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A Retrospective Analysis And Field Study Of Nanotechnology Related Ergonomic Risk In Industries Utilizing Nanomaterials

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A RETROSPECTIVE ANALYSIS AND FIELD STUDY OF NANOTECHNOLOGY-RELATED ERGONOMIC RISK IN INDUSTRIES UTILIZING NANOMATERIALS

by

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ABSTRACT

The National Science Foundation estimates that two million skilled nanotechnology workers will be needed world wide by 2015 – one million of them in the United States (2001). In the absence of scientific clarity about the potential health effects of occupational exposure to nanoparticles, guidance in decision making about hazards, risk, and controls takes on new importance. Currently, guiding principles on personal protective equipment for workers who come in contact with nanomaterials have not been standardized universally. Utilizing the NASA-TLX, this dissertation investigates the adequacy and shortcomings of research efforts that seek to determine whether or not occupational exposure to nanomaterials while wearing personal protective equipment (PPE) is or is not potentially frustrating to the worker. While wearing PPE does the worker perceive additional effort, performance, physical, mental or temporal demands or are not impacted during task performance.

I would like to pay respect and homage to all those who have come before me who marched, protested, sacrificed, fought and died so that I would have this opportunity for an advanced degree in industrial engineering at the university of my choice. This work is also dedicated to my spouse, children, parents, grandparents and especially my maternal grandmother. I owe all of you a debt of gratitude for cultivating in me the desire to learn and seek excellence. All of you inspire and empower me daily.

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LIST OF ABBREVIATIONS AND ACRONYMS

ENP - Engineered nanoparticles

EPA - The United States Environmental Protection Agency

EU-OSHA- European Agency for Safety and Health at work

FDA - The Food and Drug Administration

FY- Fiscal year

IRSST- Institut de recherché Robert-Sauvé en santé et en sécurité du travail

NCPI - Nanotechnology Consumer Product Inventory

NIH - The National Institute of Health

NIOSH - National Institute for Occupational Safety and Health

NNI - National Nanotechnology Initiative

NSF - The National Science Foundation

NIST - National Institute for Standards and Technology

PPE - Personal Protective Equipment

PEN - The Project on Emerging Nanotechnologies

CHAPTER 1: INTRODUCTION

Personal Protective Equipment (PPE) is increasingly common in nanotechnology manufacturing, but the effect of PPE on the mental demand, physical demand, temporal demand, performance, effort, and frustration on nanotechnology workers remains unclear.

1.1 Background and Rationale

The science of nanotechnology is the understanding, manipulation, and control of matter on a near-atomic scale (between 1 and 100 nanometers (10^{-9}) in one dimension) to produce new structures, materials, and devices with unique and astonishing new properties (National Research Council 2002 and Drecher 2004). The promising fields of nanotechnology and nanosciences are global technologies that can possibly transform the world's economy, and its workforce is often referred to as the ''Next Industrial Revolution'' (Roco, 2005).

The nanotechnology workforce is growing. The National Science Foundation (NSF) estimates that two million skilled nanotechnology workers will be needed world wide by 2015 – one million of them in the United States (Roco, & Bainbridge, 2001). Nanotechnology and nanosciences present vast opportunities for economic growth and development in multiple areas. These areas include, but are not limited to, the manufacturing of and access to clean water, energy production, medical therapies and diagnostics, agriculture and food production, and information technology. The number of nano-related products has multiplied exponentially over the past three decades. This fact is confirmed by the vast number of nano-related products produced and marketed as well as the huge monetary amounts dedicated to research and development by governmental agencies worldwide. The National Science Foundation (NSF) predicts that nano-related goods and services could be a $1 trillion market in 2015 and will employ 2 million people, 1 million of whom will be in the United States (Roco & Bainbridge, 2007). Daniel J. Fioriono (2009) reported in the19th issue of PEN (Project for Emerging Technology), November, 2010, that the Nanotechnology Consumer Product Inventory highlighted over one thousand nano-type products in its on line inventory, an increase of 379 percent since the inventory was initially released in 2006 (p. 13). Scientist estimates put the global nanotechnology market as having grown to $29 billion by 2008 (Nel, Xia, Mädler, & Li, 2006). Further, Saniei et al. (2007) believe nanotechnology to be one of the fastest growing industries in history, even larger than the combined telecommunications and information technology industries at the beginning of the technology boom in 1998. According to Iavicoli, Rondinone, and Boccuni (2009), various databases estimate that more than a thousand nanotechnology companies worldwide are exploring across various sectors, most of them in the United States, Germany, and the United Kingdom. The United Kingdom leads the way in Europe in nanotechnology in terms of small and medium enterprises and big-business investments.

