An analysis of effect of local exhaust ventilation on tritium surface contamination in a governmental facility

by

Steven Gary Flann

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Industrial and Agricultural Technology

Program of Study Committee:
Steven A. Freeman, Major Professor
Dennis Field
Daniel Bullen

Iowa State University

Ames, Iowa

2006

UMI Number: 1439842

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

Thank you to all my family and friends who supported me during this journey. I have spent considerable time away from all of you pursuing this goal and I appreciate your support in achieving this milestone. To Dr. Freeman, Dr. Bullen, and Dr. Field who had the patience and expertise to guide me during this process. Through your coaching, I have not only grown professionally, but also personally. Throughout my life I will continuously benefit from the knowledge I gained from this experience.

ABSTRACT

The objective of this study was to analyze the effectiveness of local exhaust ventilation on tritium surface contamination in a governmental maintenance and repair facility. Samples for this study were drawn from quarterly and suspected contamination swipes over a six year period and analyzed for tritium contamination utilizing a scintillation technique. The dependent variable selected was a measurement which determined whether tritium surface contamination was present. Three models were utilized to help determine the relationships between the independent variables ("location," "time," "swipe," and "test,") and the dependent variable (tritium surface contamination). Logistical regression was used to analyze radiation contamination. Through this, it was demonstrated that a significant relationship exists between "swipe" and tritium surface contamination. The evidence also indicates there is a difference between "test," pre-local exhaust ventilation and post-local exhaust ventilation, and tritium surface contamination.

CHAPTER 1. INTRODUCTION

Introduction

Radiation plays an important role in today's society. Radioactive materials are used in generating electric power, manufacturing, industrial processes, and for medical diagnosis or therapy. Industrial applications of radioactive material can include inspection operations such as examining the integrity of welded joints or measuring the thickness of paper as it is produced. Sealed radioactive sources are also used extensively in oil and gas exploration, drilling operations, and to check the compactness of roadbeds during paving operations (DOT-RAMREG-001-98, 1998). Although there are beneficial uses for radiation, there can be many risks associated with its use.

New information is being presented every day concerning the effects of radiation exposure to humans. In 1999, the Department of Energy initiated a $220 million study spanning ten years to determine health effects of low exposures to radiation (Edwards, 2002). This research was designed to better validate the effects of very low radiation levels at the cellular level. Specifically, it addressed the cells' response to radiation damage, thresholds for low-dose radiation effects, and features distinguishing radiation-caused cell damage from damage from other, intra-cellular causes (Edwards, 2002).

In response to many known and unknown risk factors, regulatory agencies and professionals in the field of radiation safety have taken it upon themselves to do everything possible to limit radiation exposures. Radiation safety professionals try to limit radiation exposure to As Low As Reasonably Achievable (ALARA). ALARA means making every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as practical.

The effects of radiation exposures to humans are not the only concern. It is necessary to understand the costs of decontaminating these sites after a radiation incident has occurred. Radiation clean-up costs can vary widely depending on the location, operation, and radioactive material being utilized. For instance, in 1983 there was an incident in Auburn, New York that involved a cobalt-60 source that was inadvertently melted down at a steel mill. The result of the incident was a contaminated electric-arc furnace and the plant was shut down for several weeks. The total decontamination cost for this incident was $2.2 million (Rad/Comm Systems, 2003).

In May 2004, a steel mill accidentally melted a radioactive source that was imbedded in scrap steel (Rad/Comm Systems, 2003). This plant was shut down for 11 days to clean up the affected areas. The total decontamination cost for this site was $15 million. While these are extreme examples, even the smallest radiation incident can cost thousands of dollars to decontaminate. In 1996, a small-scale governmental operation dealing with tritium radioluminescent devices had an incident that released tritium gas (Department of Energy, 1998). Total decontamination for this site cost more than $60,000. These small-scale governmental sites are the focus of this study.

Small-scale radioactive sites can contain minute amounts of radioactive material. There are eighty sites, like the one discussed in this study, that contain less than 100 curies of tritium stored at any given time (Department of Defense, 2003). These operations focus on testing, calibrating, and repairing systems containing tritium radioluminescent devices. The tritium is encapsulated in Pyrex containers. Activity levels of the equipment at these facilities are between .0025-10.0 curies (DOD, 2003). There can always be a chance of possible radiation contamination when moving equipment between calibrating fixtures. The Pyrex containers are relatively fragile and can break. Thus, there also is a chance that Pyrex containers may break when the equipment is being purged with compressed gas. If Pyrex containers do break, a powder-like radioactive material is immediately released into the air.

These sites are not required, nor do they have the resources required to utilize sensitive equipment that has the capability to constantly monitor air releases or exposures to humans like the large-scale nuclear operations (Philippi, 1996). However, it is prudent to analyze large-scale specialized labs and nuclear power plants for best practices and benchmarking when trying to limit or reduce surface contamination.

Biological research labs and nuclear power plants have been utilizing negative pressure ventilation to control contaminants for years. It is important to note that most of the large-scale facilities that store or utilize significant quantities of radioactive material are mandated by law and have extensive resources to control or limit contamination (GOE FDR 1 01-07-13 R1.0, 2001). These requirements include expansive radiological and environmental monitoring systems located throughout the facility (IFEU, 2001). Small-scale sites, such as the one in this study, are not required to utilize these expensive control methods and/or simply do not have the sufficient capital to implement expansive engineering control methods.

However, the basic control methods used at large-scale sites to help limit or reduce contamination can also be implemented at small-scale facilities for a limited investment.

Small-scale sites in the past have utilized fume hoods and other negative pressure ventilation methods (LANL, 2002). These procedures have not addressed several issues that have been difficult to resolve. The operations in this study necessitate continual adjustment and calibration of the radioactive component/equipment. In order to calibrate, repair, and maintain the component, the process often involves utilizing multiple mounting fixtures that make use of fume hoods or glove boxes difficult, if not impossible.

An “elephant trunk” local exhaust ventilation system may be of use at these small-scale operations. When tritium gas is released, it acts like a fine dust dispersing into the atmosphere and covering all surfaces (e.g., doorknobs, tools, fixtures, etc.). Catching those contaminants before they reach the breathing zone of the employee and/or are dispersed throughout the room contaminating all contents within the room is crucial. Because of the difficulty of containing tritium gas and utilization of multiple mounting fixtures in the repair process; it is necessary to test new methods of eliminating surface contamination within these small-scale facilities. The ultimate goal is to reduce radiation surface contamination within the facility. While evaluating worker exposure is not within the scope of this study, it is important to note that reducing surface contamination also has implications for reducing workers exposure to radiation.

Problem of the Study

The problem of this study is to determine the effects of local exhaust ventilation on the amount of tritium surface contamination in a governmental facility. Without the ability to utilize fume hoods or glove boxes in these radiation processes, basic strategies for radiation containment are ineffective. Continuing human and economic losses are a direct result of ineffective radiation containment.

Need for the Study

In the 2000, a local exhaust ventilation (LEV) was implemented in a small-scale governmental radiation lab to control contamination (DOD, 2000). Since its inception, the effectiveness of the system has not been evaluated. Because it is paramount that safety professionals evaluate newly implemented equipment to verify its operational effectiveness, this study is necessary. This evaluation will identify if the local exhaust ventilation evacuates contaminants in the radiation lab. Specifically, this study will determine whether the local exhaust ventilation had an impact on surface contamination in the radiation work area.

Over eighty governmental facilities throughout the United States have operations similar to those at this governmental facility. Currently, no other facilities use local exhaust ventilation in the manner discussed (DOD, 2000). This research will enable radiation safety managers to make informed decisions on the use of local exhaust ventilation at their facilities.

There are no regulatory requirements that require the facility, in this study, to utilize local exhaust ventilation. This site stores small amounts of tritium and personnel are authorized to repair, calibrate, and test the equipment within the facility. Because of different operations or procedures, other locations may be able to use glove boxes or fume hoods to protect its workers from tritium exposure and surface contamination. However, personnel at the site in this study repair, test and calibrate its equipment on special mounting fixtures and are constantly moving the equipment between fixtures. The option identified best for its operation was moveable flexible LEV.

The local exhaust ventilation was implemented with the hope that it would minimize or eliminate the surface contamination. Current decontamination procedures can cost $60,000 or more. The safety committee at the facility believed that the inclusion of local exhaust ventilation system, in cooperation with administrative controls, would increase worker safety. The company addressed many of the impacts that radiation contamination may have on an organization. These impacts included: risk to the employees, lost production time, and cost of decontamination. Thus, the system was implemented with the hope that it would reduce or eliminate radiation surface contamination.

Assumptions of the Study

1. Local exhaust ventilation can have a positive effect on radiation contamination reduction in the workplace.
2. Local exhaust ventilation can help remove the health hazards from the workplace.

Delimitation's of the Study

1. This study focused on one local exhaust ventilation system in a small-scale governmental testing, calibration, and repair operation dealing with tritium radioluminescent devices.
2. This study did not evaluate: fume hoods, glove boxes, other radiation sources or contaminants, airborne contaminants, tritiated water contaminants, or workers exposure to radiation.

Procedures for the Study

The procedure of this study implemented a local exhaust ventilation system in a governmental testing, calibration, and repair operation dealing with tritium radioluminescent devices. The goal of the local exhaust ventilation implementation was to reduce the surface contamination in the radiation lab measured utilizing nitrocellulose filters and scintillation.

Definition of Terms

ALARA: Acronym for "as low as (is) reasonably achievable." ALARA means making every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as practical, consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest (NRC, 2004).

Becquerel (Bq): The amount of radioactive material undergoing 2.22 x10^12 disintegration's per minute (dpm) (CECOM, 1999).

Beta particle: Ionizing radiation particle emitted from the nucleus with a –1 charge and mass of an electron (CECOM, 1999).

Curie (Ci): The basic unit used to describe the intensity of radioactivity in a sample of material. The curie is equal to 37 billion (3.7×10^{10}) disintegrations per second, which is approximately the activity of 1 gram of radium. A curie is also a quantity of any radionuclide that decays at a rate of 37 billion disintegrations per second. It is named for Marie and Pierre Curie, who discovered radium in 1898.

DPM: Disintegrations Per Minute, The number of subatomic particles (e.g. alpha particles) or photons (gamma rays) released from the nucleus of a given atom over one second. One dps = 60 dpm (disintegrations per minute).

Electron volt (eV): The energy of an electron under a potential difference of one volt. Equal to 1.6x10^-19 joule. The electron volt is used with all multiple, sub-multiple, and prefixes now in common use. The most common are the MeV (million electron volts) and the keV (thousand electron volts) (CECOM, 1999).

Geiger-Mueller Counter: A radiation detection and measuring instrument. It consists of a gas-filled tube containing electrodes, between which there is an electrical voltage, but no current is flowing. When ionizing radiation passes through the tube, a short, intense pulse of current passes from the negative electrode to the positive electrode and is measured or counted. The number of pulses per second measures the intensity of the radiation field. It was named for Hans Geiger and W. Mueller, who invented it in the 1920s. It is sometimes called simply a Geiger counter or a G-M counter and is the most commonly used portable radiation instrument (NRC, 2004).

Half-life: The time in which one half of the atoms of a particular radioactive substance disintegrate into another nuclear form. Measured half-lives vary from millionths of a second to billions of years. Also called physical or radiological half-life (NRC, 2004).

HEPA: High Efficiency Particulate Air filters

Ionizing radiation: Any electromagnetic (EM) or particulate radiation that will directly or indirectly result in ionization (CECOM, 1999).

LEV: Local Exhaust Ventilation

Nitrocellulose filter: Composed of 100% pure nitocellulose to provide high-quality transfer with low background, contains no fabric or detergents, compatible with commonly used transfer conditions and detection methods such as staining, immunodetection, fluorescence, or radiolabeling (SignaGen, 2004).

Radioisotope: An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation. Approximately 5,000 natural and artificial radioisotopes have been identified (NRC, 2004).

Radioluminescence (RL): The process of providing illumination from the activation of a phosphor by energy from radioactive decay (CECOM, 1999).

Radioluminescent device: An illuminating device consisting of a phosphor and a radiation source. Phosphor and gaseous radiation sources are usually contained in a glass vial or ampule. The phosphor and radiation source may be solid and deposited on the surface of a dial or scale (CECOM, 1999).

Scintillation detector: The combination of phosphor, photomultiplier tube, and associated electronic circuits for counting light emissions produced in the phosphor by ionizing radiation (NRC, 2004).

Sealed source: Any radioactive material or byproduct encased in a capsule designed to prevent leakage or escape of the material (NRC, 2004).

Survey meter: Any portable radiation detection instrument especially adapted for inspecting an area or individual to establish the existence and amount of radioactive material present (NRC, 2004).

Tritium: A radioactive isotope of hydrogen (one proton, two neutrons). Because it is chemically identical to natural hydrogen, tritium can easily be taken into the body by any ingestion path. It decays by beta emission. It has a radioactive half-life of about 12.5 years (NRC, 2004).

Wipe Sample: A sample made for the purpose of determining the presence of removable radioactive contamination on a surface. It is done by wiping, with slight pressure, a piece of soft filter paper over a representative type of surface area. It is also known as a "swipe" or "smear" sample (NRC, 2004).

CHAPTER 2. LITERATURE REVIEW

Literature Review Methodology

The researcher made industrial and professional contacts throughout the last several years at professional safety conferences, national radiation seminars and other work settings. Several Internet resources and libraries were utilized to construct the literature review. The focus of the review dealt with radiation ventilation and contamination.

The libraries used for the literature review resources, references, dissertations, journals, and books included the following: Iowa State University Parks Library, Drake University Cowles Library and on-line libraries. Examples of web-based tools included search engines such as: Yahoo, MSN, Google, Alta Vista, Fast Search, Lycos, Excite, AOL, and Info Highway Search.

Keyword search terms included the following: tritium safety, tritium contamination, tritium ventilation, H-3 safety, H-3 contamination, H-3 ventilation, radiation safety, radiation contamination, radiation ventilation, fume hoods, glove boxes, local exhaust ventilation, radiation safety programs, limiting radiation contamination, radiation containment, tritium surface contamination, radiation incidents, NRC, working with tritium, radiation statistics, local exhaust used in radiation, containing radiation leaks, tritium, health effects of radiation, luminescent radiation sources, reduce tritium airborne concentrations, exposure to radiation, tritium source cells, exposure levels, radiation program evaluation, local exhaust ventilation controls, ALARA, facility decontamination, tritium cleanup, radiological monitoring, radiation protection, controlling airborne hazards, ventilation, air control systems, controlling radiation release, lab ventilation controls, industrial hygiene, hydrogen isotope, and airborne dusts.

