that you think best represents the attributes that characterize each system variable compared to other radiological systems.

1. **Operating nuclear power reactors – Pressure water reactors (PWRs)**

System Interaction
linear 0 1 2 3 4 5 6 7 8 9 10 complex

System Coupling
loose 0 1 2 3 4 5 6 7 8 9 10 tightly coupled

Potential to Impact
negligible 0 1 2 3 4 5 6 7 8 9 10 catastrophic

2. **Operating nuclear power reactors – Boiling water reactors (BWRs)**

System Interaction
linear 0 1 2 3 4 5 6 7 8 9 10 complex

System Coupling
loose 0 1 2 3 4 5 6 7 8 9 10 tightly coupled

Potential to Impact
negligible 0 1 2 3 4 5 6 7 8 9 10 catastrophic

3. Nuclear power reactors undergoing decommissioning

System Interaction
linear 0 1 2 3 4 5 6 7 8 9 10 complex

System Coupling
loose 0 1 2 3 4 5 6 7 8 9 10 tightly coupled

Potential to Impact
negligible 0 1 2 3 4 5 6 7 8 9 10 catastrophic

4. Operating non-power (test or research) reactors

System Interaction
linear 0 1 2 3 4 5 6 7 8 9 10 complex

System Coupling
loose 0 1 2 3 4 5 6 7 8 9 10 tightly coupled

Potential to Impact
negligible 0 1 2 3 4 5 6 7 8 9 10 catastrophic

5. Non-power (test or research) reactors undergoing decommissioning

System Interaction
linear 0 1 2 3 4 5 6 7 8 9 10 complex

System Coupling
loose 0 1 2 3 4 5 6 7 8 9 10 tightly coupled

Potential to Impact
negligible 0 1 2 3 4 5 6 7 8 9 10 Catastrophic

6. High-level waste disposal site - Independent spent fuel storage installations – Spent fuel ponds

System Interaction
linear 0 1 2 3 4 5 6 7 8 9 10 complex

System Coupling
loose 0 1 2 3 4 5 6 7 8 9 10 tightly coupled

Potential to Impact
negligible 0 1 2 3 4 5 6 7 8 9 10 catastrophic

7. High-level waste disposal site - Independent spent fuel storage installations – Dry cask storage

System Interaction
linear 0 1 2 3 4 5 6 7 8 9 10 complex

System Coupling
loose 0 1 2 3 4 5 6 7 8 9 10 tightly coupled

Potential to Impact
negligible 0 1 2 3 4 5 6 7 8 9 10 catastrophic

8. Nuclear material facilities – Uranium milling facilities

System Interaction
linear 0 1 2 3 4 5 6 7 8 9 10 complex

System Coupling
loose 0 1 2 3 4 5 6 7 8 9 10 tightly coupled

Potential to Impact
negligible 0 1 2 3 4 5 6 7 8 9 10 catastrophic

9. Nuclear material facilities – Fuel cycle facilities

System Interaction
linear 0 1 2 3 4 5 6 7 8 9 10 complex

System Coupling
loose 0 1 2 3 4 5 6 7 8 9 10 tightly coupled

Potential to Impact
negligible 0 1 2 3 4 5 6 7 8 9 10 catastrophic

10. Low-level waste disposal site

System Interaction
linear 0 1 2 3 4 5 6 7 8 9 10 complex

System Coupling
loose 0 1 2 3 4 5 6 7 8 9 10 tightly coupled

Potential to Impact
negligible 0 1 2 3 4 5 6 7 8 9 10 catastrophic

11. Transuranic (TRU) waste disposal site

System Interaction
linear 0 1 2 3 4 5 6 7 8 9 10 complex

System Coupling
loose 0 1 2 3 4 5 6 7 8 9 10 tightly coupled

Potential to Impact
negligible 0 1 2 3 4 5 6 7 8 9 10 catastrophic

12. <u>Active in-state licensees</u>

System Interaction

linear 0 1 2 3 4 5 6 7 8 9 10 complex

System Coupling

loose 0 1 2 3 4 5 6 7 8 9 10 tightly coupled

Potential to Impact

negligible 0 1 2 3 4 5 6 7 8 9 10 catastrophic

13. State in which you work _______________

14. Total years of work experience ________________

15. Years in current position _________________

16. Organization (check the one category that best describes your current organization/agency):

____ Radiation Control
____ Emergency Management
____ Homeland Security
____ DOE
____ DOD
____ NRC
____ Nuclear Power Industry
____ Public Health, specify area:_______________________________
____ Other: ____

17. Job Role (check the one category that best describes your current job)

____ Radiation Control
____ Regulatory Compliance
____ Emergency Planner
____ Security
____ Health Physicist
____ Administration
____ Other: ____

18. Primary organization type:

____ Local
____ County
____ State
____ Federal
____ Tribal
____ Private

Electronic Glossary

The System Attributes

A. *System Interaction* - System interaction describes interactive complexity of the system. Interactive complexity determines the risk of experiencing normal accidents or those "unintended or untoward" events that disrupt the normal output of the organization or system.

The following determinants contribute to interactive complexity. If all of the following statements are very true, the radiological system probably rates a high score (10) meaning that it has a high degree of complexity as compared to other radiological systems. If all the statements are false, the radiological system rates a low score (0) meaning the system is linear relative to other radiological systems.

- tightly spaced production equipment,
- closely aligned production steps,
- common-mode interconnections,
- limited isolation of failed components,
- personnel specialization,
- limited ability to substitute materials and supplies,
- unfamiliar and unintended feedback loops,
- multiple control parameters with possible interactions,
- indirect and inferential information systems, and
- limited understanding of production transformations.

B. *System Coupling* –System coupling gauges the slack or buffer between subsystems. A tightly coupled system means that what happens in one subsystem will directly affect what happens in other subsystems. The more tightly coupled systems live with a higher degree of vulnerability.

If all of the following statements are very true, the radiological system probably rates a high score (10) meaning the system is tightly coupled relative to other radiological systems. If all the statements are false, the radiological system rates a low score (0) meaning the system is loose relative to other radiological systems.

- higher degree of time dependence in a process,
- lack of flexibility in process sequencing,
- single path to a goal, and
- lack of availability of slack resources.