According to data compiled by Jae-Young Choi et al 2009, there were 329 firms in the United States. Fifty-three of which are publicly traded firms and two hundred and seventy six privately owned firms. As of February, 2011, data released by the Project on Emerging nanotechnologies (PEN) highlights more than 1,200 companies, universities, government laboratories and organizations (http://www.nanotechproject.org/inventories/map/). For these reasons, it is clear that there will be more nanotechnology workers over time.

Presently, human factors and ergonomic principles do not exist for workers interacting with nano-materials. Therefore, nanotechnology presents new challenges for measuring, monitoring, and minimizing contaminants in the workplace and the environment (International Council on Nanotechnology (ICON), 2006).

The limited state of current knowledge about the risks posed by some manufactured nanomaterials presents a number of obstacles to any attempt to regulate in this area (Gavaghan & Moore, 2011). Further, the lack of understanding of the impact of the work task environment as it relates to the nanotechnology worker while wearing personal protective equipment (PPE) presents a unique engineering challenge for the human factors and ergonomic community. The Occupational Safety and Health Act (OSHA) was enacted by the United States Congress in 1970, with the objective of protecting employees by providing workers with a safe work environment, free from known hazards such as mechanical dangers, unsanitary conditions, toxic chemicals and excessive heat, cold, noise and vibrations. However, in 1970, OSHA did not anticipate the nanotechnology work environment.

Nanomaterials pose occupational health risk (NIOSH, 2009). Preliminary findings show that manufactured nanoparticles may pose risks to human health due to their composition, size, and ability to cross cell membranes (Nel et al, 2006). Workplaces such as research laboratories, production or operation facilities at which nanomaterials are engineered, processed, used, disposed or recycled are areas of concern because these are areas where workers are exposed to nanomaterials. Protecting workers is important moral because worker health is a moral issue. Training new workers is expensive, and worker health, worker performance, worker attitudes, worker frustration may each contribute to worker retention. It is possible that improving worker protection may reduce insurance rates. For these reasons, management has an interest in protecting workers.

1.1.1 Protecting Workers

Towards protecting workers, human factors and ergonomic environmental health and safety controls can be divided into three categories: Environmental Barriers, Engineering Controls, and Administrative Controls (Hedge, 2006; Konz, 1995, 2006). Engineering Controls (Table 1) and Administrative Controls (Table 2) represent controls management can take to protect workers by changing the work environment (Engineering Controls) or by reducing exposure times and monitoring workers (Administrative Controls) (Konz, 1995, 2006). Table 3 shows that Environmental Barriers for protecting workers includes enclosures and protective clothing (Hedge, 2006).

Table 1. Engineering Controls (adapted from S. Konz 1995, 2006)

Engineering Control	**Solution Examples**
Substitute a less harmful material	• Use latex paint instead of organic base • Use glues without solvents
Change the material or process	• Reduce CO_2 by using electric powered vehicles not gasoline powered • Use a vacuum system instead of blowing with compressed air
Enclose or isolate the process	• Physical enclose the process or equipment • Remove air from the enclosure (hood) (i.e. negative pressure)
Use wet methods	• Wet floor before sweeping
Provide local ventilation	• The worker is upwind of the contaminant
Provide general (dilution) ventilation	• Forced ventilation (fan, blowers) • Natural ventilation (open door)
Use good housing	• Fix leaking containers • Clean up chemical spills • Remove and prevent dust movement
Control waste disposal	• Establish specific procedures for disposal of dangerous substances