Databases utilized to locate industry information resources for this research included the Nuclear Regulatory Commission (NRC); American Conference of Governmental Industrial Hygienists (ACGIH), American Industrial Hygiene Association (AIHA), Occupational Safety and Health Administration (OSHA), Iowa Occupational Safety and Health Administration (IOSHA), National Institute of Occupational Safety and Health (NIOSH), Department of Energy (DOE), Centers for Disease Control (CDC), Environmental Protection Agency (EPA), Agency for Toxic Substances and Disease Registry (ATSDR), National Cancer Institute (NCI), Los Alamos National Laboratory (LANL), Idaho National Engineering and Environmental Laboratory (INEEL), and Argonne National Laboratory (ANL).

Tritium Properties

Tritium is a radioisotope of hydrogen and has a half-life of 12.26 years (Figure 2.1). It decays into He^3, a stable isotope, by the emission of a beta particle of a maximum energy of 18 keV (CECOM, 2002). Tritium is the only radioactive isotope of hydrogen; however, it still shares many of the same chemical properties. Tritium has a relatively high specific activity and is generated by both natural and artificial processes.

Tritium History

The United States has not produced tritium since 1988 when the Department of Energy (DOE) closed its tritium production facility in South Carolina (NRC, 2005).

Radioactive Properties of Tritium

Isotope	Half-Life *(yr)*	Natural Abundance *(%)*	Specific Activity *(Ci/g)*	Decay Mode	Radiation Energy *(MeV)*		
					Alpha *(α)*	Beta *(β)*	Gamma *(γ)*
H-3	12	a trillionth	9,800	β	-	0.0057	-

Ci = curie, g = gram, and MeV = million electron volts; a dash means the entry is not applicable. (See the companion fact sheet on Radioactive Properties, Internal Distribution, and Risk Coefficients for an explanation of terms and interpretation of radiation energies.) Values are given to two significant figures.

Figure 2.1. Radioactive Properties of Tritium (ANL, 2001)

Immediate tritium needs are being met by recycling tritium from dismantled U.S. nuclear weapons (Department of Energy, 1998).

There are new developments being made in artificial tritium production. The Department of Energy has experimented with developing a technology for producing tritium in pressurized water reactors that use lithium, rather than boron (which is normally used), as a neutron absorber (NRC, 2005). As a result of irradiation by neutrons in the reactor core, lithium in special rods will be converted to tritium. The rods can then be removed from the fuel assemblies and the tritium extracted by Department of Energy personnel (Department of Energy, 1998).

Tritium Presence

Tritium is present in small amounts of water in vapor and liquid forms (ANL, 2001). Interactions of cosmic radiation with gases in the upper atmosphere result in tritium production and the natural steady-state global inventory is estimated to be about 7 kilograms. Tritium enters the hydrologic cycle through water falling to earth as it rains (ANL, 2001).

An additional way that tritium is produced in the environment is through nuclear weapons tests (ANL, 2001). These tests account for about five times the amount of tritium found in the natural environment. This tritium is produced as a “fission product with a yield of about 0.01%… or about one atom of tritium is produced per 10,000 fissions” (ANL, 2002).

Scientists have had to find ways to artificially produce tritium on a larger scale because of the lack of naturally occurring tritium in the environment (DOE, 1998). They have turned in many cases to production nuclear reactors to meet the needs of tritium generation. One process involves neutron absorption of a lithium-6 atom. “The lithium-6 atom, with three protons and four neutrons and the absorbed neutron combine to form an atom of tritium and an atom of helium-4. The United States has recovered an estimated 225-kg of tritium, of which 150 kg has decayed into helium-3, leaving a current inventory of approximately 75 kg” (ANL, 2001). To give you an idea of the complexity of the process, a large commercial nuclear power reactor could produces about 2 grams of tritium a year (DOE, 1998).

Tritium in the Body

Routine daily functions like drinking water, eating food, or breathing air are all ways that tritium can get into the human body (ANL, 2001). Tritium is a low-energy beta particle emitter. This means that it has significant difficulties in penetrating substances or traveling significant distances through air (Mathew, 2002). A piece of paper or human skin has the capabilities to stop the penetration of this low-energy beta particle. Hence, tritium generally must be ingested, inhaled or injected into the body to pose a health hazard (ANL, 2001). The health hazard associated with tritium uptake is cell damage caused by the ionizing radiation that results from radioactive decay (Edwards, 2002). This cell damage could allow the subsequent induction of cancer development (ANL, 2001) (Figure 2.2).

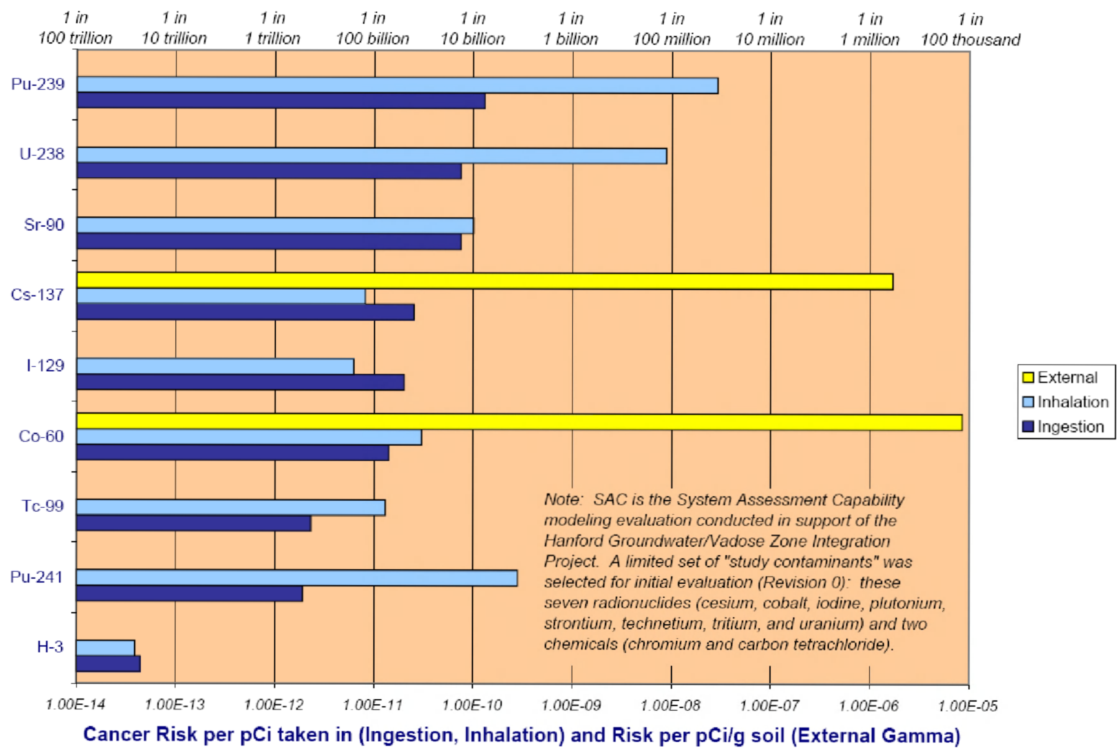


Figure 2.2. Cancer Risk (ANL, 2001)

Inhaled tritium can be taken into the body from the lungs, and will be distributed throughout the human body from blood circulation. Once absorbed it moves quickly from the gastrointestinal tract to the bloodstream. Studies have found that within minutes of being introduced into the human body, it is detectable in varying concentrations in body fluids, organs, and other tissues (Figure 2.3).

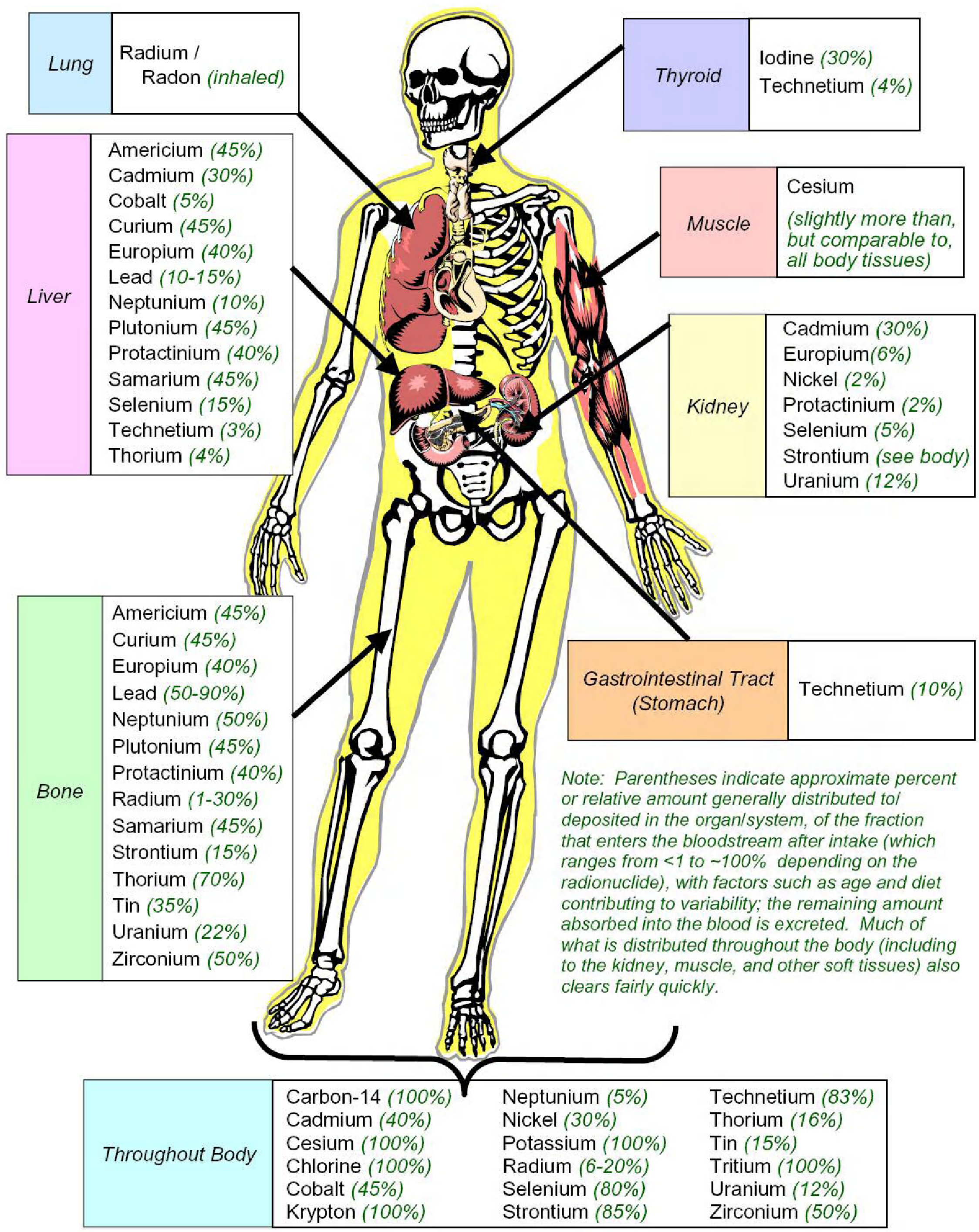


Figure 2.3. Radiation health effects (ANL, 2001)

Depending on the conditions, skin absorption of tritium can be a major concern for exposure. For instance, if a tritium cloud incident occurred in a location with high humidity associated with hot weather. Because of normal body mechanism of sweating and movement of water through the skin, a person may be more susceptible to an exposure of high concentrations of tritium through absorption. However, the uptake of tritium through absorption would still be half that associated with inhalation (ANL, 2001).

Regardless of the exposure method into the body, tritium is uniformly distributed through all biological fluids within a very short period of time, usually one to two hours. Because tritium mimics water in it's' behavior, tritium is eliminated from the body with a biological half-life of 10 days (ANL, 2001).

There are several risks associated with low dose exposures from radiation. One risk is genetic, "genetic effects are biological effects of radiation that result in mutations, or changes, in the genes of the reproductive system and are observed in the descendants of the exposed person. Mutations occur in all living organisms and agents such as radiations or chemicals can induce them" (NRC, 1996). This implies that the smallest exposure to radiation may trigger a genetic effect. The relationship between exposure and delayed effects is difficult to establish. First, other agents in the environment can cause effects such as cancer. Second, long periods may elapse between an exposure and observation of any effect (Schleien, 1992). Exposure to tritium may also have immeasurable biological effects:

> tritium contamination and airborne radioactivity are biological hazards. If you breathe tritium oxide (tritiated water vapors) or it contacts your skin, the tritium will be absorbed by your body. Studies have shown that a person exposed to an atmosphere containing tritiated vapor will absorb about one-third to one-half as much tritium through the skin as via inhalation (i.e., one-third through the skin and two-thirds via inhalation).

> Therefore, release of tritium into a closed space may constitute a very serious internal hazard. Tritium distributes equally among all body fluids because these fluids contain water. All tissue in contact with body fluids will be exposed. These tissues are all soft tissues and make up about 90 percent of the body. (Schleien, 1992)

Tritium can come in many forms, metal tritides, tritiated pump oil, and tritium gas (DOE, 2002). It can be used in hydrological studies, tracers for biological research, luminous paints, and activators in phosphor light sources (CECOM, 2002). Tritium is the most common radioisotope used for illuminating equipment such as: "meter faces, dials, compasses, watches, telescopes, fire control devices, rifle sights, and radio-luminous devices" (Department of Defense, 1998). Tritium gas encapsulated in glass ampoules used in radio-luminous devices will be the focus of this evaluation (Figure 2.4).