C. *Potential to Impact* – This attribute is needed to rate each system variable for its potential to impact human health, environment, and economy as a result of system failure. Accidents are inevitable and happen all of the time; serious ones are inevitable but infrequent; catastrophes are inevitable but extremely rare. When the rare catastrophe occurs, what will be the potential impacts to human health, environment and economy as a result?

The radiological system probably rates a high score (10) if the potential of human health, environmental, and economic impacts is catastrophic to the community in which it exist relative to other radiological systems. The radiological system rates a low score (0) if the potential of human health, environmental, and economic impacts are negligible relative to other radiological systems.

The System Variables

1. Operating nuclear power reactors – Pressure water reactors (PWRs) - PWRs are designed to keep water in the reactor vessel from boiling at a maximum operating temperature of 620°F by maintaining a pressure of 2250 psi. NRC describes PWRs as pressurized light-water reactors. These type reactors have a primary and secondary loop system. The reactor core creates heat that is carried to a steam generator by the pressurized water in the primary coolant loop. In the steam generator the heat from the primary loop vaporizes water that is contained in the secondary loop. This steam drives the turbine to produce electricity. (Source: http://www.nrc.gov)

2. Operating nuclear power reactors – Boiling water reactors (BWRs) - BWRs are designed in a single closed loop system where water is heated by the reactor core generating steam that is delivered to the turbines that generate electricity and then returns to the reactor core in a liquid state. The water is force-circulated by electrical pumps. Emergency cooling water is provided by other pumps that can run off of diesel generators or some other type of backup power source. (Source: http://www.nrc.gov)

3. Nuclear power reactors undergoing decommissioning – This variable will constitute nuclear power reactors that are undergoing decontamination and decommissioning. During this process the facility or site is removed from service and the residual radioactivity is reduced to a level that will allow the property to be released for either restricted or unrestricted use. (Source: http://www.nrc.gov)

4. Operating non-power (test or research) reactors – This variable will represent Class I, II and III research and test reactors licensed to operate in the United States. Research and test reactors -- also called "non-power" reactors-- are nuclear reactors primarily used for research, training and development. These reactors contribute to almost every field of science including physics, chemistry, biology, medicine, geology, archeology, and environmental sciences. The radiation produced by research reactors is the key output, not the very little amount of energy produced. The most common use of this radiation is for experiments. Primarily, two types of radiation are used from research reactors: neutrons and gamma rays. Some experiments require more of one type radiation than the other. The amount and types of radiation may be controlled by placing different types of "filters" between the reactor and the experiment, or positioning the experiment at

different locations relative to the radioactive fuel in the core. (Source: http://www.nrc.gov)

5. Non-power reactors undergoing decommissioning - Nuclear non-power reactors that are undergoing decontamination and decommissioning are regulated by the NRC or the Agreement State with the ultimate goal of terminating the license. During this process the facility or site is removed from service and the residual radioactivity is reduced to a level that will allow the property to be released for either restricted or unrestricted use. (Source: http://www.nrc.gov)

6. High-level waste disposal site - Independent spent fuel storage installations – Spent fuel ponds - Spent fuel refers to "uranium-bearing fuel elements that have been used at commercial nuclear reactors and that are no longer producing enough energy to sustain a nuclear reaction." One-fourth to one-third of the fuel load is removed from the reactor core every 12 to 18 months. After its removal from the reactor core, these materials must be stored in one or two ways, one of which is spent fuel pools. Spent fuel pools are designed to store spent fuel rods under at least 20 feet of water in order to provide adequate shielding for anyone who nears the pool. (Source: http://www.nrc.gov)

7. High-level waste disposal site - Independent spent fuel storage installations – Dry cask storage - Once pool capacity is reached at a facility, spent fuels that have already been cooled in the spent fuel pool for at least one year can be moved to dry cask storage. The cask is usually a steel cylinder that is either welded or bolted closed once the fuel rods are inserted and surrounded by an inert gas. The cask is then surrounded by additional steel and concrete to provide shielding for workers as well as the general public. (Source: http://www.nrc.gov)

8. Nuclear material facilities – Uranium milling facilities - There are fifteen active uranium milling licenses. All uranium milling sites are located in the western United States because the population density is lower. Ore from uranium mining operations contain only a fraction (typically less than 1%) of uranium 235 (^{235}U). It is necessary then to separate it from the other minerals in the ore to produce a concentrated form of Uranium called yellowcake (U_3O_8). To do this, the ore is ground and leached with an acid or base. The uranium is then separated from the other material, called tailings. Of the fifteen active facilities, four are "in situ leach facilities" and the other eleven are conventional uranium milling facilities. Of the eleven conventional facilities all but one facility in Wyoming is undergoing decommissioning. Each of these sites is contaminated with uranium mill tailings. These tailings are a sandy process waste material that contains the radioactive decay products from the uranium chains and heavy metals. (Source: http://www.nrc.gov)

9. Nuclear material facilities – Fuel cycle facilities –Fuel cycle facilities are facilities that enrich uranium. Several processes were developed to increase the fraction of ^{235}U above the 0.72% present naturally in ore. All enrichment processes utilized gaseous forms of uranium, where yellowcake is converted via diffusion, centrifugation, or electromagnetic

means to uranium hexafluoride (UF_6). There are twelve licensed fuel cycle facilities. Six uranium fuel fabrication facilities, one uranium hexafluoride production (conversion) facility, two gaseous diffusion enrichment facilities, two gas centrifuge enrichment facilities, and one mixed oxide fuel fabrication facility. (NRC, 2008h) These facilities create highly enriched uranium (HEU), containing more than 20% ^{235}U, and uranium products containing lower amounts of ^{235}U (LEU). HEU with levels of ^{235}U greater than 90% are used for weapons production. Various grades of LEU are used for commercial reactor fuels. The DOE has leased enrichment facilities in Ohio and Kentucky to the U.S. Enrichment Corporation to produce commercial-reactor fuel-grade LEU. Two new facilities have been proposed, one for Piketon, Ohio, the other in New Mexico, that will use centrifuge technology to enrich uranium.