Table 2. Administrative Control adapted from S. Konz 1995, 2006)

Administrative Controls	Solution
Reduce exposure time	• Reduce exposure time from 8 hrs to 4
Periodically monitor employees	• Biological monitoring (i.e. blood, urine)
Train supervisors, engineers and workers	• Read Material Safety Data Sheet
Screen potential employees	• Avoid workers who are hypersensitive to substances

Table 3. Environmental Barriers (from Hedge, 2006)

Type of Barrier	Function
Clothing (personal protective equipment: Respirators, aprons, gloves, masks, goggles and boots)	• Second skin from adverse conditions • Thermal comfort and protection from adverse conditions such as extreme heat, cold, wetness, air pressure and chemical contaminants.
Enclosures (secondary barrier that functions as third skin)	• Vehicles – provides transportation as well as a third barrier that allows human survival. (i.e. Planes, space shuttle and submarines) • Structures – Climate conditions within buildings are designed to provide appropriate ambient environment for humans or inhospitable terrestrial locations.

1.1.2 Personal Protective Equipment

Personal protective equipment (PPE) represents a class of clothing designed to protect workers. PPE represent an Environmental Barrier (Table 3), which allows the worker to create a physical barrier between themselves and the hostile environment in which they are working in. Environmental ergonomics research focuses on requirements for clothing and enclosures that allow us to live in extreme terrestrial climates that range from deserts to Polar Regions, or that allow us to venture into extremely harsh environments such as the ocean floor or outer space (Hedge, 2006). Chemical protective equipment protects the user by providing a barrier between the individual and hazardous environment (Grugle & Kleiner, 2006). Unfortunately, the same equipment that is designed to support the user can potentially cause heat stress, reduced task efficiency, and reduced range-of-motion. (Grugle & Kleiner, 2006). The Processing Efficiency Theory (PET) was specifically developed to account for how anxiety influences performance.

However, the effect of Personal protective equipment (PPE) on the mental demand, physical demand, temporal demand, performance, effort, and frustration in nanotechnology workers had not been explored. The literature and survey analysis revealed an absence in epidemiological knowledge regarding the impact of nano-particles on operators from an ergonomic, attitudes, or performance perspective. Therefore, there is a need to explore worker's physical performance and cognitive experiences during nanotechnology work task performance while utilizing PPE and in absence of PPE. This research fills a crucial gap in our knowledge of how PPE can impact nanotechnology worker attitudes and performance, which can inform theory and practice, protecting both workers and shareholders.

1.2 Problem Statement

No published studies to date explore the effect of PPE on the mental demand, physical demand, temporal demand, performance, effort, and frustration in nanotechnology workers. Epidemiology studies predict the potential for worker exposure to ultrafine particles at relatively high concentrations in industrial workplaces where nanoparticles are manufactured (Kim & Jaques, 2004) Further, a great number of animal studies have documented toxicological reactions to nanoparticle exposure which resulted in translocation of particles to the blood stream and distal organs, oxidative stress and pulmonary inflammation (Ferin et al. 1992, Heyder and Takenaka 1996, Baggs et al, Oberdörster, 1996, Zhang et al.1998, Zhang et al 2003, Zhou et al 2003, Warheit et al 2004 and Warheit 2007). Appropriate and universally accepted standards, guidelines do not presently exist, and legislation does not presently exist for nanomanufacturing, handling, and safe utilization of nanomaterials (National Institute for Occupational Safety and Health (NIOSH) 2007, 2009, California Council on Science and Technology, 2010, Greaves-Holmes, 2010, Maynard, 2009; International Council on Nanotechnology, 2006).