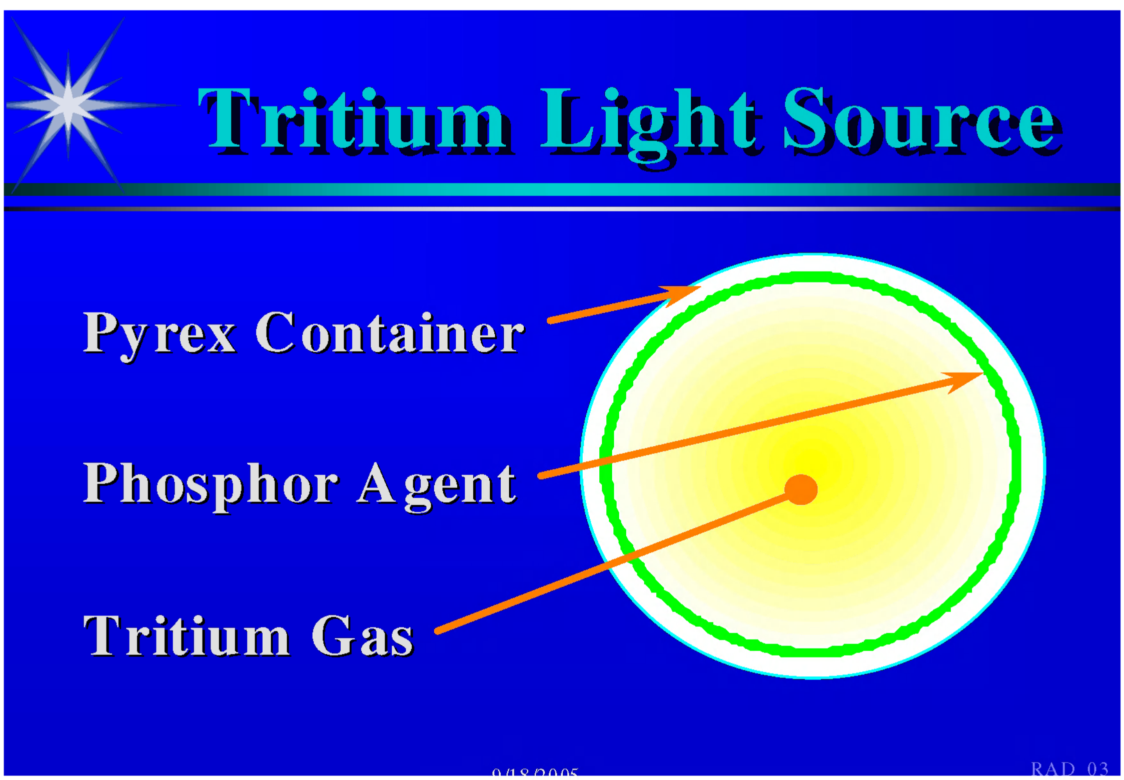


Figure 2.4. Capsulated tritium light source (Department of Defense presentation, 2003)

There is always a risk that a failure with the Pyrex container or a significant force to the equipment could break an ampoule and release tritium gas into the room:

> airborne tritium released to room air moves readily with normal air current. The room or building ventilation system should be designed to prevent the air from being carried to uncontaminated areas, such as offices or other laboratories where tritium is not allowed. For that reason, differential pressure zoning is commonly used, and released tritium is directed outside through the building stack. In some newer facilities where large quantities of tritium are being handled, room air cleanup systems are available for emergency use. Following a significant release, the room ventilation system is effectively shut down, the room is isolated, and cleanup of room air is begun. (DOE-HDBK-1079-94, 1994)

This dispersion is particularly hazardous because tritium then can be introduced into the body through inhalation. LEV should limit the dispersion of tritium in the atmosphere resulting in a reduced amount of tritium inhaled by the radiation worker. The control of tritium gas as it escapes the broken ampoule should also limit surface contamination in the radiation work area.

Local Exhaust Ventilation

Safety professionals and industrial hygienists utilize many strategies to protect workers from hazardous contaminants. They understand that duration, frequency, and intensity of exposure all add to the risks of disease or damage to health (Martin, 2002). Control measures for employees should include substitution to a less harmful substance, alteration of the process to minimize contact, and/or engineering controls in conjunction with training and education. Engineering controls, specifically local exhaust ventilation, often dominate industrial hygiene hazard prevention and control practice literature (Martin, 2002).

Many facilities utilize LEV in its operations to provide a safer work environment for its employees. These operations involve dust, vapors, fumes, and many other hazards. In identifying close to ninety articles containing contaminants in the workplace, almost seventy-five percent had LEV as a preventative measure (Roelofs, 2003).

There have been many studies that have evaluated the effectiveness of commercially available local exhaust ventilation in controlling dust. Researchers have found that utilizing local exhaust ventilation has reduced exposures to contaminants by eighty percent (Croteau, 2002). Local exhaust ventilation systems operate on the principle of capturing a contaminant at or near its source. It is the preferred method of control because it can be extremely effective when used properly (ACGIH, 1998).

There are several main components of local exhaust ventilation. A LEV will usually contain a hood, duct system, air cleaning device and fan (Figure 2.5) (National Safety Council 1996, p. 554). There are many factors that can affect the performance of a LEV. The type of hood used, capture velocities, duct size, and contaminant characteristics can have an impact on the performance of the system (Teschke, 2002). However, the basic design principle remains the same, use a fan to exhaust contaminants from the breathing zone of a worker.

For small operations, ventilation is commonly provided at the work site through a moveable flexible ventilation duct, or “elephant trunk,” directed to the room exhaust system. The exhaust of these ducts is generally directed to the building ventilation exhaust system, which itself may be adequate to supply the needed airflow (ACGIH, 1998).

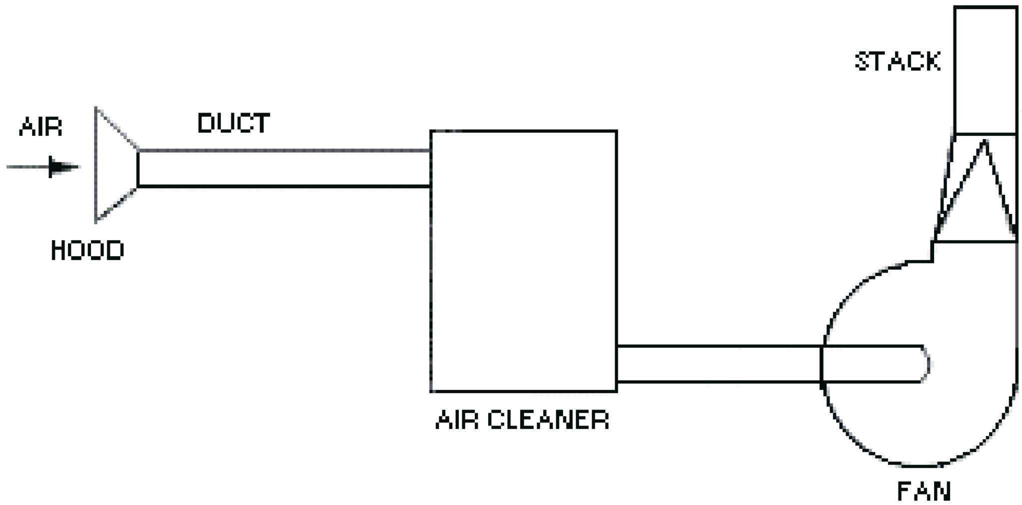


Figure 2.5. Local exhaust ventilation system components (OSHA, 2006)

Nuclear power plants utilize LEV to control tritium contamination (Philippi, 1996). These power plants are mandated to have extensive exhaust systems that can be continually monitored. In particular, "air radiation monitoring is provided in all areas where tritium is handled, processed or stored. The tritium monitoring system in the plant exhaust is redundant and is designed to remain operable under accidents and loss of normal electrical power. It provides real-time indication of tritium releases" (GAO FDR 101-07-13R1.0, 2001). However, many of these plants are more concerned with tritiated vapor than tritium gas. In fact, a major national laboratory has over 13,000 curies of tritium and they state, "although emissions of tritium gas are only partially reported, this is of minor importance due to the much lower toxicity compared to water containing tritium" (Franke, 2001).

Glove boxes (Figure 2.6) and Fume hoods (Figure 2.7) are commonly used at tritium facilities for handling or storing material with low quantities of tritium or with low-level contamination (LANL, 2002). For instance, when utilizing fume hoods, "any tritium released

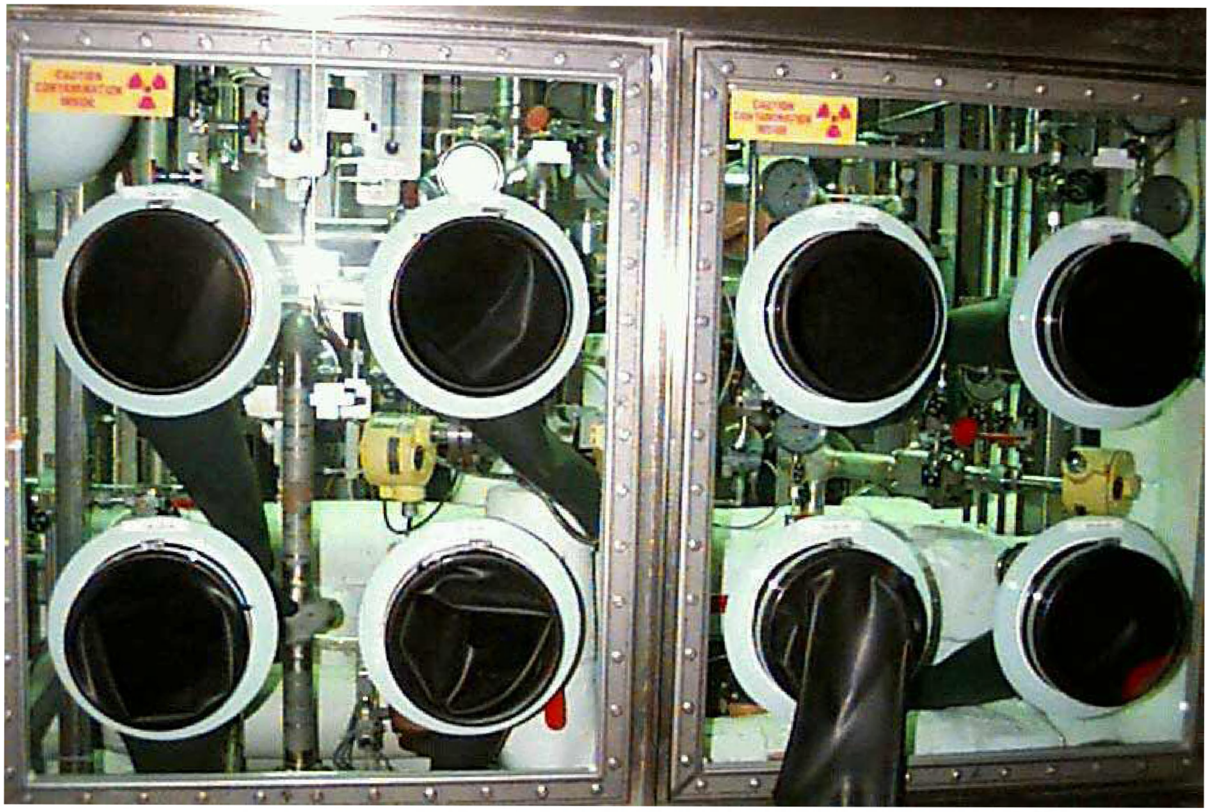


Figure 2.6. Radiation glove box (Department of Energy, 1998)

Figure 2.7. Fume hood (www.fumehood.com, 2003)

in a hood from outgassing or a leaky container…is routed to the hood's exhaust duct. However, turbulence may occur at the hood entrance, resulting in backwash and possible contamination of personnel if the face velocity is not adequate for the design of the hood" (DOE 1079-94, 2002).

The Princeton Plasma Physics Laboratory uses an "elephant trunk" system to draw airborne contaminants away from workers breathing zone (Raftopoulos, 2002). They utilize a 3", 6" and 12" diameter flexible hose. Their contaminants pass through a HEPA filter before being released to the stack. Stack monitors then measure tritium being released into the atmosphere to help identify potential problems early (Raftopoulos, 2002).

Measuring tritium surface contamination through routine monitoring of surface contamination is also important. "Experience at tritium laboratories has shown that many tritium exposures to personnel occur as a result of contact with highly contaminated surfaces" (DOE1079-94, 1994). To help reduce tritium surface contamination, exhaust systems can capture the contaminants at the source, thus, preventing further dispersion of the contaminants within the room and providing a more safe work environment for the employees.

A review of the scientific literature indicates a need for additional methods for controlling radiation contamination in small-scale facilities that utilize tritium. Researches and safety professionals have several engineering methods to choose from, but broadly implementing the systems to every possible process exposes limitations to current equipment.

CHAPTER 3. MATERIALS AND METHODS

Description of Data

The objective of this study was to analyze the effects of local exhaust ventilation. In achieving this, data was collected through swipes at a government facility from 1997-2003. Nitrocellulose filters (Figure 3.1) were used to take radiation swipe samples in designated areas throughout the facility. The swipe procedures for this study were established by the Department of Defense (DOD, 2003). After the swipes were collected, they were sent to an accredited lab, which applied a scintillation technique. This technique identifies radiation surface contamination that accumulates on the nitrocellulose filters during the swipe procedure.

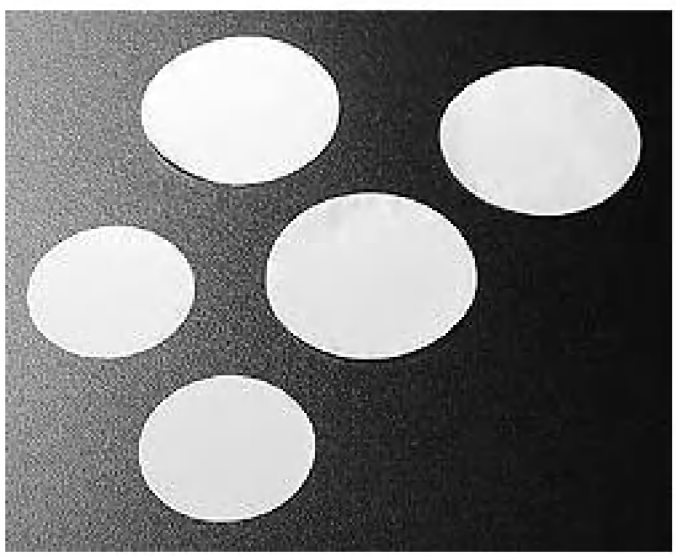


Figure 3.1. Nitrocellulose filters, 7cm x 8.5 cm, (SignaGen, 2003)

Two types of radiation swipes were used in this study: quarterly and contamination. Quarterly swipes were taken at specific intervals to periodically monitor possible surface contamination levels at the facility. Contamination swipes were used when there was evidence that contamination may have occurred. This contamination occurred either in the handling procedure or during the repair, testing, or evaluation of the radioactive material. Both of these swipe techniques used nitrocellulose filters.