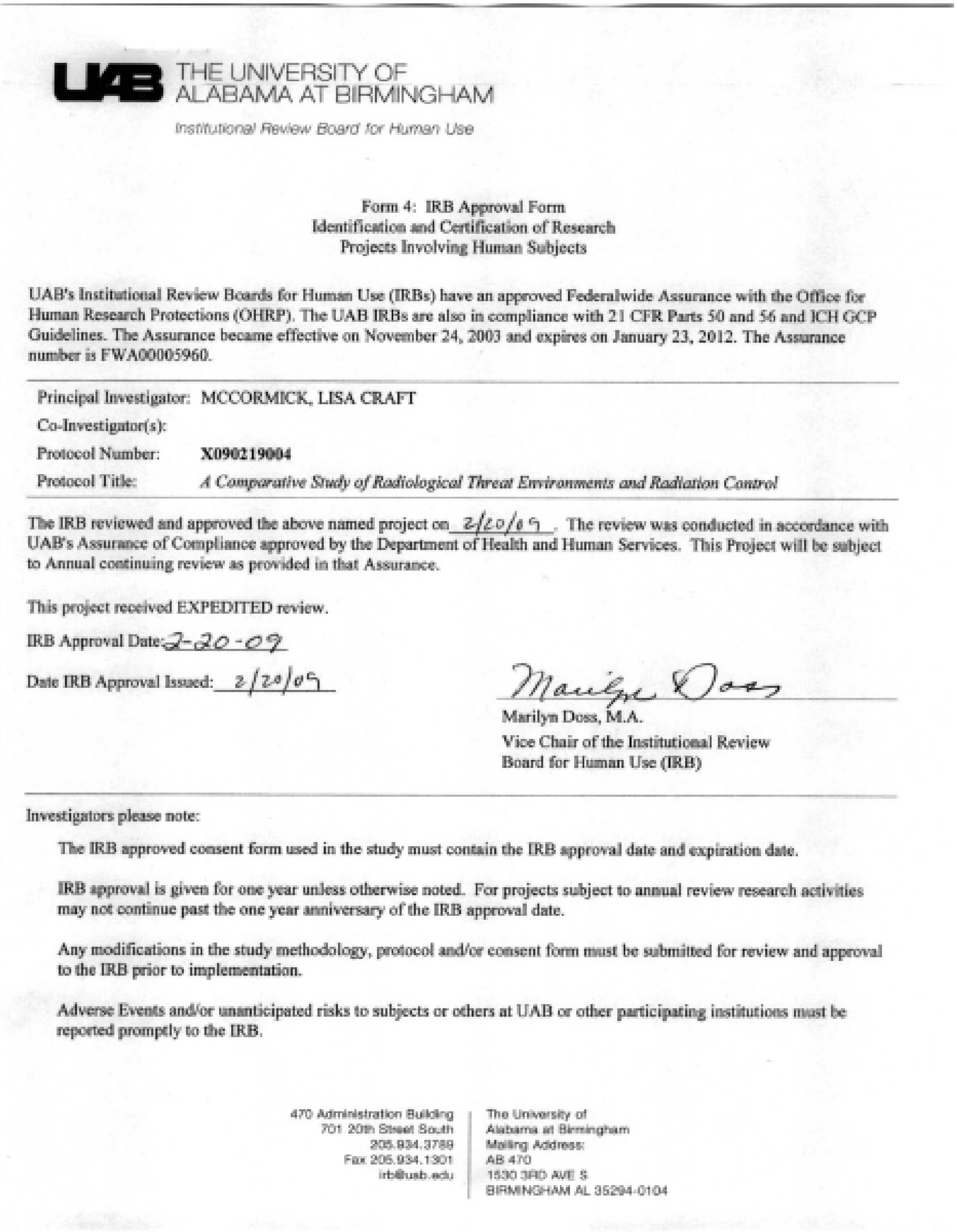
10. Low-level waste disposal site - There are three active low-level waste sites licensed by the NRC in the United States. Low-level waste includes items such as contaminated protective clothing, tools, filters, rags, medical tubes, and many other items that become contaminated during use in nuclear reactors and other applications.

11. Transuranic (TRU) waste disposal site - High-level radioactive wastes called transuranic (TRU) waste are produced by DOE defense spent fuel reprocessing programs in DOE facilities across the country and by commercial reprocessing operations at West Valley, New York. The purpose of this reprocessing is to separate plutonium for use in the fabrication of nuclear weapons. TRU waste is contaminated with U-233, its daughter products, certain isotopes of plutonium, and nuclides with atomic numbers greater than 92 (uranium). The DOE is responsible for TRU waste management as it is not regulated by the NRC. There are nine sites across the country that DOE defines as producing large quantities of TRU waste and thirteen additional sites that produce small quantities. The Waste Isolation Pilot Plant (WIPP) located in the Chihuahuan Desert outside of Carlsbad, New Mexico also accepts TRU waste from some of these facilities.

12. Active in-state licensees - The NRC Regional Office in Non-agreement states and RCPs located in States that are participants in the NRC Agreement State Program regulate, license, and inspects the use of all radioactive materials within its jurisdiction. This variable will represent the number of entities; whether industrial, medical, academic or other; that hold active licenses both ‘specific source’ and ‘broad byproduct’ to use, store, process, sell, or produce ionizing radioactive materials within the States jurisdiction.

APPENDIX C

INSTITUTIONAL REVIEW BOARD (IRB) FOR HUMAN USE APPROVAL FORM



UAB THE UNIVERSITY OF
ALABAMA AT BIRMINGHAM

Institutional Review Board for Human Use

Form 4: IRB Approval Form
Identification and Certification of Research Projects Involving Human Subjects

UAB's Institutional Review Boards for Human Use (IRBs) have an approved Federalwide Assurance with the Office for Human Research Protections (OHRP). The UAB IRBs are also in compliance with 21 CFR Parts 50 and 56 and ICH GCP Guidelines. The Assurance became effective on November 24, 2003 and expires on January 23, 2012. The Assurance number is FWA00005960.

Principal Investigator:	MCCORMICK, LISA CRAFT
Co-Investigator(s):	
Protocol Number:	**X090219004**
Protocol Title:	*A Comparative Study of Radiological Threat Environments and Radiation Control*

The IRB reviewed and approved the above named project on 2/20/09. The review was conducted in accordance with UAB's Assurance of Compliance approved by the Department of Health and Human Services. This Project will be subject to Annual continuing review as provided in that Assurance.

This project received EXPEDITED review.