The advent of nanomanufacturing may be negatively impacting physical ergonomic factors of the nanomanufacturing workforce, yet these factors have yet to be investigated adequately. The challenge for the human factors community lies in understanding the health, safety, ergonomic and human factors risks associated with work load during task performance of the nanotechnology worker. A study was needed to explore the ergonomic factors that impact worker's performance and provide insight into worker's needs, capabilities and limitations as it relates to the nanomanufacturing process. Further, a study was needed to explore the operator perceptions and performance related to PPE in nanomanufacture workers.

1.2.1 Statement of Purpose

The purpose of the present study was to measure the mental demand, physical demand, temporal demand, performance, effort, and frustration in nanotechnology workers when using PPE and when not using PPE. To foster generalizability, these measures were assessed in workers representing three job types which are common in nanomanufacturing: sorters, repetitive motion mixers, and loaders. PPE and no-PPE conditions were assessed following a two-hour portion of a workshift, simulating a work duration between breaks. Differences contrasting PPE and no-PPE were determined using the paired t-test at a statistical significance threshold of $p < .05$.

1.2.2 Significance of Research

This line of research is important. It is important to evaluate the worker's protection needs in this environment from HFE perspective. In spite of the rapid growth of the field, the human factors and ergonomic issues surrounding the nano workforce need clarity (Karwowski, 2003, 2005). There is limited information from an occupational or ergonomic risk perspective. Waldemar Karwowski, (2003) originator of the emerging domains of theory and applications of nanoergonomics, reveals that the field of nanoergonomics is composed of four main specialty focuses. Customer domain: safety and health, usability, productivity, performance and human well-being. Studies reveal that the appropriate use of personal protective equipment (PPE) can reduce injuries and illnesses (Breish, 1989; LaBar, 1990). A survey, based on 1986-88 United States Occupational Safety and Health Administration (OSHA) forms used to log occupational injuries and illnesses, revealed that the proper application of PPE could have prevented up to 37.6% of the occupational injuries and illnesses reported (LaBar, 1990). Indeed, according to OSHA statistics, about 12-14% of total disabling occupational injuries occur because workers do not wear the appropriate PPE (Breisch, 1989). Further, National Institute of Safety (NIOSH) has established upper limits for occupational exposure. Given the rapid growth in the field of nanotechnology manufacturing NIOSH has identified personal protective equipment as a primary means by which to address occupational safety. Additionally, environmental conditions can have a profound effect on work performance (Kolish, 2006). As a result, analysis of workers perception of personal protective equipment is important.

This line of inquiry can potentially

- Inform theory
- Inform shareholders

- Inform the human factors community
- Inform the ergonomic community
- Foster the construction of ppe guidelines and protocols in nano industries
- Inform governmental agencies
- Help administrators make good decisions regarding ppe
- Foster a healthy workplace

1.3 Research Questions

Six research questions were addressed, each reflecting potential differences between PPE and no-PPE conditions in performing work in a nanotechnology environment. For each research question, the null (H_0) and alternative hypotheses (H_a) are presented.

Research Question 1: PPE and Mental Demand. *Is Perceived Mental Demand significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE?*

$H1_0$: Perceived Mental Demand is not significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.

$H1_a$: Perceived Mental Demand is significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.

Research Question 2: PPE and Physical Demand. *Is Perceived Physical Demand significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE?*

$H2_0$: Perceived Physical Demand is not significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.

$H2_a$: Perceived Physical Demand is significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.

Research Question 3: PPE and Temporal Demand. *Is Perceived Temporal Demand significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE?*

$H3_0$: Perceived Temporal Demand is not significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.

$H3_a$: Perceived Temporal Demand is significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.

Research Question 4: PPE and Performance. *Is Perceived Performance significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE?*

$H4_0$: Perceived Performance is not significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.

$H4_a$: Perceived Performance is significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.

Research Question 5: PPE and Perceived Effort. *Is Perceived Effort significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE?*

$H5_0$: Perceived Effort is not significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.

$H5_a$: Perceived Effort is significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.

Research Question 6: PPE and Perceived Frustration. *Is Perceived Frustration significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE?*

$H6_0$: Perceived Frustration is not significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.