Swipe Procedure

The Radiation Safety Officer course sponsored by the Department of Defense (2003) outlines the swipe procedures which are discussed below. To begin, this procedure requires two people; one to swipe surfaces with nitrocellulose filters, the other to hold the vials to prevent cross-contamination between these samples. The Department of Defense recommends the following swipe procedure:

1. Swipe tests can be used on any surface or piece of equipment where tritium contamination is suspected or where the routine quarterly sampling points are located. Broken devices should not be swiped. These broken devices should be double bagged in two plastic bags and tagged with the following information:
    a. "DO NOT OPEN, POSSIBLE RADIOACTIVE CONTAMINATION"
    b. Nomenclature, National Stock Number (NSN), and serial number
    c. Isotope and activity
    d. Quantity of isotope per NSN
    e. Name and telephone number so that additional information may be obtained
2. Two people are needed to perform swipes; one person to swipe, while the other holds the vial. This ensures no cross contamination between samples.
3. Those taking swipes must wear latex gloves. One person removes nitrocellulose filter from between the colored paper separators. (The nitrocellulose filter is white with very smooth surface.) Dampen nitrocellulose filter with approximately 20 drops of distilled water, the other person should open the vial.
4. Using the nitrocellulose filter, swipe approximately 4"x 4" area of the surface to be tested. For equipment, all accessible surfaces suspected of being contaminated should be swiped. Use one

nitrocellulose filter per location. Several swipes may be needed for a piece of equipment depending on size and possible contamination.

5. Each nitrocellulose filter should be carefully rolled and gently place inside the vial. Each nitrocellulose filter **MUST** have its own vial. Next, add 10 drops of deionized water inside of each of the vial.
6. Place an identifying number on the vial cap. DO NOT WRITE ON VIAL OR APPLY TAPE TO VIAL. This number corresponds to a location on the survey form to identify each location of the swipe.
7. Utilize the map survey form (Appendix D) to identify location of swipe.
8. Both people must remove and discard latex gloves in trash bag. Repeat this step after each swipe is taken. After the last swipe is taken, close the trash bag and tape it shut with duct tape. This bag will also be tested for contamination and then disposed of in accordance with local, state and federal regulations.
9. Next, fill out survey form (Appendix B). The control number must be recorded as follows. The first letter must be either an "I" for Incident or "Q" for Quarterly.
10. Carefully pack the vials to prevent breakage or spillage and submit to counting laboratory for analysis.
11. Ensure copies are kept and results "logged in" when received and identify those results that indicate high contamination levels. (DOD, 2003)

Sample

For this evaluation, 134 swipes were taken over a six-year period; specifically, 79 of these swipes were pre-ventilation and 55 were post-ventilation. Of the 79 pre-ventilation swipes, 72 were quarterly swipes and 7 were contamination swipes. Of the 55 post-ventilation swipes, 50 were quarterly swipes and 5 were contamination swipes (Appendix A).

Results that reveal surface contamination are reported with contamination numbers expressed as disintegrations per minute (dpm). However, because the scintillation process at the lab can only identify a contamination level of 13 dpm or greater, a result of 0 does not necessarily mean there is no contamination. If there is less than 13 dpm, the results state Lower than the Detectable Limit (LDL).

The components that are known to have a broken radiation source were placed in a pre-entry, limited access storage area. Swipes taken of these radiation sources were not included in this study. Further, 23 swipes were not used because the swipe location could not be verified on the survey form.

Materials

The following materials are needed for the swipe procedure:

1. Nitrocellulose filters
2. Liquid scintillation vials, clear 20 ml, with screw caps
3. Distilled or de-ionized water in eye dropper or similar container
4. Gloves, latex
5. Permanent marking pen
6. Trash bags
7. Duct tape

Description of Variables

In this study, independent and dependent variables were used. “Swipe,” “test,” and “y01” were broken down into dichotomous variables to be used in logistical regression. “Location” was an ordinal value and “time” was a sequential ordinal value to be used in logistical regression. A brief discussion of the independent and dependent variables is below and Table 3.1 contains additional descriptive data.

Table 3.1 Variables

VARIABLE	VARIABLE DESCRIPTION
Location	Location of the swipe, identified by: 1=Inside door knob 2=Azimuth test fixture 3=Telescope fixture 4=Cross level fixture 5=Work bench 6=Other
Swipe	Defines Quarterly or Contamination swipe 1=Quarterly; Routine swipes we perform every three months 2=Contamination swipes; These are taken if: • Suspect contamination because of physical evidence • There is a broken radioactive component • Verify surface contamination levels after decontamination because of confirmed contamination
Time	Based on sequential ordinal values by seasons. Lower number indicates earlier samples, higher number indicates more recent samples. 1=Spring (April-June) 1997 2=Summer (July-September) 1997 3=Fall (October-December) 1997 4= Winter (January-March) 1998 5=Summer (July-September) 1998 6=Fall (October-December) 1998 7=Winter (January-March) 1999 8=Spring (April-June) 1999 9=Summer (July-September) 1999 10=Winter (January-March) 2000 11=Summer (July-September) 2000 12=Winter (January-March) 2001 13=Spring (April-June) 2001 14=Summer (July-September) 2001 15=Fall (October-December) 2001 16=Winter (January-March) 2002 17=Spring (April-June) 2002 18=Summer (July-September) 2002 19=Fall (October-December) 2002 20=Winter (January-March) 2003 21=Spring (April-June) 2003 22=Summer (July-September) 2003
Test	Did the event occur Pre-ventilation implementation or Post-ventilation implementation. 1=Pre 2=Post
y01 (response variable)	Radiation surface contamination expressed as: 0=0 DPM 1=Any DPM

Dependent variables

The dependent variable identified in this study was radiation contamination, “y01.” Contamination levels identified as LDL, are coded as 0, which means no contamination or coded as 1, meaning contamination.

Independent variables

The independent variables that were used in this study were “location,” “time,” “swipe,” and “test.”

“Location” was a nominal variable sequencing from 1-6. Each number in this sequence corresponded to a location within the radiation room where the sample was taken. Swipes taken at specific locations were coded in the following sequence: inside door knob coded as 1, azimuth test fixture coded as 2, telescope fixture coded as 3, cross level fixture were coded as 4, work bench were coded as 5, and other coded as 6. “Location” was utilized to determine if areas within the room were more susceptible to radiation surface contamination.

“Time” was originally recorded as the date that the swipe was taken. The first swipe was taken in September 1997. Swipes were continuously taken throughout the next six years and the last swipe was taken in December 2003. The dates were changed to sequential ordinal values. The sequential ordinal data ranged between 1 and 22. Lower number indicated earlier samples; higher numbers indicated more recent samples. This variable is discussed in greater detail in Table 3.1.

“Swipe” was a dichotomous variable. Quarterly swipes coded as 1 and contamination swipes were coded as 2.

"Test" was a dichotomous variable. Pre-ventilation implementation, which occurred pre-September 2000, was coded as 1 and post-ventilation implementation, which occurred post-September 2000, was coded as 2.

Logistical Regression

Logistical Regression is a multivariate technique which is used to estimate the probability associated with a dichotomized or binary outcome variable (Hosmer and Lemeshow, 2000). Logistical regression equations were used to determine the probabilities associated with the outcome variable.

Logistical regression was used to predict the likelihood that radiation surface contamination occurred. This determination was made based on whether covariates of contamination were present. The assumptions needed to use logistic regression are as follows: 1) multicollinearity 2) linearity of the logits and 3) the omission of outliers (www.statisticssolutions.com, 2005).

The odds ratio is a method of comparing the probability an outcome will occur over the probability that event will not occur (Hosmer and Lemeshow, 2000). This ratio is interpreted to be the odds of the dependent variable occurring. "Odds ratios provide a method of describing the strength of the partial relationship between an individual predictor and the predicted event" (Wuensch, 2006). Equation 3.1 below presents the odds ratio as a function of predictor variables.

$$\ln (p/(1-p)) = \alpha+\beta \mathbf{x} \quad \text{Equation 3.1}$$

Logistical regression models can also be expressed directly in terms of p (Equation 3.2). It estimates the probability that the dependent variable will occur. If the probability is greater than .5, it is usually assumed that the event will occur (Wuensch, 2006).

$$p = [(e^{(\alpha+\beta x)})/(1+ e^{(\alpha+\beta x)})] \quad \text{Equation 3.2}$$

Both of these methods may be used to determine the various relationships between the independent and dependent variables. In this study, the odds ratio was used to analyze the data. The dependent variable indicated whether tritium surface contamination was detected (coded as one) or not detected (coded as zero).

To establish the best-fit model, several models were used to determine the relationship to radiation contamination (Table 3.2). A stepwise regression was used to aid in determining significant variables in Model III.

Table 3.2. Logistical regression models

	Model I (n=134)	**Model II (n=134)**	**Model III (n=134)**
Model specifics	Binary logit	Binary logit	Stepwise regression, binary logit
Number of Response Levels	2	2	2
Dependent Variable	Radiation Contamination 0= no contamination 1= any contamination	Radiation Contamination 0= no contamination 1= any contamination	Radiation Contamination 0= no contamination 1= any contamination
Variables in models	Location Swipe Test Time	Location Swipe Test	Swipe Test

Stepwise regression

Stepwise regression provides a fast and efficient means to screen the covariates for significant statistical associations. Stepwise regression may be used "when the outcome studied is relatively new and the important covariates may not be known and associations with the outcome not well understood" (Hosmer and Lemeshow, 2000, p. 116).

The stepwise procedure for selection or deletion of variables from the models is based on a statistical algorithm that checks for the "importance" of variables based on a fixed decision rule (Hosmer and Lemeshow, 2000). In logistic regression, "the errors are assumed to follow a binomial distribution, and significance is assessed via the likelihood ratio chi-square test" (Hosmer and Lemeshow, 2000, p. 116). Thus, the most important variable is the one that would result in the largest likelihood ratio statistic (Hosmer and Lemeshow, 2000).

Local Exhaust System Specifications

Local exhaust system performance and specifications are critical to the study. A poorly designed local exhaust ventilation system will not effectively eliminate contaminants from a work area. Although an in-depth analysis of ventilation principles is not covered in this study, a general overview of ventilation principles along with system specification and operating performance levels will be discussed.

The flow rate of an exhaust system is defined Equation 3.3. The cross-sectional area of airflow in this study is 0.196 ft^2. This ventilation system was tested for efficiency twice a year for the duration of the study. Since its inception, there were no major changes in the ventilation system over the six years of the study. Thus, the average volume of the flow rate for the local exhaust ventilation used in this study was 1430 cfm.

$$Q=VA \quad \text{Equation 3.3}$$

where Q=volume flow rate (cubic feet per minute)
V= velocity (feet per minute)
A= cross-sectional area of air flow (square feet)

Qualified government engineers established the design specifications for the exhaust system in this study. Schematic for the building and the local exhaust ventilation are found in Appendix D and E. The following criteria for the local exhaust system were established for a room size of 143 square foot.

Air handling and distribution system

Electric motors

Motors for the local exhaust system shall be “General Electric®, Louis Allis®, Reliance®, U.S. Electric®, Westinghouse®, or approved equal domestic manufacture, open drip-proof, Class B insulation, pre-lubricated ball bearing, 40° C rise, 1.15 service factor, built to NEMA frame sizes and NEMA performance specifications of design B, normal torque, and 1800 rpm” (GPQ#022CS028, 2000, p. 3).

Ducts

All ductwork fabrication and installation must conform to Sheet Metal and Air-conditioning Contractors’ National Association (SMACNA) 1995 Heating, Ventilation, and Air-Conditioning (HVAC) Duct Construction standards. Transformations shall maintain “full equivalent round duct capacity and slopes shall not exceed 1:3” (GPQ#022CS028, 2000, p. 1).

Elbows will be radius type with centerline radius at least equal to duct width or right angle type with single thickness vanes with nominal 2” radius, spaced on 1-1/2” centers and installed in accordance with SMACNA Standards (GPQ#022CS028, 2000).

Flexible duct connectors

Thermaflex® Type M-KC or approved equal insulated flexible duct connector consisting of inner sleeve, insulation, and outer vapor barrier jacket (GPQ#022CS028, 2000) (Figure 3.2). Inner sleeve shall consist of a continuous galvanized steel wire helix fused to a layer of Fiberglas impregnated and coated with neoprene. A 1” thick layer of Fiberglas wool and an outer jacket of Fiberglas reinforced metalized film laminate shall enclose the sleeve. The assembly shall be “UL listed as Class I air duct and shall comply with National Fire Protection Association (NFPA) Standards 90A and 90B. It shall be suitable for up to 16” static pressure and to 2” negative pressure” (GPQ#022CS028, 2000).

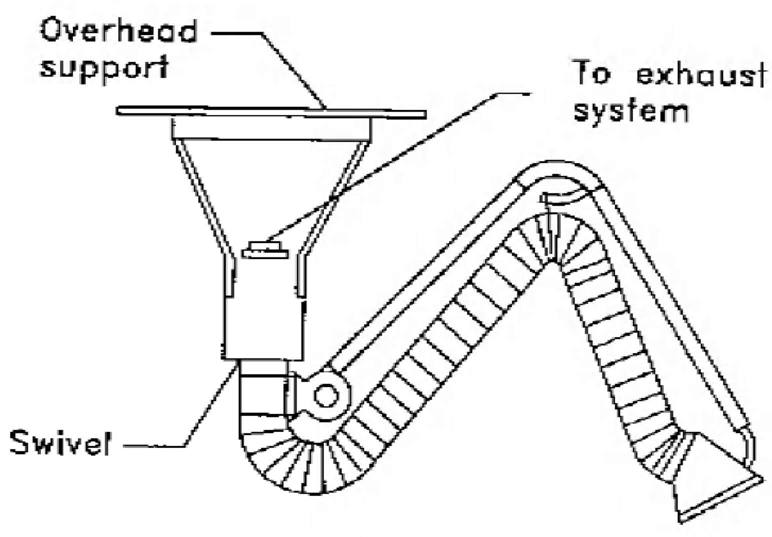
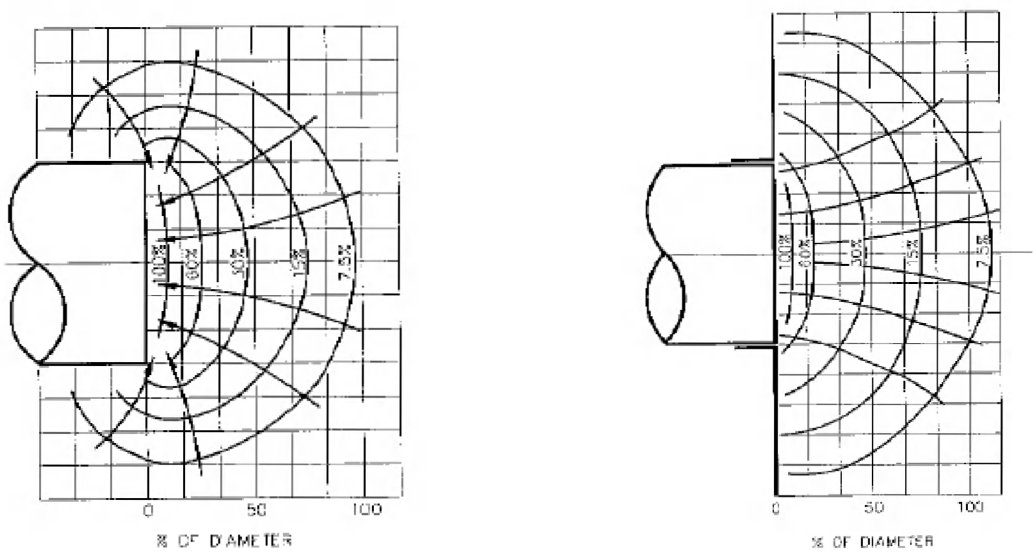


Figure 3.2. Flexible duct connector (ACGIH, 1998)

Maximum permissible length of the flexible connectors is 6' with no more than one 90° bend or equivalent (GPQ#022CS028, 2000). A coned flange opening will be placed around the duct opening to increase local exhaust system efficiency (NSC, 1996). Although the same total amount of air is exhausted, a larger portion will come from the front of the duct. A large flange will increase useful airflow by 30-40% for the same total volume of air handled (Figure 3.3) (NSC, 1996).