IRB Approval Date: 2-20-09

Date IRB Approval Issued: 2/20/09

Marilyn Doss

Marilyn Doss, M.A.
Vice Chair of the Institutional Review
Board for Human Use (IRB)

Investigators please note:

The IRB approved consent form used in the study must contain the IRB approval date and expiration date.

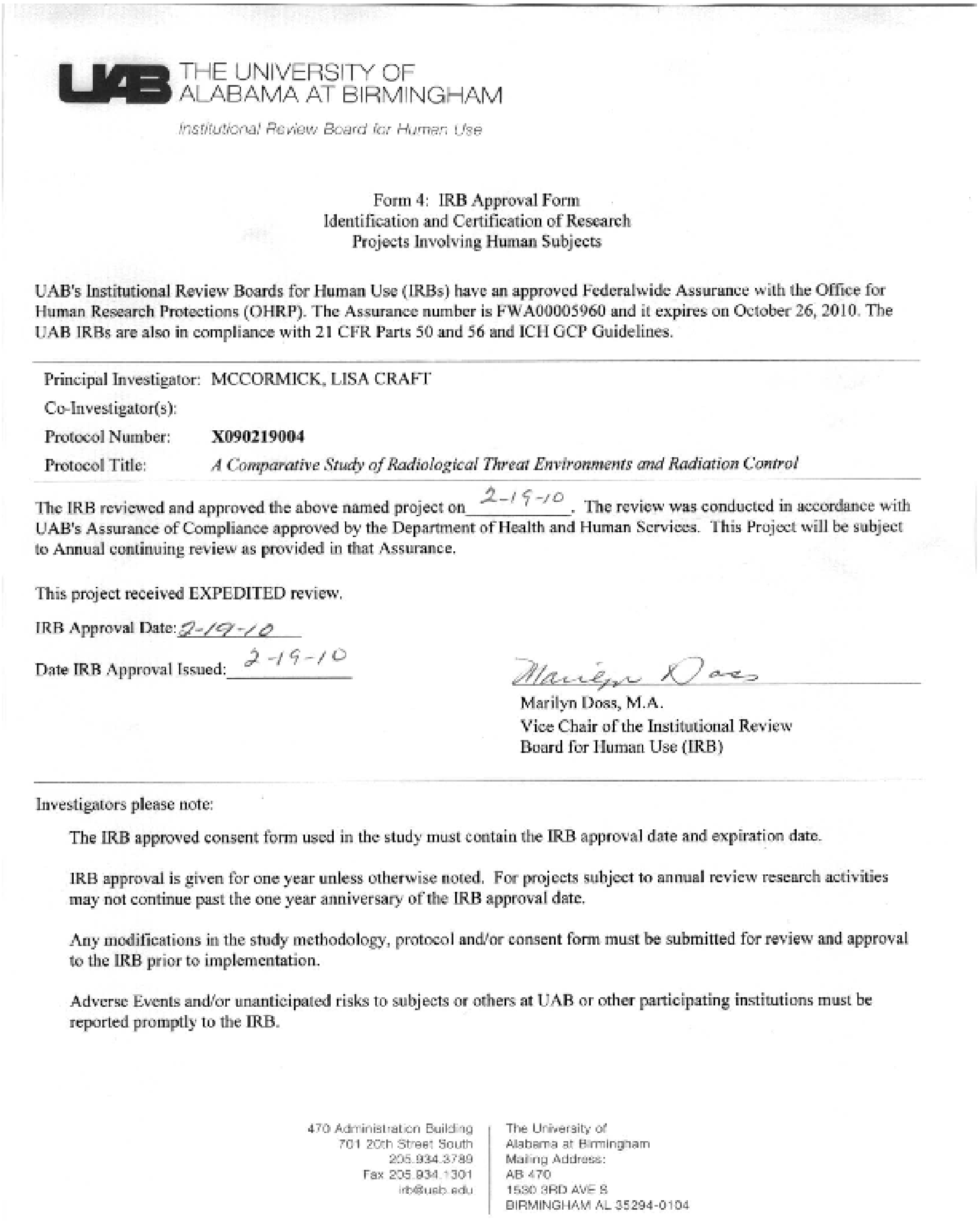
IRB approval is given for one year unless otherwise noted. For projects subject to annual review research activities may not continue past the one year anniversary of the IRB approval date.

Any modifications in the study methodology, protocol and/or consent form must be submitted for review and approval to the IRB prior to implementation.

Adverse Events and/or unanticipated risks to subjects or others at UAB or other participating institutions must be reported promptly to the IRB.

470 Administration Building
701 20th Street South
205.934.3789
Fax 205.934.1301
irb@uab.edu

The University of
Alabama at Birmingham
Mailing Address:
AB 470
1530 3RD AVE S
BIRMINGHAM AL 35294-0104



UAB THE UNIVERSITY OF ALABAMA AT BIRMINGHAM

Institutional Review Board for Human Use

Form 4: IRB Approval Form
Identification and Certification of Research
Projects Involving Human Subjects

UAB's Institutional Review Boards for Human Use (IRBs) have an approved Federalwide Assurance with the Office for Human Research Protections (OHRP). The Assurance number is FWA00005960 and it expires on October 26, 2010. The UAB IRBs are also in compliance with 21 CFR Parts 50 and 56 and ICH GCP Guidelines.

Principal Investigator: MCCORMICK, LISA CRAFT
Co-Investigator(s):
Protocol Number: **X090219004**
Protocol Title: *A Comparative Study of Radiological Threat Environments and Radiation Control*

The IRB reviewed and approved the above named project on 2-19-10. The review was conducted in accordance with UAB's Assurance of Compliance approved by the Department of Health and Human Services. This Project will be subject to Annual continuing review as provided in that Assurance.

This project received EXPEDITED review.

IRB Approval Date: 2-19-10

Date IRB Approval Issued: 2-19-10

Marilyn Doss

Marilyn Doss, M.A.
Vice Chair of the Institutional Review
Board for Human Use (IRB)

Investigators please note:

The IRB approved consent form used in the study must contain the IRB approval date and expiration date.

IRB approval is given for one year unless otherwise noted. For projects subject to annual review research activities may not continue past the one year anniversary of the IRB approval date.

Any modifications in the study methodology, protocol and/or consent form must be submitted for review and approval to the IRB prior to implementation.