$H6_a$: Perceived Frustration is significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.

1.4 Theoretical Basis of Research

The theoretical basis of the research is the foundation used to establish the methodology and to identify variables measured in the study. Growing complexity and increasingly automated features of modern human machine systems are presenting operators with fewer physical demands and greater cognitive demands (Tsung, 2006). Further, Tsung states, unlike physical demands, cognitive or mental demands are not directly observable. The concept of mental workload is used to benchmark the mental demands of complex systems (Tsung, 2006). O'Donnell and Eggemeier (1986) defined mental workload as "That portion of the operator's limited capacity required to perform a task. "If task demands exceed available resources, performance falters. Sheridan (1979) describes dominant factors as busyness (rate of coping), complexity (difficulty of the task), and anxiety (about consequences of the task).

Table 4. Theories of Mental Workload

Researcher	Mental Work Load Theories
Tsung (2006)	Unlike physical demands, cognitive or mental demands are not directly observable. The concept of mental workload is used to benchmark the mental demands of complex systems
O'Donnell and Eggemeier (1986)	Defined mental workload as "That portion of the operator's limited capacity required to perform a task. "If task demands exceed available resources, performance falters.
MIT Sheridan et al. (1979)	Dominant factors of mental workload (busyness = rate of coping) (Complexity = difficulty of task) (Anxiety = about consequences of action)

Table 5. Theories Concerning Environment and the Effect of Environment on Performance (adapted from Kolich, 2006; Burke, Szalma, Gilad, Duley, & Hancock, 2005)

Theories	Definition
Arousal Theory	For all tasks, there is an optimum level of arousal (readiness to act) at which maximum performance occurs. Environmental extremes can increase arousal level whereas overly comfortable can lower the level of arousal.
Competing Theory	Environmental extremes can have a distracting effect – performance declines because of momentary shifts of attention from the task toward the environment
The Processing Efficiency Theory (PET)	Developed to account for how anxiety influences performance.

It is the objective of this research to examine the ergonomic factors that impact nano workers performance while wearing PPE and offer insight into worker perceived capabilities and limitations in their use of personal protective equipment for safety purposes during occupational activities exposing workers to nanomaterials. Moreover, understand cognitive and performance issues impacting the nanotechnology workplace environment.

This introductory chapter provided the background and rationale for the present study, including an introduction to the challenges facing the nanotechnology industry in protecting worker health while protecting the interests of shareholders. PPE may confer significant health benefits, but PPE may hamper worker performance and attitude. The Literature Review chapter that follows builds on the theoretical foundation provided here, including nanomaterials and health, the dangers in the nanoworker workplace, and what is known and unknown regarding PPE in nanotechnology workers.

CHAPTER 2: LITERATURE REVIEW

> Every day in America, 12 people go to work and never come home. Every year in America, 3.3 million people suffer a workplace injury from which they may never recover. These are preventable tragedies that disable our workers, devastate our families, and damage our economy. – Secretary of Labor Hilda Solis, April 28, 2011

This chapter provides a review of the relevant literature regarding nanotechnology, nanomaterials, health, ergonomics, performance, and PPE. Nano-workers employed at research laboratories, production or operation facilities at which nanomaterials are engineered, processed, used, disposed or recycled are areas of concern because these are areas where workers are initially exposed to nanomaterials. This chapter begins with an overview of Nanotechnology and Nanomaterials. A review of nanomaterials and health follows, including Inhalation and Dermal Exposure to Nanomaterials. The reasons for and effectiveness of Personal Protective Equipment (PPE) includes a review of the trade-off between PPE and Worker Performance. This chapter ends with a summary, including identification of gaps in the reviewed literature, leading the methodology employed in the present study.