Plain Opening

Flanged Opening

Figure 3.3 Velocity contours-expressed as percentages of velocity at the opening (solid curved lines) and stream lines for both plain and flanged circular openings (National Safety Council, 1996)

Diffusers

A Krueger® diffuser is used in this study. Desired features for the diffuser are equal surface adjustable four-way blow patterns and all steel louver face complete with opposed blade volume control (GPQ#022CS028, 2000).

CHAPTER 4. RESULTS AND DISCUSSION

Results

During this evaluation, 6% (5) of the 79 pre-ventilation swipes tested positive for radiation contamination. Forty percent of these swipes were quarterly swipes and 60% were contamination swipes. Sixteen percent (9) of the 55 post-ventilation swipes had detectable levels of radiation. Of the swipes that had detectable levels of radiation, 67% were quarterly swipes and 33% were contamination swipes

The percentages of swipes taken at specific locations were as follows: inside door knob (16%), azimuth test fixture (16%), telescope fixture (16%), cross level fixture (17%), work bench (22%), and other locations (13%). Test was a dichotomous variable with pre-ventilation implementation (59%) and post-ventilation implementation (41%).

“Swipe” was a dichotomous variable that consisted of quarterly swipes (91%) and contamination swipes (9%). Quarterly swipes were routine taken every three months. However, contamination swipes were taken if there was physical evidence of a break, a known radioactive source was broken, or to verify surface contamination levels after decontamination occurred.

In this study, pre-ventilation contamination swipes numbering 51-53 (Appendix A) were taken because of physical evidence of a potential problem. Pre- ventilation contamination swipes numbering 54-57 (Appendix A) were then taken to verify effective clean-up procedures to ensure no residual radiation surface contamination remained. Post-ventilation contamination swipes numbering 51-55 (Appendix A) were taken because of physical evidence of a break.

Three models are presented in the logistical regression results are in Table 4.1. The dependant variable in each model was whether tritium surface contamination was detected (0=no contamination, 1=any contamination). Stepwise regression was utilized to find the best-fit model; the best-fit model is the model with the variables swipe and test.

Table 4.1. Logistical regression results

	Model I		Model II		Model III	
Variable	**Coefficient**	**Wald Statistic**	**Coefficient**	**Wald Statistic**	**Coefficient**	**Wald Statistic**
Intercept	-0.7906	0.2740	-1.2986	8.6609	0.7609	1.0938
Swipe	-1.5741*	8.8486	-1.5618*	8.9810	-2.8329*	14.8474
Test	-0.7681	1.3511	-0.5719	2.7928	-1.2918	3.7323
Location 1	-0.5693	0.3725	-0.5872	0.3948		
Location 2	0.4715	0.3964	0.4779	0.4070		
Location 3	-0.2838	0.0900	-0.2778	0.0863		
Location 4	0.1895	0.0677	0.1815	0.0618		
Location 5	0.6076	0.9387	0.6480	1.1153		
Time	-0.0317	0.1227				
Model Chi-Square [df]	15.4346 [8]		15.5812 [7]		15.8035 [2]	
Pseudo R^2	0.2858		0.2842		0.2590	

Note: The Wald statistics are distributed chi-square with 1 degree of freedom.
*Indicates that the coefficient is statistically significant at least at the .05 level.
**Percentages for P= .08

Model I

Model I (Table 4.2) included the following 8 variables: "swipe," "test," "location 1," "location 2," "location 3," "location 4," "location 5," and "time." The variable "swipe" was included to determine the association between the type of swipe and radiation surface contamination. "Test was included because it can establish the correlation between pre- and post-ventilation and radiation surface contamination.

Table 4.2. Logistical model I

Variable	Parameter Estimate (b)	Standard Error	Odds Ratio	95% Confidence Interval	Approximate Significance
Swipe	-1.5741	0.5292	0.043	[0.005, 0.342]	0.0029*
Test	-0.7681	0.6608	0.215	[0.016, 2.869]	0.2451
Location 1	-0.5693	0.9328	0.857	[0.046, 15.879]	0.5417
Location 2	0.4715	0.7489	2.428	[0.144, 40.870]	0.5290
Location 3	-0.2838	0.9456	1.141	[0.049, 26.567]	0.7641
Location 4	0.1895	0.7279	1.831	[0.130, 25.708]	0.7946
Location 5	0.6076	0.6271	2.782	[0.229, 33.830]	0.3326
Time	-0.0317	0.0905	0.969	[0.811, 1.157]	0.7261
Model Chi-Square	15.4346				
Degrees of freedom	8				
Pseudo R^2	0.2858				
*significant at the p<.05 level					

The geographical variable “location” was included so that the relationship between the location of the swipe taken in the room and radiation surface contamination could be examined. Lastly, “time.” was included to determine if there was a connection between time and radiation surface contamination.

The coefficient of the “swipe” had a Wald statistic equal to 8.85, which is statistically significant at the .05 level. According to the Wald test, none of the other variables were statistically significant. The odds ratio was 0.043, which is insignificantly different from zero and interpretation of this magnitude has little meaning in logistical regression. Under the model chi-square statistic, the overall model is significantly different from zero at the .05 level. The Psuedo-R^2 is 0.2858.

Model II

Model II (Table 4.3) removes “time” as a variable, but includes: “swipe,” “test,” “location 1,” “location 2,” “location 3,” “location 4,” and “location 5.” The coefficient on the “swipe” variable had a Wald statistic equal to 8.98, which is statistically significant at the .05 level. Under the Wald test, none of the other variables were statistically significant. The odds ratio is 0.044, which is insignificantly different from zero and interpretation of this magnitude has little meaning in logistical regression. Under the model chi-square statistic, the overall model is significant at the .05 level. The Psuedo-R^2 value is 0.2842.

Model III

In the most parsimonious model (Table 4.4), swipe and test were the only variable included because they are the only theoretically important variables. The results from Model III indicate that it is superior to the other two models. Pseudo R^2 for Model III was 0.2590.

Table 4.3. Logistical model II

Variable	Parameter Estimate (b)	Standard Error	Odds Ratio	95% Confidence Interval	Approximate Significance
Swipe	-1.5618	0.5212	0.044	[0.006, 0.339]	0.0027*
Test	-0.5719	0.3422	0.319	[0.083, 1.219]	0.0947
Location 1	-0.5872	0.9346	0.865	[0.048, 15.745]	0.5298
Location 2	0.4779	0.7491	2.51	[0.153, 41.267]	0.5235
Location 3	-0.2778	0.9458	1.179	[0.052, 26.879]	0.7689
Location 4	0.1815	0.7300	1.866	[0.135, 25.755]	0.8036
Location 5	0.6480	0.6136	2.976	[0.258, 34.322]	0.2909
Model Chi-Square	15.5812				
Degrees of freedom	7				
Pseudo R^2	0.2842				
*significant at the p<.05 level					

Application of the binary logit model utilized two response levels and pre-post test yielded strong evidence that there is a difference between “swipe 1” and “swipe 2” with a p-value of 0.0001 and a Wald statistic equal to 14.85. The odds ratio for the swipe coefficient is 0.059 with a 95% confidence interval of [.014, .249].

The 95% confidence interval for “test” is [0.074, 1.019]. The p-value for “test” is 0.0534. The estimate for the odds ratio for “test” is 0.275, which means that the odds for Test 1 is 0.275 times the odds for Test 2 where odds is p/(1-p) and p represents the probability of a success or being contaminated.

Table 4.4. Logistical model III

Variable	Parameter Estimate (b)	Standard Error	Odds Ratio	95% Confidence Interval	Approximate Significance
Swipe	-2.8329	0.7352	0.059	[0.014, 0.249]	0.0001*
Test	-1.2918	0.6686	0.275	[0.074, 1.019]	0.0534
Model Chi-Square	15.8035				
Degrees of freedom	2				
Pseudo R2	0.2590				
*significant at the p<.05 level					

To determine if contamination swipes had any affect on quarterly swipes, the odds ratio was utilized. The estimate of the odds ratio is 0.000, which means the odds of a positive quarterly swipe given a positive contamination swipe is 0.000 times greater than the odds of a positive quarterly swipe given a negative contamination swipe.

Discussion

The government facility, that was the focus of this study, under went numerous changes throughout the six years that the data was collected. These changes were due to an overseas military occupation that began in 2001. This occupation may have had an effect on this research because the facility performed maintenance activities for government agencies that were involved in these operations.

The equipment maintained and repaired prior to 2001 was rarely used in harsh conditions. For instance, such equipment may have been used 3 days in a month and such use was mostly in a controlled environment. Further, when the equipment entered the facility, it was for routine preventative maintenance. However, subsequent to the 2001 occupation, the equipment had been used daily and in harsh conditions. Such use could result in more equipment entering the facility with possible radiation leakage.

CHAPTER 5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary of Study

The objective of the study was to analyze the effectiveness of local exhaust ventilation on tritium surface contamination in a governmental maintenance and repair facility. Samples for this study were drawn from quarterly and suspected contamination swipes over a six year period and analyzed for tritium surface contamination utilizing a scintillation technique. The dependent variable selected was a measurement which determined whether tritium surface contamination was present. Three models were utilized to help determine the relationships between the independent variables: “location,” “time,” “swipe,” and “test,” and the dependent variable, tritium surface contamination. Logistical regression was then used to analyze radiation surface contamination.

Conclusions

Through logistical regression, it was demonstrated that a significant relationship exists between the type of “swipe,” quarterly or contamination, and tritium surface contamination with a p-value of 0.0001. The evidence also indicates there is a difference between “test,” pre-local exhaust ventilation and post-local exhaust ventilation, and tritium surface contamination with a p-value of 0.0534.

It is important to reiterate that LEV is not a regulatory requirement for this facility. Unfortunately, more often than not, facilities do not address environmental, safety and health concerns that are not regulatory requirements. Nevertheless, it is critical that safety professionals analyze new techniques and look towards facilities that utilize new engineering control measures in their processes for guidance and insight. Safety professionals around the world should be committed to providing a safe working environment for everyone at their facilities, and to do this it is necessary to implement equipment and programs that go beyond the regulatory requirements.

Recommendations

This study indicates a need for the following future research:

1. Real-time tritium monitors should be studied to analyze the amount of tritium being pulled from the atmosphere in a small radiation maintenance and repair facility. Positive radiation levels that are detected in the LEV could trigger a contamination swipe and a researcher could analyze the relationship between contamination levels in LEV vs. the surface.
2. A controlled study should be conducted to determine the effectiveness of LEV at specific distances from tritium radiation sources.
3. Tracking the number of repaired equipment between each swipe should be analyzed to determine if varying amounts of equipment being repaired in the facility between swipes could have an effect on radiation surface contamination.
4. Additional studies should be conducted to evaluate and determine the effects LEV on worker’s exposures to radiation, which was not reviewed in this study.

APPENDIX A. SURFACE CONTAMINATION DATA

Sample	Date	Location	y	Swipe	Time	Test	y01
1.00	23-Apr-97	1.00	0.00	1.00	2.00	1.00	0.00
2.00	23-Apr-97	6.00	0.00	1.00	2.00	1.00	0.00
3.00	23-Apr-97	6.00	0.00	1.00	2.00	1.00	0.00
4.00	23-Apr-97	5.00	0.00	1.00	2.00	1.00	0.00
5.00	23-Apr-97	5.00	0.00	1.00	2.00	1.00	0.00
6.00	23-Apr-97	4.00	0.00	1.00	2.00	1.00	0.00
7.00	23-Apr-97	6.00	0.00	1.00	2.00	1.00	0.00
8.00	23-Apr-97	3.00	0.00	1.00	2.00	1.00	0.00
9.00	23-Apr-97	2.00	0.00	1.00	2.00	1.00	0.00
10.00	23-Jul-97	1.00	0.00	1.00	3.00	1.00	0.00
11.00	23-Jul-97	2.00	0.00	1.00	3.00	1.00	0.00
12.00	23-Jul-97	3.00	0.00	1.00	3.00	1.00	0.00
13.00	23-Jul-97	4.00	0.00	1.00	3.00	1.00	0.00
14.00	23-Jul-97	5.00	0.00	1.00	3.00	1.00	0.00
15.00	23-Jul-97	5.00	0.00	1.00	3.00	1.00	0.00
16.00	5-Nov-97	1.00	0.00	1.00	4.00	1.00	0.00
17.00	5-Nov-97	2.00	0.00	1.00	4.00	1.00	0.00
18.00	5-Nov-97	3.00	0.00	1.00	4.00	1.00	0.00
19.00	5-Nov-97	4.00	0.00	1.00	4.00	1.00	0.00
20.00	5-Nov-97	5.00	0.00	1.00	4.00	1.00	0.00
21.00	5-Nov-97	5.00	0.00	1.00	4.00	1.00	0.00
22.00	31-Mar-98	1.00	0.00	1.00	5.00	1.00	0.00
23.00	31-Mar-98	2.00	0.00	1.00	5.00	1.00	0.00
24.00	31-Mar-98	3.00	0.00	1.00	5.00	1.00	0.00
25.00	31-Mar-98	4.00	0.00	1.00	5.00	1.00	0.00
26.00	31-Mar-98	5.00	0.00	1.00	5.00	1.00	0.00
27.00	31-Mar-98	5.00	0.00	1.00	5.00	1.00	0.00
28.00	14-Jul-98	2.00	0.00	1.00	7.00	1.00	0.00
29.00	14-Jul-98	3.00	0.00	1.00	7.00	1.00	0.00
30.00	14-Jul-98	4.00	0.00	1.00	7.00	1.00	0.00
31.00	14-Jul-98	5.00	0.00	1.00	7.00	1.00	0.00
32.00	6-Nov-98	2.00	25.00	1.00	8.00	1.00	1.00
33.00	6-Nov-98	3.00	0.00	1.00	8.00	1.00	0.00
34.00	6-Nov-98	4.00	15.00	1.00	8.00	1.00	1.00
35.00	6-Nov-98	5.00	0.00	1.00	8.00	1.00	0.00
36.00	21-Sep-99	1.00	0.00	1.00	11.00	1.00	0.00
37.00	21-Sep-99	2.00	0.00	1.00	11.00	1.00	0.00
38.00	21-Sep-99	3.00	0.00	1.00	11.00	1.00	0.00
39.00	21-Sep-99	4.00	0.00	1.00	11.00	1.00	0.00
40.00	21-Sep-99	5.00	0.00	1.00	11.00	1.00	0.00
41.00	17-Feb-99	1.00	0.00	1.00	9.00	1.00	0.00
42.00	17-Feb-99	2.00	0.00	1.00	9.00	1.00	0.00
43.00	17-Feb-99	3.00	0.00	1.00	9.00	1.00	0.00
44.00	17-Feb-99	4.00	0.00	1.00	9.00	1.00	0.00
45.00	17-Feb-99	5.00	0.00	1.00	9.00	1.00	0.00
46.00	9-Jun-99	1.00	0.00	1.00	10.00	1.00	0.00