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The University of
Alabama at Birmingham
Mailing Address:
AB 470
1530 3RD AVE S
BIRMINGHAM AL 35294-0104

APPENDIX D

PILOT SURVEY RESPONDENT FEEDBACK FORM

(Electronic version of survey can be found at www.soph.uab.edu/radsurvey/pilot)

Pilot Survey Response Form

Are instructions and items clearly stated and understandable? If not what changes would you recommend?

Are there items that you feel are not of value on this survey? If so, please explain.

Does this survey include system variables that you feel should not be included? Are there system variables that are not included that you would include?

How useful was the glossary information?

APPENDIX E

PILOT SURVEY AND STUDY SURVEY ADMINISTRATION

Pilot Study Administration Email

Hello,

I am inviting you to participate in a pilot research project that will explore radiological systems and the public health preparedness demands that are critical to insuring comprehensive and competent response capabilities. You have been asked to participate in this study because of your knowledge and familiarity in this area.

Below is a link that leads to a short survey that ask you to score radiological systems for system attributes as defined by C. Perrow's Normal Accident Theory (1984), system interactions and system couplings, as well as the potential to impact human health, environment, and economy during a catastrophic failure. I am asking you to look over the questionnaire and, if you choose to do so, complete it and click the submit button at the bottom of the survey. Since this is a pilot survey, once you click the 'submit' button another short form will appear that will solicit your thoughts on the survey, its layout, and content. It should take no more than 10-15 minutes of your time to complete both forms.

Survey link:
https://www.soph.uab.edu/radsurvey

The results of this project will ultimately be used to explore how the organizational structure of Radiation Control Program's are associated with environmental variables of the organization. Please understand that the information you provide will be used for research purposes. Your participation in this survey is voluntary and all responses are strictly confidential. Your completion of this questionnaire indicates your informed consent to participate in this evaluation research. If you have any questions or concerns about completing the questionnaire or about being in this study, you may contact me at (205)934-7148 or by emailing lcraft@uab.edu.

The Institutional Review Board (IRB) at the University of Alabama at Birmingham has approved this study. If you have any concerns about your rights as a research participant, or concerns or complaints about the research, you may contact Ms. Sheila Moore. Ms. Moore is the Director of the Office of the Institutional Review Board for Human Use (OIRB). Ms. Moore may be reached at (205) 934-3789 or 1-800-822-8816. If calling the toll-free number, press the option for "all other calls" or for an operator/attendant and ask for extension 4-3789. Regular hours for the Office of the IRB are 8:00 a.m. to 5:00 p.m. CT, Monday through Friday. You may also call this number in the event the research staff cannot be reached or you wish to talk to someone else.

Final Study Administration Email

Hello,

I am inviting you to participate in a research project that will explore radiological systems and the public health preparedness demands that are critical to insuring comprehensive and competent response capabilities. You have been asked to participate in this study because of your knowledge and familiarity in this area. This research project was presented to the CDC's Radiation Studies Branch and they are interested in using this data in evaluating the nation's radiological preparedness.

Below is a link that leads to a short survey that ask you to score radiological systems for system attributes as defined by C. Perrow's Normal Accident Theory (1984), system interactions and system couplings, as well as the potential to impact human health, environment, and economy during a catastrophic failure. I am asking you to look over the questionnaire and, if you choose to do so, complete it and click the submit button at the bottom of the survey. It should take no more than 10-15 minutes of your time to complete.

Survey link:
https://www.soph.uab.edu/radsurvey

The results of this project will ultimately be used to explore how the organizational structure of Radiation Control Program's are associated with environmental variables of the organization. Please understand that the information you provide will be used for research purposes. Your participation in this survey is voluntary and all responses are strictly confidential. Your completion of this questionnaire indicates your informed consent to participate in this evaluation research. If you have any questions or concerns about completing the questionnaire or about being in this study, you may contact me at (205)934-7148 or by emailing lcraft@uab.edu.

The Institutional Review Board (IRB) at the University of Alabama at Birmingham has approved this study. If you have any concerns about your rights as a research participant, or concerns or complaints about the research, you may contact Ms. Sheila Moore. Ms. Moore is the Director of the Office of the Institutional Review Board for Human Use (OIRB). Ms. Moore may be reached at (205) 934-3789 or 1-800-822-8816. If calling the toll-free number, press the option for "all other calls" or for an operator/attendant and ask for extension 4-3789. Regular hours for the Office of the IRB are 8:00 a.m. to 5:00 p.m. CT, Monday through Friday. You may also call this number in the event the research staff cannot be reached or you wish to talk to someone else.

APPENDIX F

RCP CODING SHEET

(Q 1) State:

Formalization

(Q2) Agreement State Status 0 Non-agreement state 1 Agreement state	**(Q3) State Regulation Status:** 0 Not current 1 Current

(Q4) Centralization

Circle all that apply

1 Department of public health

2 Department of environmental protection/ quality/management/natural resources

3 Emergency management agency

4 Office of homeland security

5 Stand alone state agency

6 Other:_______________

(Q4) Standardization of Function

Circle all that apply

Public Health (1)	**Environmental (2)**	**EMA (3)**	**HS (4)**	**Stand Alone (5)**	**Other (6)**
1 EPR – Ionizing	1 EPR – Ionizing	1 EPR – Ionizing	1 EPR – Ionizing	1 EPR – Ionizing	1 EPR – Ionizing
2 EPR- Non-ionizing	2 EPR- Non-ionizing	2 EPR- Non-ionizing	2 EPR- Non-ionizing	2 EPR- Non-ionizing	2 EPR- Non-ionizing
3 Rad Materials	3 Rad Materials	3 Rad Materials	3 Rad Materials	3 Rad Materials	3 Rad Materials
4 Radon	4 Radon	4 Radon	4 Radon	4 Radon	4 Radon
5 Surveillance and Monitoring	5 Surveillance and Monitoring	5 Surveillance and Monitoring	5 Surveillance and Monitoring	5 Surveillance and Monitoring	5 Surveillance and Monitoring
6 Low level waste	6 Low level waste	6 Low level waste	6 Low level waste	6 Low level waste	6 Low level waste
7 Emergency Response	7 Emergency Response	7 Emergency Response	7 Emergency Response	7 Emergency Response	7 Emergency Response