2.1 Nanotechnology and Nanomaterials

Nanotechnology workers manipulate and control matter on a near-atomic scale (between 1 and 100 nanometers (10^{-9}) in one dimension) to produce new structures, materials, and devices with unique and astonishing new properties (National Research Council 2002 and Drecher 2004). The prefix *nano* means one billionth; therefore, a nanometer is one billionth of a meter (The Royal Society & The Royal Academy of Engineering 2004). To highlight how minute a nanometer is a single strand of human hair measures 50,000–100,000 nanometers in diameter, a nanometer is one hundred thousand times smaller than the diameter of a human hair, a thousand times smaller than a red blood cell, or about half the size of the diameter of DNA (EPA, 2007). The smallest objects that might be seen by the unaided human eye are approximately 10,000 nanometers. A single nano is about 80,000 times smaller than a single strand of human hair. One sheet of paper is approximately 100,000 nanometers thick. Objects in the range of 1 to 100 nanometers can exhibit unexpected chemical, physical, and biological properties that are not exhibited when in bulk form (The Royal Society & The Royal Academy of Engineering, 2004).

At the nanoscale, the physical, chemical, and biological properties of materials often differ in fundamental and valuable ways from the properties of individual atoms and molecules or from the properties of bulk matter. (The National Nanotechnology Initiative, 2008) One reason nano-sized materials can behave differently is that they have high surface-to-volume ratios, so a large proportion of their atoms is on the surface, allowing them to more readily react with adjacent atoms (Jefferson 2000).

2.1.1 Nanomaterials and Health

There are two general categories of nanoparticles, incidental nanoparticles (natural or anthropogenic i.e. commonly found in the diesel combustion and welding industry) and engineered nanoparticles (created with specific properties). Welding produces aerosols containing nanosized metal particles that have been associated with acute responses known as metal fume fever and chronic bronchitis (Antonini 2003, Sferlazza and Beckett 1991). Acute pulmonary and systematic inflammation has been associated with short tern exposure to particulates formed from diesel exhaust (Salvi et al 1999).

An innovative and relatively new area of research called nanotoxicology investigates the distinctive biokinetics and toxicological potential of engineered and fabricated nanomaterials. Greaves-Holmes (2009). Engineered nanomaterials are generally identified as ultrafine particulate matter measuring between 1and 100 nm (10^{-9}) in one dimension. The tendency of these nanoparticles of different shapes (e.g., geodesic spherical domes, crystalline structures, rods, tubes), different chemistries (e.g., carbon, silicon, gold, cadmium, and other metals), possessing different surface characteristics, and exhibiting distinctly different properties from their original bulk materials respectively (due to varying mass, charges, solubility, and porosity) to translocate from the location of deposit in the respiratory tract to extra-pulmonary organs, such as the brain, heart, liver, and bone marrow, are being researched, examined, and evaluated using various multidisciplinary approaches. (Greaves-Holmes, 2009) These findings are not unanticipated.

A limited number of occupational nanoparticle exposure studies were conducted to evaluate engineered ambient nanoparticle concentration. Boffetta et al., 2004, investigated respirable Titanium dioxide ($TiO_{2)}$ dust exposure and which was conducted in eleven production factories in Europe and found that no carcinogenic effect and no increase mortality due to TiO2 exposure. Other scientist observed that there was no increased incidence of cancer attributable to TiO_2 exposure in the work place (Hext et al. 2005, Boffetta et al, 2001, Fryzek et al. 2003, Chen and Fayerweather 1988). The aforementioned researchers evaluated mortality statistics from four United States and eleven European TiO_2 manufacturing facilities and found no carcinogenic effect as a result of TiO_2 exposure in these occupational settings. However, an assessesment of epidemiological research studies have documented that acute adverse health effects (e.g., cardiovascular disease) can be related to exposure to airborne particles (Oberdörster et al. 2004).