47.00	9-Jun-99	2.00	0.00	1.00	10.00	1.00	0.00
48.00	9-Jun-99	3.00	0.00	1.00	10.00	1.00	0.00
49.00	9-Jun-99	4.00	0.00	1.00	10.00	1.00	0.00
50.00	9-Jun-99	5.00	0.00	1.00	10.00	1.00	0.00
51.00	17-Mar-00	6.00	141.00	2.00	13.00	1.00	1.00
52.00	17-Mar-00	6.00	73.00	2.00	13.00	1.00	1.00
53.00	17-Mar-00	6.00	57.00	2.00	13.00	1.00	1.00
54.00	22-Mar-00	6.00	0.00	2.00	13.00	1.00	0.00
55.00	22-Mar-00	6.00	0.00	2.00	13.00	1.00	0.00
56.00	22-Mar-00	4.00	0.00	2.00	13.00	1.00	0.00
57.00	22-Mar-00	1.00	0.00	2.00	13.00	1.00	0.00
58.00	24-Jan-00	1.00	0.00	1.00	13.00	1.00	0.00
59.00	24-Jan-00	2.00	0.00	1.00	13.00	1.00	0.00
60.00	24-Jan-00	3.00	0.00	1.00	13.00	1.00	0.00
61.00	24-Jan-00	4.00	0.00	1.00	13.00	1.00	0.00
62.00	24-Jan-00	5.00	0.00	1.00	13.00	1.00	0.00
63.00	29-Mar-00	1.00	0.00	1.00	13.00	1.00	0.00
64.00	29-Mar-00	2.00	0.00	1.00	13.00	1.00	0.00
65.00	29-Mar-00	3.00	0.00	1.00	13.00	1.00	0.00
66.00	29-Mar-00	4.00	0.00	1.00	13.00	1.00	0.00
67.00	29-Mar-00	5.00	0.00	1.00	13.00	1.00	0.00
68.00	9-Aug-00	1.00	0.00	1.00	15.00	1.00	0.00
69.00	9-Aug-00	2.00	0.00	1.00	15.00	1.00	0.00
70.00	9-Aug-00	3.00	0.00	1.00	15.00	1.00	0.00
71.00	9-Aug-00	4.00	0.00	1.00	15.00	1.00	0.00
72.00	9-Aug-00	5.00	0.00	1.00	15.00	1.00	0.00
73.00	9-Aug-00	6.00	0.00	1.00	15.00	1.00	0.00
74.00	9-Aug-00	6.00	0.00	1.00	15.00	1.00	0.00
75.00	9-Aug-00	6.00	0.00	1.00	15.00	1.00	0.00
76.00	9-Aug-00	6.00	0.00	1.00	15.00	1.00	0.00
77.00	9-Aug-00	6.00	0.00	1.00	15.00	1.00	0.00
78.00	9-Aug-00	6.00	0.00	1.00	15.00	1.00	0.00
79.00	9-Aug-00	6.00	0.00	1.00	15.00	1.00	0.00
1.00	3-Jan-01	1.00	0.00	1.00	17.00	2.00	0.00
2.00	3-Jan-01	2.00	0.00	1.00	17.00	2.00	0.00
3.00	3-Jan-01	3.00	0.00	1.00	17.00	2.00	0.00
4.00	3-Jan-01	4.00	0.00	1.00	17.00	2.00	0.00
5.00	3-Jan-01	5.00	0.00	1.00	17.00	2.00	0.00
6.00	17-Apr-01	1.00	0.00	1.00	18.00	2.00	0.00
7.00	17-Apr-01	2.00	0.00	1.00	18.00	2.00	0.00
8.00	17-Apr-01	3.00	0.00	1.00	18.00	2.00	0.00
9.00	17-Apr-01	4.00	0.00	1.00	18.00	2.00	0.00
10.00	17-Apr-01	5.00	0.00	1.00	18.00	2.00	0.00
11.00	1-Oct-01	1.00	0.00	1.00	20.00	2.00	0.00
12.00	1-Oct-01	2.00	0.00	1.00	20.00	2.00	0.00
13.00	1-Oct-01	3.00	0.00	1.00	20.00	2.00	0.00
14.00	1-Oct-01	4.00	0.00	1.00	20.00	2.00	0.00
15.00	1-Oct-01	5.00	13.95	1.00	20.00	2.00	1.00
16.00	7-Jan-02	1.00	232.23	1.00	21.00	2.00	1.00
17.00	7-Jan-02	2.00	394.31	1.00	21.00	2.00	1.00

18.00	7-Jan-02	3.00	317.16	1.00	21.00	2.00	1.00
19.00	7-Jan-02	4.00	335.00	1.00	21.00	2.00	1.00
20.00	7-Jan-02	5.00	367.87	1.00	21.00	2.00	1.00
21.00	5-Apr-02	1.00	0.00	1.00	22.00	2.00	0.00
22.00	5-Apr-02	2.00	0.00	1.00	22.00	2.00	0.00
23.00	5-Apr-02	3.00	0.00	1.00	22.00	2.00	0.00
24.00	5-Apr-02	4.00	0.00	1.00	22.00	2.00	0.00
25.00	5-Apr-02	5.00	0.00	1.00	22.00	2.00	0.00
26.00	7-Jul-02	1.00	0.00	1.00	23.00	2.00	0.00
27.00	7-Jul-02	2.00	0.00	1.00	23.00	2.00	0.00
28.00	7-Jul-02	3.00	0.00	1.00	23.00	2.00	0.00
29.00	7-Jul-02	4.00	0.00	1.00	23.00	2.00	0.00
30.00	7-Jul-02	5.00	0.00	1.00	23.00	2.00	0.00
31.00	9-Oct-02	1.00	0.00	1.00	24.00	2.00	0.00
32.00	9-Oct-02	2.00	0.00	1.00	24.00	2.00	0.00
33.00	9-Oct-02	3.00	0.00	1.00	24.00	2.00	0.00
34.00	9-Oct-02	4.00	0.00	1.00	24.00	2.00	0.00
35.00	9-Oct-02	5.00	0.00	1.00	24.00	2.00	0.00
36.00	13-Jan-03	1.00	0.00	1.00	25.00	2.00	0.00
37.00	13-Jan-03	2.00	0.00	1.00	25.00	2.00	0.00
38.00	13-Jan-03	3.00	0.00	1.00	25.00	2.00	0.00
39.00	13-Jan-03	4.00	0.00	1.00	25.00	2.00	0.00
40.00	13-Jan-03	5.00	0.00	1.00	25.00	2.00	0.00
41.00	28-Apr-03	1.00	0.00	1.00	26.00	2.00	0.00
42.00	28-Apr-03	2.00	0.00	1.00	26.00	2.00	0.00
43.00	28-Apr-03	3.00	0.00	1.00	26.00	2.00	0.00
44.00	28-Apr-03	4.00	0.00	1.00	26.00	2.00	0.00
45.00	28-Apr-03	5.00	0.00	1.00	26.00	2.00	0.00
46.00	22-Sep-03	1.00	0.00	1.00	27.00	2.00	0.00
47.00	22-Sep-03	2.00	0.00	1.00	27.00	2.00	0.00
48.00	23-Sep-03	3.00	0.00	1.00	27.00	2.00	0.00
49.00	23-Sep-03	4.00	0.00	1.00	27.00	2.00	0.00
50.00	23-Sep-03	5.00	0.00	1.00	27.00	2.00	0.00
51.00	17-Aug-01	5.00	35.52	2.00	19.00	2.00	1.00
52.00	17-Aug-01	5.00	86.83	2.00	19.00	2.00	1.00
53.00	17-Aug-01	5.00	105.19	2.00	19.00	2.00	1.00
54.00	17-Aug-01	6.00	0.00	2.00	19.00	2.00	0.00
55.00	17-Aug-01	6.00	0.00	2.00	19.00	2.00	0.00

APPENDIX B. MODEL I SAS© OUTPUT

```
PROC LOGISTIC descending simple;
CLASS location swipe test;
MODEL y01 = location swipe test time / ctable rsquare;
run;

PROC LOGISTIC descending simple;
CLASS location swipe test;
MODEL y01 = location swipe test / ctable rsquare;
run;
```

The SAS System 14:22 Tuesday, September 20, 2005 6

The LOGISTIC Procedure

Model Information

Data Set	WORK.PREPOST	
Response Variable	y01	y01
Number of Response Levels	2	
Number of Observations	134	
Model	binary logit	
Optimization Technique	Fisher's scoring	

Response Profile

Ordered Value	y01	Total Frequency
1	1	14
2	0	120

Probability modeled is y01=1.

Class Level Information

Class	Value	Design Variables 1	2	3	4	5
Location	1	1	0	0	0	0
	2	0	1	0	0	0
	3	0	0	1	0	0
	4	0	0	0	1	0
	5	0	0	0	0	1
	6	-1	-1	-1	-1	-1
Swipe	1	1				
	2	-1				
Test	1	1				
	2	-1				

Descriptive Statistics for Continuous Variables

Variable	y01	Mean	Standard Deviation	Variable Minimum	Maximum	Label
Time	1	16.928571	4.890561	8.000000	21.000000	Time
	0	13.950000	7.867442	2.000000	27.000000	
	Total	14.261194	7.652145	2.000000	27.000000	

The SAS System 14:22 Tuesday, September 20, 2005 7

The LOGISTIC Procedure

Frequency Distribution of Class Variables

Class	Value	y01 1	0	Total
Location	1	1	20	21
	2	2	20	22
	3	1	21	22
	4	2	21	23
	5	5	24	29
	6	3	14	17
Swipe	1	8	114	122
	2	6	6	12
Test	1	5	74	79
	2	9	46	55

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	91.729	87.594
SC	94.627	113.674
-2 Log L	89.729	69.594

R-Square 0.1395 Max-rescaled R-Square 0.2858

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	20.1357	8	0.0098
Score	27.8362	8	0.0005
Wald	15.4346	8	0.0512

The SAS System 14:22 Tuesday, September 20, 2005 8

The LOGISTIC Procedure

Type III Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Location	5	1.5558	0.9065
Swipe	1	8.8486	0.0029
Test	1	1.3511	0.2451
Time	1	0.1227	0.7261

Analysis of Maximum Likelihood Estimates

Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept		1	-0.7906	1.5103	0.2740	0.6007
Location	1	1	-0.5693	0.9328	0.3725	0.5417
Location	2	1	0.4715	0.7489	0.3964	0.5290
Location	3	1	-0.2838	0.9456	0.0900	0.7641
Location	4	1	0.1895	0.7279	0.0677	0.7946
Location	5	1	0.6076	0.6271	0.9387	0.3326
Swipe	1	1	-1.5741	0.5292	8.8486	0.0029
Test	1	1	-0.7681	0.6608	1.3511	0.2451
Time		1	-0.0317	0.0905	0.1227	0.7261

Odds Ratio Estimates

Effect	Point Estimate	95% Wald Confidence Limits	
Location 1 vs 6	0.857	0.046	15.879
Location 2 vs 6	2.428	0.144	40.870
Location 3 vs 6	1.141	0.049	26.567
Location 4 vs 6	1.831	0.130	25.708
Location 5 vs 6	2.782	0.229	33.830
Swipe 1 vs 2	0.043	0.005	0.342
Test 1 vs 2	0.215	0.016	2.869
Time	0.969	0.811	1.157

Association of Predicted Probabilities and Observed Responses

Percent Concordant	81.1	Somers' D	0.629
Percent Discordant	18.2	Gamma	0.633
Percent Tied	0.7	Tau-a	0.119
Pairs	1680	c	0.814

The SAS System 14:22 Tuesday, September 20, 2005 9

The LOGISTIC Procedure

Classification Table

Prob Level	Correct Event	Correct Non-Event	Incorrect Event	Incorrect Non-Event	Percentages Correct	Sensitivity	Specificity	False POS	False NEG
0.000	14	0	120	0	10.4	100.0	0.0	89.6	.
0.020	12	13	107	2	18.7	85.7	10.8	89.9	13.3
0.040	10	38	82	4	35.8	71.4	31.7	89.1	9.5
0.060	9	63	57	5	53.7	64.3	52.5	86.4	7.4
0.080	9	85	35	5	70.1	64.3	70.8	79.5	5.6
0.100	8	88	32	6	71.6	57.1	73.3	80.0	6.4
0.120	6	94	26	8	74.6	42.9	78.3	81.3	7.8
0.140	6	100	20	8	79.1	42.9	83.3	76.9	7.4
0.160	6	107	13	8	84.3	42.9	89.2	68.4	7.0
0.180	6	112	8	8	88.1	42.9	93.3	57.1	6.7

0.200	6	114	6	8	89.6	42.9	95.0	50.0	6.6
0.220	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.240	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.260	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.280	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.300	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.320	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.340	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.360	3	116	4	11	88.8	21.4	96.7	57.1	8.7
0.380	3	116	4	11	88.8	21.4	96.7	57.1	8.7
0.400	3	116	4	11	88.8	21.4	96.7	57.1	8.7
0.420	3	116	4	11	88.8	21.4	96.7	57.1	8.7
0.440	3	116	4	11	88.8	21.4	96.7	57.1	8.7
0.460	3	116	4	11	88.8	21.4	96.7	57.1	8.7
0.480	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.500	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.520	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.540	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.560	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.580	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.600	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.620	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.640	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.660	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.680	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.700	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.720	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.740	3	118	2	11	90.3	21.4	98.3	40.0	8.5
0.760	3	118	2	11	90.3	21.4	98.3	40.0	8.5
0.780	3	118	2	11	90.3	21.4	98.3	40.0	8.5
0.800	0	120	0	14	89.6	0.0	100.0	.	10.4

APPENDIX C. MODEL II SAS© OUTPUT

The SAS System 14:22 Tuesday, September 20, 2005 10

The LOGISTIC Procedure

Model Information

Data Set	WORK.PREPOST
Response Variable	y01 y01
Number of Response Levels	2
Number of Observations	134
Model	binary logit
Optimization Technique	Fisher's scoring

Response Profile

Ordered Value	y01	Total Frequency
1	1	14
2	0	120

Probability modeled is y01=1.