APPENDIX G

RADIATION CONTROL FUNCTION AVAILABILITY BY STATE

Radiation Control Function Availability by State

ALABAMA					
Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	1	PH*	0	
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	0		1	PH*, DECA**
7	1	0		1	PH*, EMA***
Total	6	4		2	

*Alabama Department of Public Health; Division of Radiation Control
** Department of Economic and Community Affairs - Energy Division
***Alabama Emergency Management Agency

ALASKA					
Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	1	1	PH*	0	
3	1	0		1	PH*, NRC****
4	1	1	UA Fairbanks**	0	
5	0				
6	1	1	Env***	0	
7	1	1	Env***	0	
Total	6	5		1	

*AK Department of Health & Social Services; State Public Health Laboratories; Radiological Health
**University of Alaska Fairbanks
***AK Department of Environmental Conservation
****NRC Region IV

ARIZONA					
Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	ARRA*	0	
2	1	1	ARRA*	0	
3	1	1	ARRA*	0	
4	1	1	ARRA*	0	
5	1	1	ARRA*	0	
6	1	1	ARRA*	0	
7	1	1	ARRA*	0	
Total	7	7		0	

* Arizona Radiation Regulatory Agency

ARKANSAS					
Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	1	PH*	0	
4	1	1	PH*	0	
5	0				
6	1	0		1	PH*, APC&E**
7	1	1	PH*	0	
Total	5	4		1	

* Arkansas Department of Health; Health Systems Licensing and Regulation Branch; Radiation Control Section

**Arkansas Pollution Control and Ecology Commission

CALIFORNIA					
		Function within one agency		Function split between agencies	
Functions	Availability Yes – 1/ No - 0	Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	1	1	DCA**	0	
3	1	1	PH*	0	
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	1	PH*	0	
7	1	1	PH*	0	
Total	7	7		0	

*California Department of Public Health; Division of Food, Drug & Radiation Safety; Radiologic Health Branch

**California Department of Consumer Affairs

COLORADO					
		Function within one agency		Function split between agencies	
Functions	Availability Yes – 1/ No - 0	Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	1	PH*	0	
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	1	PH*	0	
7	1	1	PH*	0	
Total	6	6		0	

*Colorado Department of Public Health and Environment; Hazardous Materials and Waste Management Division; Radiation Materials Inspection and Licensing

CONNECTICUT					
		Function within one agency		Function split between agencies	
Functions	Availability Yes – 1/ No - 0	Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	0		1	PH*, ENV**
2	0				
3	1	0		1	ENV**, NRC***
4	1	1	PH*	0	
5	1	1	ENV**	0	
6	1	1	ENV**	0	
7	1	1	ENV**	0	
Total	6	4		2	

*Connecticut Department of Public Health; Regulatory Services Branch; Environmental Health Section; Radon Program

**Connecticut Department of Environmental Protection

***NRC Region I

DELAWARE					
		Function within one agency		Function split between agencies	
Functions	Availability Yes – 1/ No - 0	Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	0		1	PH*, NRC***
4	1	1	PH*	0	
5	0				
6	1	1	PH*	0	
7	1	1	ENV**	0	
Total	5	4		1	

*Delaware Health and Social Services; Division of Public Health; Office of Radiation Control

**Delaware Department of Natural Resources & Environmental Control

***NRC Region I

FLORIDA

Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	1	1	PH*	0	
3	1	1	PH*	0	
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	1	PH*	0	
7	1	1	PH*	0	
Total	7	7		0	

*Florida Department of Health; Division of Environmental Health; Bureau of Radiation Control

GEORGIA

Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	1	ENV**	0	
4	1	1	DCA***	0	
5	1	1	ENV**	0	
6	1	1	ENV**	0	
7	1	0		1	ENV**, EMA****
Total	6	5		1	

*Georgia Department of Community Health; Healthcare Facility Regulation Division
**Georgia Department of Natural Resources; Environmental Protection Division
***Georgia Department of Community Affairs; Office of Environmental Management
****Georgia Emergency Management Agency

HAWAII					
		Function within one agency		Function split between agencies	
Functions	Availability Yes – 1/ No - 0	Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	0		1	PH*, NRC**
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	1	PH*	0	
7	1	1	PH*	0	
Total	6	5		1	

*Hawaii Department of Health; Env Health Admin; Env Health Services Division; Indoor and Radiological Health Branch; Radiation Program

**NRC Region IV

IDAHO					
		Function within one agency		Function split between agencies	
Functions	Availability Yes – 1/ No - 0	Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	0		1	ENV**, NRC***
4	1	1	PH*	0	
5	1	1	ENV**	0	
6	1	1	ENV**	0	
7	1	1	ENV**	0	
Total	6	5		1	

*Idaho Department of Health and Welfare; Bureau of Laboratories; Certification; X-ray Equipment Registration & Inspection

**Idaho Department of Environmental Quality

***NRC Region IV

ILLINOIS

Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	EMA*	0	
2	1	1	EMA*	0	
3	1	1	EMA*	0	
4	1	1	EMA*	0	
5	1	1	EMA*	0	
6	1	1	EMA*	0	
7	1	1	EMA*	0	
Total	7	7		0	

*Illinois Emergency Management Agency

INDIANA

Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	0		1	PH*, NRC***
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	1	ENV**	0	
7	1	1	PH*	0	
Total	6	5		1	

* Indiana Department of Health; Indoor and Radiologic Health Program
**Indiana Department of Environmental Management
***NRC Region III

IOWA

Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	1	1	PH*	0	
3	1	1	PH*	0	
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	1	ENV**	0	
7	1	1	PH*	0	
Total	7	7		0	

*Iowa Department of Public Health

**Iowa Department of Natural Resources

KANSAS

Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	1	PH*	0	
4	1	1	KSU**	0	
5	1	1	PH*	0	
6	1	1	PH*	0	
7	1	1	PH*	0	
Total	6	6		0	

*Kansas Department of Health and Environment; Division of Health; Bureau of Environmental Health; Radiation Section

**Kansas State University

KENTUCKY					
Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	1	PH*	0	
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	1	PH*	0	
7	1	1	PH*	0	
Total	6	6		0	

*Kentucky Cabinet for Health & Family Services; Department for Public Health; Radiation Health Branch

LOUISIANA					
Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	ENV*	0	
2	0				
3	1	1	ENV*	0	
4	1	1	ENV*	0	
5	1	1	ENV*	0	
6	1	1	ENV*	0	
7	1	1	ENV*	0	
Total	6	6		0	