Class Level Information

Class	Value	Design Variables 1	2	3	4	5
Location	1	1	0	0	0	0
	2	0	1	0	0	0
	3	0	0	1	0	0
	4	0	0	0	1	0
	5	0	0	0	0	1
	6	-1	-1	-1	-1	-1
Swipe	1	1				
	2	-1				
Test	1	1				
	2	-1				

Frequency Distribution of Class Variables

Class	Value	y01 1	0	Total
Location	1	1	20	21
	2	2	20	22
	3	1	21	22
	4	2	21	23

The SAS System 14:22 Tuesday, September 20, 2005 11

The LOGISTIC Procedure

Frequency Distribution of Class Variables

y01

Class	Value	1	0	Total
	5	5	24	29
	6	3	14	17
Swipe	1	8	114	122
	2	6	6	12
Test	1	5	74	79
	2	9	46	55

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	91.729	85.716
SC	94.627	108.899
-2 Log L	89.729	69.716

R-Square 0.1387 Max-rescaled R-Square 0.2842

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	20.0136	7	0.0055
Score	27.5231	7	0.0003
Wald	15.5812	7	0.0292

Type III Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Location	5	1.7451	0.8832
Swipe	1	8.9810	0.0027

The SAS System 14:22 Tuesday, September 20, 2005 12

The LOGISTIC Procedure

Type III Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Test	1	2.7928	0.0947

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-1.2986	0.4413	8.6609	0.0033

Location 1	1	-0.5872	0.9346	0.3948	0.5298
Location 2	1	0.4779	0.7491	0.4070	0.5235
Location 3	1	-0.2778	0.9458	0.0863	0.7689
Location 4	1	0.1815	0.7300	0.0618	0.8036
Location 5	1	0.6480	0.6136	1.1153	0.2909
Swipe 1	1	-1.5618	0.5212	8.9810	0.0027
Test 1	1	-0.5719	0.3422	2.7928	0.0947

Odds Ratio Estimates

Effect	Point Estimate	95% Wald Confidence Limits	
Location 1 vs 6	0.865	0.048	15.745
Location 2 vs 6	2.510	0.153	41.267
Location 3 vs 6	1.179	0.052	26.879
Location 4 vs 6	1.866	0.135	25.755
Location 5 vs 6	2.976	0.258	34.322
Swipe 1 vs 2	0.044	0.006	0.339
Test 1 vs 2	0.319	0.083	1.219

Association of Predicted Probabilities and Observed Responses

Percent Concordant	78.0	Somers' D	0.607
Percent Discordant	17.3	Gamma	0.638
Percent Tied	4.8	Tau-a	0.114
Pairs	1680	c	0.804

The SAS System 14:22 Tuesday, September 20, 2005 13

The LOGISTIC Procedure

Classification Table

Prob Level	Correct Event	Correct Non-Event	Incorrect Event	Incorrect Non-Event	Percentages Correct	Sensitivity	Specificity	False POS	False NEG
0.000	14	0	120	0	10.4	100.0	0.0	89.6	.
0.020	12	10	110	2	16.4	85.7	8.3	90.2	16.7
0.040	10	43	77	4	39.6	71.4	35.8	88.5	8.5
0.060	9	63	57	5	53.7	64.3	52.5	86.4	7.4
0.080	9	88	32	5	72.4	64.3	73.3	78.0	5.4
0.100	8	88	32	6	71.6	57.1	73.3	80.0	6.4
0.120	6	97	23	8	76.9	42.9	80.8	79.3	7.6
0.140	6	97	23	8	76.9	42.9	80.8	79.3	7.6
0.160	6	106	14	8	83.6	42.9	88.3	70.0	7.0
0.180	6	114	6	8	89.6	42.9	95.0	50.0	6.6
0.200	6	114	6	8	89.6	42.9	95.0	50.0	6.6
0.220	6	114	6	8	89.6	42.9	95.0	50.0	6.6
0.240	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.260	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.280	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.300	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.320	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.340	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.360	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.380	3	116	4	11	88.8	21.4	96.7	57.1	8.7
0.400	3	116	4	11	88.8	21.4	96.7	57.1	8.7
0.420	3	116	4	11	88.8	21.4	96.7	57.1	8.7
0.440	3	116	4	11	88.8	21.4	96.7	57.1	8.7
0.460	3	116	4	11	88.8	21.4	96.7	57.1	8.7
0.480	3	116	4	11	88.8	21.4	96.7	57.1	8.7

0.500	3	116	4	11	88.8	21.4	96.7	57.1	8.7
0.520	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.540	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.560	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.580	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.600	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.620	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.640	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.660	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.680	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.700	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.720	3	117	3	11	89.6	21.4	97.5	50.0	8.6
0.740	3	120	0	11	91.8	21.4	100.0	0.0	8.4
0.760	3	120	0	11	91.8	21.4	100.0	0.0	8.4
0.780	0	120	0	14	89.6	0.0	100.0	.	10.4

APPENDIX D. MODEL III SAS© OUTPUT

```
proc import datafile="H:/Consulting/Clients/Steve_Flann/Prepost.xls"
      out=prepost;

proc import datafile="H:/Consulting/Clients/Steve_Flann/Prepost2.xls"
      out=prepost2;

proc logistic data=prepost;
      class Location Swipe Test / param=glm;
      model y01(event='1')=Location Swipe Test Time Test*Time/
selection=stepwise slentry=0.25 slstay=0.25
            scale=none alpha=.05 ctable rsquare;
      run;
```

The SAS System 12:48 Tuesday, July 11, 2006 14

The LOGISTIC Procedure

Model Information

Data Set	WORK.PREPOST	
Response Variable	y01	y01
Number of Response Levels	2	
Model	binary logit	
Optimization Technique	Fisher's scoring	

Number of Observations Read	134
Number of Observations Used	134

Response Profile

Ordered Value	y01	Total Frequency
1	0	120
2	1	14

Probability modeled is y01=1.

Stepwise Selection Procedure

Class Level Information

Class	Value	Design Variables					
Location	1	1	0	0	0	0	0
	2	0	1	0	0	0	0
	3	0	0	1	0	0	0
	4	0	0	0	1	0	0
	5	0	0	0	0	1	0
	6	0	0	0	0	0	1
Swipe	1	1	0				
	2	0	1				
Test	1	1	0				

2 0 1

Step 0. Intercept entered:

The SAS System 12:48 Tuesday, July 11, 2006 15

The LOGISTIC Procedure

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

-2 Log L = 89.729

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
29.1957	9	0.0006

Step 1. Effect Swipe entered:

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	91.729	79.692
SC	94.627	85.488
-2 Log L	89.729	75.692

R-Square 0.0995 Max-rescaled R-Square 0.2038

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	14.0371	1	0.0002
Score	22.0378	1	<.0001
Wald	15.1108	1	0.0001

The SAS System 12:48 Tuesday, July 11, 2006 16

The LOGISTIC Procedure

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
7.2300	8	0.5120

NOTE: No effects for the model in Step 1 are removed.

Step 2. Effect Test entered:

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	91.729	77.617
SC	94.627	86.311
-2 Log L	89.729	71.617

R-Square 0.1264 Max-rescaled R-Square 0.2590

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	18.1122	2	0.0001
Score	25.4583	2	<.0001
Wald	15.8035	2	0.0004

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
2.8812	7	0.8958

NOTE: No effects for the model in Step 2 are removed.

The SAS System 12:48 Tuesday, July 11, 2006 17

The LOGISTIC Procedure

NOTE: No (additional) effects met the 0.25 significance level for entry into the model.

Summary of Stepwise Selection

Step	Effect Entered	Effect Removed	DF	Number In	Score Chi-Square	Wald Chi-Square	Pr > ChiSq	Variable Label
1	Swipe		1	1	22.0378		<.0001	Swipe
2	Test		1	2	4.0898		0.0431	Test

Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Swipe	1	14.8474	0.0001
Test	1	3.7323	0.0534

Analysis of Maximum Likelihood Estimates

Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept		1	0.7609	0.7275	1.0938	0.2956
Swipe	1	1	-2.8329	0.7352	14.8474	0.0001
Swipe	2	0	0	.	.	.
Test	1	1	-1.2918	0.6686	3.7323	0.0534
Test	2	0	0	.	.	.

Odds Ratio Estimates

Effect		Point Estimate	95% Wald Confidence Limits	
Swipe	1 vs 2	0.059	0.014	0.249
Test	1 vs 2	0.275	0.074	1.019

Association of Predicted Probabilities and Observed Responses

Percent Concordant	66.4	Somers' D	0.580
Percent Discordant	8.5	Gamma	0.774
Percent Tied	25.1	Tau-a	0.109
Pairs	1680	c	0.790

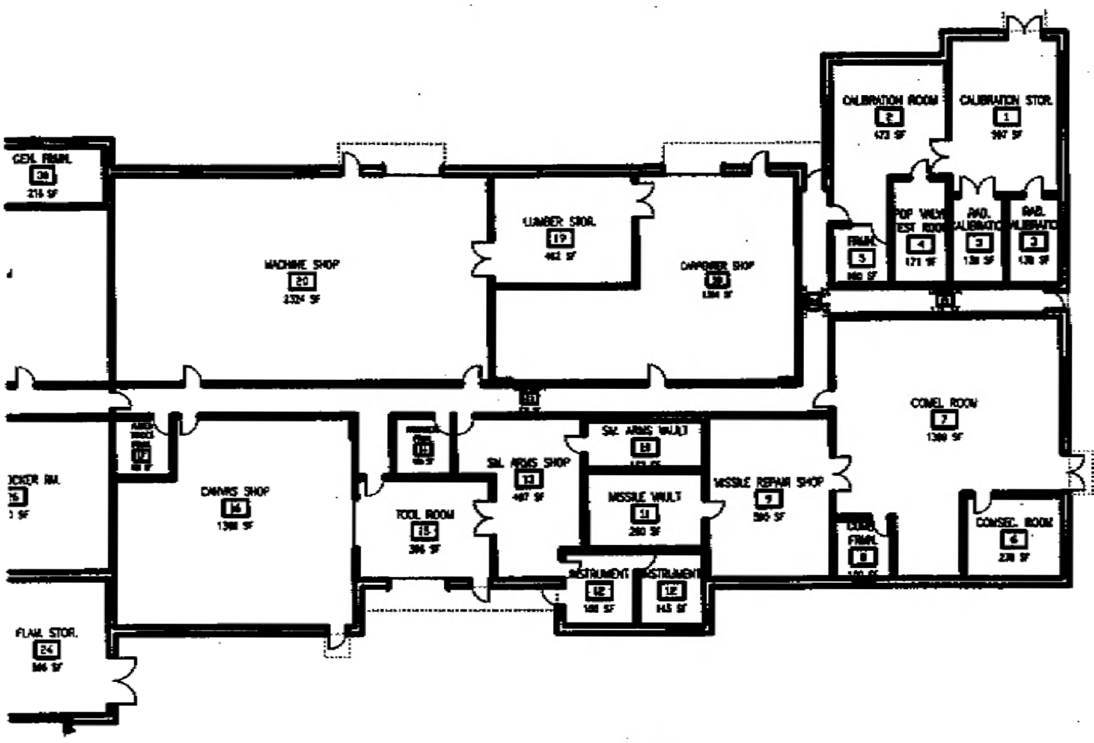
The SAS System 12:48 Tuesday, July 11, 2006 18

The LOGISTIC Procedure

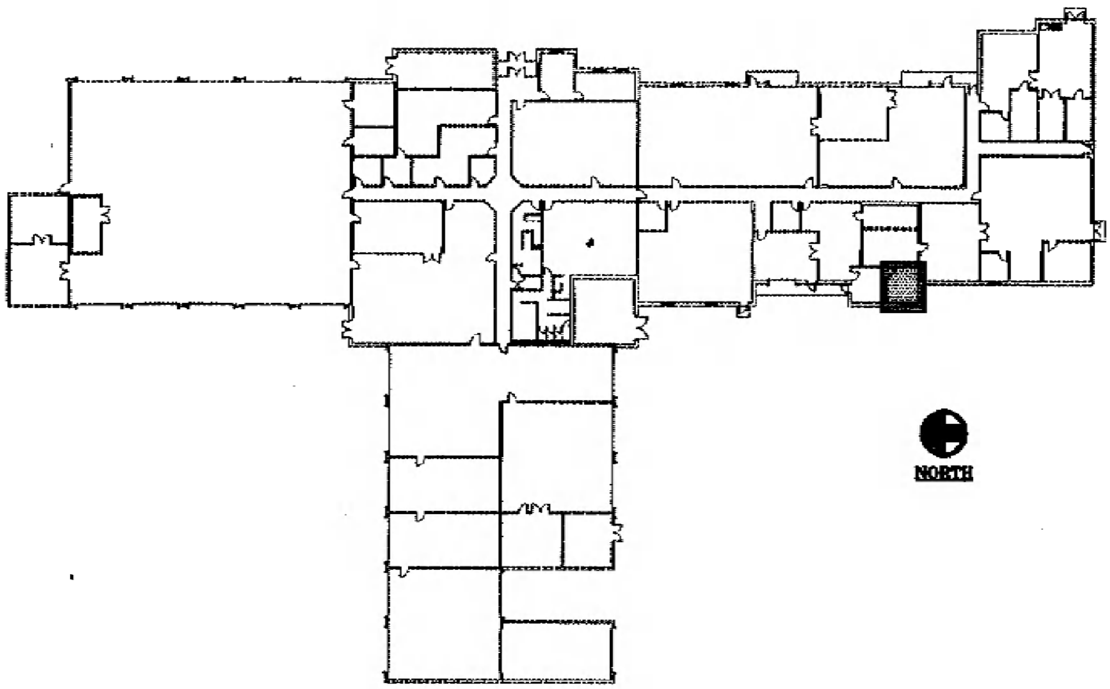
Classification Table

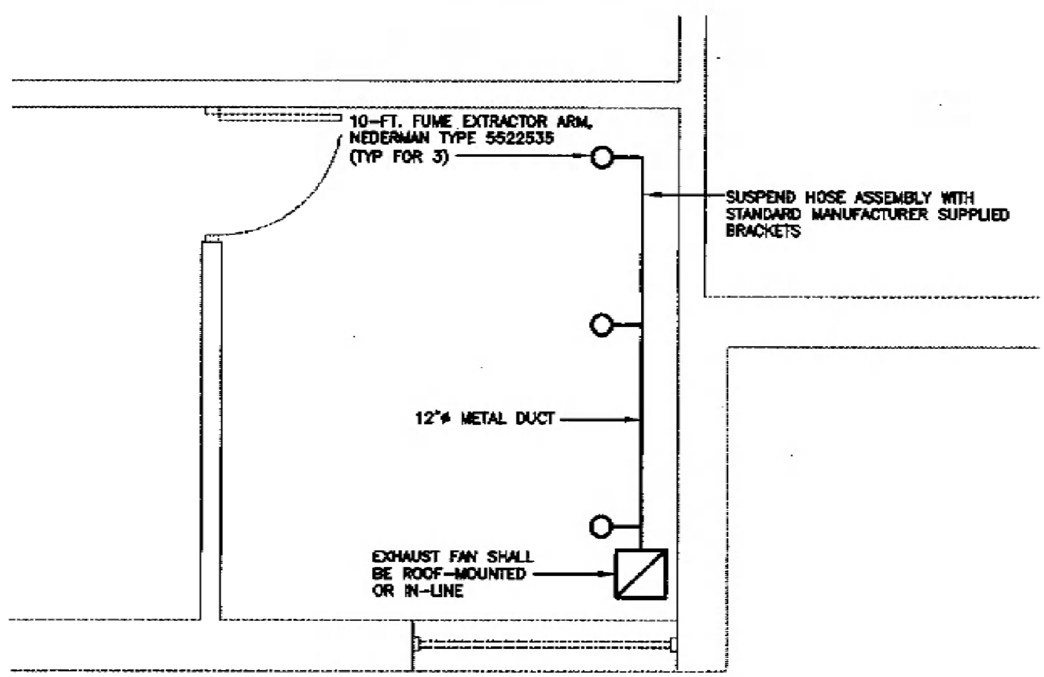
	Correct		Incorrect		Percentages				
Prob		Non-		Non-		Sensi-	Speci-	False	False
Level	Event	Event	Event	Event	Correct	tivity	ficity	POS	NEG
0.020	14	0	120	0	10.4	100.0	0.0	89.6	.
0.040	12	70	50	2	61.2	85.7	58.3	80.6	2.8
0.060	12	70	50	2	61.2	85.7	58.3	80.6	2.8
0.080	12	70	50	2	61.2	85.7	58.3	80.6	2.8
0.100	6	70	50	8	56.7	42.9	58.3	89.3	10.3
0.120	6	114	6	8	89.6	42.9	95.0	50.0	6.6
0.140	6	114	6	8	89.6	42.9	95.0	50.0	6.6
0.160	6	114	6	8	89.6	42.9	95.0	50.0	6.6
0.180	6	114	6	8	89.6	42.9	95.0	50.0	6.6
0.200	6	114	6	8	89.6	42.9	95.0	50.0	6.6
0.220	6	114	6	8	89.6	42.9	95.0	50.0	6.6
0.240	6	114	6	8	89.6	42.9	95.0	50.0	6.6
0.260	6	114	6	8	89.6	42.9	95.0	50.0	6.6
0.280	6	114	6	8	89.6	42.9	95.0	50.0	6.6
0.300	6	114	6	8	89.6	42.9	95.0	50.0	6.6
0.320	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.340	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.360	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.380	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.400	3	114	6	11	87.3	21.4	95.0	66.7	8.8
0.420	3	118	2	11	90.3	21.4	98.3	40.0	8.5
0.440	3	118	2	11	90.3	21.4	98.3	40.0	8.5
0.460	3	118	2	11	90.3	21.4	98.3	40.0	8.5
0.480	3	118	2	11	90.3	21.4	98.3	40.0	8.5
0.500	3	118	2	11	90.3	21.4	98.3	40.0	8.5
0.520	3	118	2	11	90.3	21.4	98.3	40.0	8.5
0.540	3	118	2	11	90.3	21.4	98.3	40.0	8.5
0.560	3	118	2	11	90.3	21.4	98.3	40.0	8.5
0.580	3	118	2	11	90.3	21.4	98.3	40.0	8.5
0.600	3	118	2	11	90.3	21.4	98.3	40.0	8.5
0.620	3	118	2	11	90.3	21.4	98.3	40.0	8.5
0.640	0	118	2	14	88.1	0.0	98.3	100.0	10.6
0.660	0	118	2	14	88.1	0.0	98.3	100.0	10.6
0.680	0	118	2	14	88.1	0.0	98.3	100.0	10.6
0.700	0	118	2	14	88.1	0.0	98.3	100.0	10.6
0.720	0	118	2	14	88.1	0.0	98.3	100.0	10.6
0.740	0	118	2	14	88.1	0.0	98.3	100.0	10.6
0.760	0	118	2	14	88.1	0.0	98.3	100.0	10.6
0.780	0	120	0	14	89.6	0.0	100.0	.	10.4

APPENDIX E. SCHEMATIC OF BUILDING



APPENDIX F. SCHEMATIC OF ROOM AND VENTILATION





SCALE: 1/4" = 1'-0"

APPENDIX G. WIPE TEST ANALYSIS FORM

WIPE TEST ANALYSIS REQUEST FORM

(Instructions On Reverse Side)

(1) FROM: (2) TO:

(3) SAMPLE # (4) DESCRIPTION OF WIPE (5) ISOTOPE RESULTS(μCi) DPM

1.

2.

3.

4.

5.

(6) WIPE TAKEN BY/DATE:

(7) PHONE: DSN: Commercial: ( )

(8) COMMENTS:

********** FOR USE BY DIRECTORATE OF SAFETY RISK MANAGEMENT**********

REFERENCES

American Conference of Governmental Industrial Hygienists (ACGIH), 1998. *Industrial Ventilation: A Manual of Recommended Practice*. 23rd Edition. Cincinnati, Ohio: ACGIH, Inc.

Agresti, A., and B. Finlay. 1997. Statistical Methods for the Social Sciences. 3rd Edition. New Jersey: Prentice Hall, Inc.

Argonne National Laboratory (ANL), 2001. Relative Radiological Toxicities.

Burton, J. 2001. Important New OH&S Standard Now in Effect. *Occupational Health & Safety* 70:26-28.

Chan, W., C. Chang, and E. Symanski. 2001. Mixed-Effects Models for the Evaluation of Long-term Trends in Exposure Levels with an Example from the Nickel Industry. *Occupational Hygiene* 45:71-81.

Croft, J., and C. Lefaure. 1999. Overview of Occupational Exposure Optimization Challenges in Industrial and Research Uses. 3rd European ALARA Network Workshop. Neuherberg, Germany.

Croteau, G. 2002. The Effect of Local Exhaust Ventilation Controls on Dust Exposures During Concrete Cutting and Grinding Activities. *AIHA Journal* 63:458-467.

Degrange, J., B. Gibert, and C. Lefaure. 1999. *ALARA and Internal Exposure: Some Lessons Learned from External Exposure Management*. Radioactive Contamination Control Guide. Washington, D.C.

Department of Defense (DOD). 2000. Radiation safety officer course. Presentation was offered for refresher course, Maryland.

Department of Defense (DOD). 2003. Radiation safety officer course. Presentation was offered for refresher course, Maryland.

Department of Energy (DOE). 1998. *Market Information Sheet: Facility Decontamination*. December 21,1998. Washington, D.C.

Department of Energy (DOE). 2002. Portable Tritium Cleanup Cart. *Innovative Technology*. DOE/EM-1089. Washington, D.C.

Department of Energy (DOE). 2002. *Primer on Tritium Safe Handling Practices*. DOE-HDBK-1079-94. Washington, D.C.

East, J., D. Marx, and K. O'Kula. 2000. A Posteriori Verification and Validation of a Tritium Dispersion & Consequences Model. SAWG Workshop 2000.

Edwards, R. 2002. Double Exposure: Safety Margins for a Radioactive Pollutant are Slimmer than We Thought. *New Scientist* 174:8-32.

Fairlie, I. 1992. Tritium: The Overlooked Nuclear Hazard. *The Ecologist* 22:225.

Faustman, E. 2000. *Worker Health at SRS: Does Tritium Exposure Impact Health Status?* CRESP Update Savannah River 5:1.

Flynn, M. 2003. Glowing with Excitement. *Bulletin of the Atomic Scientists* 59:8.

Franke, B. 2001. *Review of Radiological Monitoring at LBNL*. Heidelberg, Germany.

Fume Hood. 2003. Laboratory fume hoods. http://www.fumehood.com.

Government Accounting Office (GAO). 2000. *Radiation Standards: Scientific Basis Inconclusive, and EPA and NRC Disagreement Continues*. GAO/T-RCED-00-252. Washington, D.C.

Government Accounting Office (GAO). 2001. *ITAR Technical Basis*. GAO FDR 1 01-07-13R1.0. Washington, D.C.

Government Project Request (GPR). 2000. Project #022CS028. Department of Public Defense. Washington, D.C.

Heinonen, K. 1996. Local Ventilation for Poeder Handling-Combination of Local Supply and Exhaust Air. *American Industrial Hygiene Association Journal* 57:356.

Henkelmann, R., and F. Wagner. 1999. Internal Exposures by Tritium in a High Flux Research Reactor. 3rd European ALARA Network Workshop. Neuherberg, Germany.

Hosmer, D., and S. Lemeshow. 2000. *Applied Logistical Regression*. 2nd Edition. New York: John Wiley & Sons, Inc.

IFEU 2001. Review of Radiological Monitoring at LBNL. *IFEU Draft Final Report*. Heidelberg, Germany.

Kolb, R. 2001. *Improvements Announced at Lab's National Tritium Labeling Facility*. Berkeley Lab.

Logistical Regression by Statistics Solutions. 2005. http://www.statisticssolutions.com/Logistic_Regression.htm.

Los Alamos National Laboratory (LANL). 2003. *Engineering Standards Manual.* OST220-03-01-ESM.

Los Alamos National Laboratory (LANL). 2001. *Local Ventilation for Contaminant Control.* LIR 402-830-01.0.

Los Alamos National Laboratory (LANL). 2002. *Master Construction Specification-Fume Hoods.* LIR11612-16.

Los Alamos National Laboratory (LANL). 2002. *Occupational Radiation Protection Requirements.* LIR402-700-01.1

Martin, B. 2002. Assessing and Controlling Airborne Hazards in Your Plant. *Plant Engineering and Maintenance* 26:14.

Mathew, K., S. Ravi, N. Seshadri, and T. Subramanian. 2002. Preparation of Tritiated Polystyrene Coated Radioluminescent Phosphor. *Journal of Radioanalytical and Nuclear Chemistry* 254:209-211.

Minor, C. 1994. Well Designed Air Control Systems Diminish Exposure to Lead and Acid. *Occupational Health & Safety* 63:109.

Moeller, D. 1996. Application of Innovative Policies for Controlling Radionuclide Releases: The "Open-Market Trading Rule." 24th DOE/NRC Nuclear Air Cleaning and Treatment Conference.

Neuman, V. 2002. Lab Ventilation Controls: Understanding Your Options. *Research & Development*. Barrington.

National Institute of Safety and Health (NIOSH). 2001. NIOSH Energy Related Health Research Program. http://www.cdc.gov/niosh/2001-133i.html.

Nuclear Regulatory Commission (NRC). 2002. http://www.nrc.gov.

Nuclear Regulatory Commission (NRC). 2005. Tritium Production. *Backgrounder.* Washington D.C.

National Safety Council. 1996. *Fundamentals of Industrial Hygiene.* 4th Edition. Chicago, IL: National Safety Council, Inc.

O'hira, S. 2000. Improvement of Tritium Accountancy Technology for ITER Fuel Cycle Safety Enhancement. *Nuclear Fusion*, Vol. 40, No. 3Y. IAEA, Vienna.

Occupational Safety and Health Administration (OSHA) 2006. http://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_3.html.

Rad/Comm Systems 2005. http://www.radcommsystems.com/news.html

Raftopoulos, S. 2002. D&D Lessons Learned Workshop. Princeton Plasma Physics Laboratory. June 25, 2002.

Philippi, H. 1996. Variable Pattern Contamination Control Under Positive Pressure. 24th DOE/NRC Nuclear Air Cleaning and Treatment Conference.

Rice, P. 1996. Radioactive Waste Tank Ventilation System Incorporating Tritium Control. 24th DOE/NRC Nuclear Air Cleaning and Treatment Conference.

Roelofs, C. 2003. Prevention Strategies in Industrial Hygiene: A Critical Literature Review. *AIHA Journal* 60:62-67.

SignaGen. 2003. Nitrocellulose/filter paper sandwich. http://www.signagenlabs.com.

Teschke, K. 2002. Exposures and their Determinants in Radiographic Film Processing. *AIHA Journal* 63:11-21.

Tobin, M., and J. Yatabe. 1994. NIF Environmental Safety and Health Considerations. *E&TR*, December.

Williams, F. 2001. *Hydrogen Isotope as a Source of Light*. Fire UK.

Witschger, O. 1999. Sampling of Airborne Dusts in Workplace Atmospheres. 3rd European ALARA Network Workshop. Neuherberg, Germany.

Wuensch, K. 2006. Logistical Regression with SAS©. http://core.ecu.edu/psyc/wuenschk/StatsLessons.htm