*Louisiana Department of Environmental Quality

MAINE					
		Function within one agency		Function split between agencies	
Functions	Availability Yes – 1/ No - 0	Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	1	1	PH*	0	
3	1	1	PH*	0	
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	1	PH*	0	
7	1	1	DPS**	0	
Total	7	7		0	

*Maine Department of Health & Human Services; ME Center for Disease Control; Division of Environmental Health; Radiation Control Program

**Maine Department of Public Safety; Maine State Police

MARYLAND					
		Function within one agency		Function split between agencies	
Functions	Availability Yes – 1/ No - 0	Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	ENV*	0	
2	1	1	ENV*	0	
3	1	1	ENV*	0	
4	0				
5	0				
6	1	1	ENV*	0	
7	1	1	ENV*	0	
Total	5	5		0	

*Maryland Department of the Environment

MASSACHUSETTS					
Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	1	PH*	0	
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	1	PH*	0	
7	1	0		1	PH*, EMA**
Total	6	5		1	

*Massachusetts Health and Human Services; Department of Public Health; Center for Environmental Health; Radiation Control Program
**Massachusetts Emergency Management Agency

MICHIGAN					
Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	0		1	Env**, NRC***
4	1	1	ENV**	0	
5	1	1	ENV**	0	
6	1	1	ENV**	0	
7	1	0		1	ENV**, MSP****
Total	6	4		2	

* Michigan Department of Community Health; Radiation Safety Section
**Michigan Department of Environmental Quality
***NRC Region III
****Michigan State Police; Emergency Management Division

MINNESOTA

Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	1	PH*	0	
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	1	MPCA**	0	
7	1	1	PH*	0	
Total	6	6		0	

*Minnesota Department of Health; Environmental Health Division; Indoor Environment & Radiation; Radioactive Materials Unit

**Minnesota Pollution Control Agency

MISSISSIPPI

Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	1	1	PH*	0	
3	1	1	PH*	0	
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	1	ENV**	0	
7	1	1	PH*	0	
Total	7	7		0	

*Mississippi State Department of Health; Radiation Health Division

**Mississippi Department of Environmental Quality

MISSOURI					
Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	0		1	PH*, NRC***
4	1	1	PH*	0	
5	1	1	ENV**	0	
6	1	1	ENV**	0	
7	1	1	PH*	0	
Total	6	5		1	

*Missouri Department of Health & Senior Services; Section of Environmental Public Health; Radiation Control Program

**Missouri Department of Natural Resources

***NRC Region III

MONTANA					
Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	0		1	PH*, NRC***
4	1	1	ENV**	0	
5	0				
6	1	1	PH*	0	
7	0				
Total	4	3		1	

*Montana Department of Health and Human Services; Quality Assurance Division

**Montana Department of Environmental Quality

***NRC Region IV

NEBRASKA					
		Function within one agency		Function split between agencies	
Functions	Availability Yes – 1 / No - 0	Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	1	PH*	0	
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	0		1	PH*, ENV**
7	1	1	PH*	0	
Total	6	5		1	

*Nebraska Department of Health & Human Services; Division of Public Health; Office of Radiological Health

**Nebraska Department of Environmental Quality

NEVADA					
		Function within one agency		Function split between agencies	
Functions	Availability Yes – 1/ No - 0	Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	1	PH*	0	
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	1	ENV**	0	
7	1	1	PH*	0	
Total	6	6		0	

*Nevada Department of Health & Human Services; State Health Division; Bureau of Health Protection Services; Radiological Health Section

**Nevada Department of Conservation and Natural Resources

NEW HAMPSHIRE

Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	1	PH*	0	
4	1	1	ENV**	0	
5	1	1	PH*	0	
6	0				
7	1	1	PH*	0	
Total	5	5		0	

*New Hampshire Department of Health & Human Services; Division of Public Health; Bureau of Prevention Services; Radiological Health Section

**New Hampshire Department of Environmental Services

NEW JERSEY

Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	ENV*	0	
2	1	1	ENV*	0	
3	1	1	ENV*	0	
4	1	1	ENV*	0	
5	1	1	ENV*	0	
6	1	0		1	ENV*, NJLLRW***
7	1	1	DLPS**	0	
Total	7	6		1	

*New Jersey Department of Environmental Protection

**New Jersey Department of Laws and Public Safety; Division of State Police

***New Jersey Low-Level Radioactive Waste Disposal Facility Sitting Board

NEW MEXICO					
Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	ENV*	0	
2	0				
3	1	1	ENV*	0	
4	1	1	ENV*	0	
5	1	1	ENV*	0	
6	1	1	ENV*	0	
7	1	1	ENV*	0	
Total	6	6		0	

*New Mexico Environment Department; Radiation Control Bureau

NEW YORK					
Functions	Availability Yes – 1 / No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	0		1	PH*, NYC****
2	1	1	DOL**	0	
3	1	0		1	PH*, ENV***, NYC****
4	1	1	PH*	0	
5	1	1	ENV***	0	
6	1	1	ENV***	0	
7	1	1	PH*	0	
Total	7	5		2	

*New York State Department of Health; Center for Environmental Health; Bureau of Environmental Radiation Protection

** New York Department of Labor

***New York State Department of Environmental Conservation

****New York City Department of Health; Bureau of Environmental Radiation Protection; Office of Radiological Health

NORTH CAROLINA					
Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	ENV*	0	
2	1	1	ENV*	0	
3	1	1	ENV*	0	
4	1	1	ENV*	0	
5	1	1	ENV*	0	
6	1	1	ENV*	0	
7	1	1	ENV*	0	
Total	7	7		0	

*North Carolina Department of Environment and Natural Resources

NORTH DAKOTA					
Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*		
2	0				
3	1	1	PH*		
4	1	1	PH*		
5	1	1	PH*		
6	1	1	PH*		
7	1	1	PH*		
Total	6	6		0	

*North Dakota Department of Health; Environmental Health; Division of Air Quality; Radiation and Indoor Air Branch

OHIO					
Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	1	PH*	0	
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	1	PH*	0	
7	1	0		1	PH*, EMA**
Total	6	5		1	

*Ohio Department of Health; Bureau of Radiation Protection

**Ohio Emergency Management Agency; Radiological Branch

OKLAHOMA					
Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	ENV*	0	
2	1	1	ENV*	0	
3	1	1	ENV*	0	
4	1	1	ENV*	0	
5	1	0		1	ENV*, US DOE**
6	1	1	ENV*	0	
7	1	1	ENV*	0	
Total	7	6		1	

*Oklahoma Department of Environmental Quality

**U.S. Department of Energy, Atmospheric Radiation Monitoring Program

OREGON					
		Function within one agency		Function split between agencies	
Functions	Availability Yes – 1/ No - 0	Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	1	PH*	0	
4	1	1	PH*	0	
5	0				
6	1	1	OR DOE**	0	
7	1	0		1	PH*, OR DOE**
Total	5	4		1	

*Oregon Department of Human Services; Public Health Division; Office of Environmental Public Health; Radiation Protection Services

**Oregon Department of Energy

PENNSYLVANIA					
		Function within one agency		Function split between agencies	
Functions	Availability Yes – 1/ No - 0	Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	ENV*	0	
2	0				
3	1	1	ENV*	0	
4	1	1	ENV*	0	
5	1	1	ENV*	0	
6	1	1	ENV*	0	
7	1	1	ENV*	0	
Total	6	6		0	

*Pennsylvania Department of Environmental Protection

RHODE ISLAND

Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	1	1	PH*	0	
3	1	1	PH*	0	
4	1	1	PH*	0	
5	0				
6	1	0		1	PH*, RI AEC**
7	0				
Total	5	4		1	

*Rhode Island Department of Health; Division of Environmental & Health Regulation; Radiological Health Program

**Rhode Island Atomic Energy Commission

SOUTH CAROLINA

Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	1	1	PH*	0	
3	1	1	PH*	0	
4	1	1	PH*	0	
5	0				
6	1	1	PH*	0	
7	1	1	PH*	0	
Total	6	6		0	

*South Carolina Department of Health and Environmental Control; Deputy Commission for Health Regulation; Bureau of Radiological Health & Deputy Commission for Environmental Quality Control; & Bureau of Land and Waste Management; Division of Waste Management

SOUTH DAKOTA					
		Function within one agency		Function split between agencies	
Functions	Availability Yes – 1/ No - 0	Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	0		1	PH*, NRC***
4	1	1	ENV**	0	
5	0				
6	1	1	ENV**	0	
7	1	1	ENV**	0	
Total	5	4		1	

*South Dakota Department of Health; Office of Licensure and Certification; Radiological Health

**South Dakota Department of Environment & Natural Resources

***NRC Region IV

TENNESSEE					
		Function within one agency		Function split between agencies	
Functions	Availability Yes – 1/ No - 0	Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	ENV*	0	
2	0				
3	1	1	ENV*	0	
4	1	1	ENV*	0	
5	1	1	ENV*	0	
6	1	1	ENV*	0	
7	1	1	ENV*	0	
Total	6	6		0	

*Tennessee Department of Environment and Conservation

TEXAS

Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agencies	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	1	1	PH*	0	
3	1	0		1	PH*, ENV**, TX RC***
4	1	1	PH*	0	
5	1	1	ENV**	0	
6	1	1	ENV**	0	
7	1	1	PH*	0	
Total	7	6		1	

*Texas Department of State Health Services; Division for Regulatory Services; Environmental & Consumer Safety; Inspection Unit; Radiation Branch

**Texas Commission on Environmental Quality

***Texas Railroad Commission

UTAH

Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	ENV*	0	
2	0				
3	1	1	ENV*	0	
4	1	1	ENV*	0	
5	1	1	ENV*	0	
6	1	1	ENV*	0	
7	1	1	ENV*	0	
Total	6	6		0	

*Utah Department of Environmental Quality

VERMONT					
Functions	Availability Yes – 1/ No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	0		1	PH*, NRC***
4	1	1	PH*	0	
5	1	1	PH*	0	
6	0				
7	1	1	EMA**	0	
Total	5	4		1	

*Vermont Department of Health; Division of Health Protection; Radiation Control Program

**Vermont Emergency Management Agency

***NRC Region I

VIRGINIA					
Functions	Availability Yes - 1 / No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	1	PH*	0	
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	1	ENV**	0	
7	1	0		1	PH*, EMA***
Total	6	5		1	

*Virginia Department of Health; Office of Epidemiology; Division of Radiological Health

**Virginia Department of Environmental Quality

***Virginia Department of Emergency Management

WASHINGTON					
		Function within one agency		Function split between agencies	
Functions	Availability Yes - 1 / No - 0	Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	1	PH*	0	
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	1	WA DOE**	0	
7	1	1	PH*	0	
Total	6	6		0	

*Washington State Department of Health; Division of Environmental Health; Office of Radiation Protection

**Washington Department of Ecology

WEST VIRGINIA					
		Function within one agency		Function split between agencies	
Functions	Availability Yes - 1 / No - 0	Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	0				
3	1	0		1	PH*, NRC**
4	1	1	PH*	0	
5	0				
6	1	1	PH*	0	
7	1	1	PH*	0	
Total	5	4		1	

*West Virginia Department of Health & Human Resources; Bureau of Public Health; Office of Environmental Health Services; Radiation, Toxics & Indoor Air Division; Radiological Health Program

**NRC Region II

WISCONSIN

Functions	Availability Yes - 1 No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	1	1	PH*	0	
2	1	1	PH*	0	
3	1	1	PH*	0	
4	1	1	PH*	0	
5	1	1	PH*	0	
6	1	1	WI DOA**	0	
7	1	1	PH*	0	
Total	7	7		0	

*Wisconsin Department of Health and Family; Division of Public Health; Bureau of Environmental Health; Radiation Protection Section

**Wisconsin Department of Administration

WYOMING

Functions	Availability Yes - 1 No - 0	Function within one agency		Function split between agencies	
		Yes - 1/No - 0	Agency	Yes - 1/No - 0	Agencies
1	0				
2	1	1	WY DOA*	0	
3	1	0		1	WY HS**, NRC***
4	1	1	PH****	0	
5	0				
6	1	1	ENV*****	0	
7	0				
Total	4	3		1	

*Wyoming Department of Agriculture; Board of Cosmetology

**Wyoming Office of Homeland Security

***NRC Region IV

****Wyoming State Department of Health; Preventive Health & Safety Division; Radon Program

*****Wyoming Department of Environmental Quality