A growing number of studies on engineered nanomaterials show that some of these materials can have detrimental biological effects (Powell et. al, 2008). Further, toxicity research conducted by Tran et al. 2000, Oberdörster 2000, Oberdörster et al. 2004, Peters et al. 1997, observed that size and surface area rather than particle mass are dose metrics most closely related to nanoparticle toxicity. Additionally, scientific investigators affirm that small particles can create ill effects that are associated with the molecular composition and physical attributes of the substance. As a case in point, nanoscale titanium dioxides used in sunscreens and cosmetics have been associated with pulmonary effects such as lung inflammation, pulmonary damage, and fibrosis in animal studies and related effects in vitro (Bermudez and others 2002, 2004; Grassian et al, 2007; Long et al, 2007). Nanoparticles in the circulatory system may translocate to organs such as the liver, heart, or brain (Oberdorster et al. 2004). Further, pulmonary exposure to minute quartz particles impairs endothelium and pulmonary muscle and tissues; however, the identical particles slightly coated with clay are less detrimental to the respiratory system (Bermudez and others 2002, 2004; Grassian et al, 2007; Long et al, 2007). Many different types of carbon nanotubes, which have fibrous structures similar to that of asbestos, are used in electronics, pharmaceuticals, and a variety of other applications; some forms of carbon nanotubes have been associated with oxidative stress, 16ytotoxicity, inflammation, granuloma formation, and fibrogenesis in in vitro and in vivo studies (Donaldson and others 2006; Muller et. al, 2006). Moreover, the long, thin fibers of asbestos poses a major risk to humans when inhaled, yet, if these fibers are pulverized into tiny particles with the exact same chemical composition, the danger is appreciably reduced. (Donaldson and others 2006; Muller et. al, 2006)

Fullerenes, or ‘‘buckyballs,’’ are soccer-shaped balls of carbon used in catalysts, copolymers and composites, lubricants, drugs and drug delivery systems, cosmetics, health care products, and sporting goods. Due to their antioxidant properties, they show promise as treatments for cancer, Auto immune deficiency syndrome (AIDS), and bacterial infections, but some studies suggest that they can cause DNA damage, lipid peroxidation, and leaky cell membranes (Oberdorster 2004; Sayes 2005) Science suggests that synthetic carbon molecules (Carbon $_{60}$ molecules, also known as buckminsterfullerene, fullerene, or buckyballs) have a high potential for being accumulated in animal tissue, but the molecule appears to break down in sunlight, perhaps reducing its possible environmental dangers (Purdue University, 2008).

In the October 2008 issue of *Science Daily*, a featured article highlighted a toxicology study that concluded that some types of nanomaterials (Carbon $_{60}$ molecules) can be harmful to animal cells and other living organisms (University of Calgary, 2008). Existing scientific data indicates that ultrafine nanoparticles may be more biologically reactive than larger particles of similar chemical composition and thus may pose an increased health risk when inhaled (*Science Daily, 2008).* Quantum dots, nano-sized particles used or being developed for use in electronics, biomedical imaging, and surveillance, are typically made of cadmium or lead, well-known toxins (University of Calgary, 2008). Toxicological and pharmaceutical studies suggest that protective coatings of quantum dots can degrade in light and oxidative conditions, releasing these metals into cells and organisms and causing toxic effects (Hardman 2005). Particle physics scientists and researchers of fine atmospheric pollutants state that ultrafine nanoparticulate matter released into the atmosphere can remain airborne for a significant period of time, be inhaled repeatedly, and then collect in all regions of the respiratory system with over one-third of the nanoparticles being deposited in the deepest regions of the lungs. The potential health risk following exposure to a substance is generally associated with the magnitude and duration of the exposure, the persistence of the material in the body, the inherent toxicity of the material, and the susceptibility or health status of the person (Lonone, Sophine, Boczkowski, Jorge, 2006). There are numerous other types of nanomaterials currently in production, most of which have not been studied for toxicity. Adequate risk assessments for emerging nanotechnologies and nanomaterials are extremely difficult because of significant data gaps and unknowns. Relatively few toxicological studies have been done to date, there are many methodological uncertainties and inconsistencies among these studies, and it is difficult to extrapolate study results done primarily in controlled settings in labs to human beings and wildlife within complex ecosystems. Little to nothing is known about actual human exposures to engineered nanomaterials in real workplaces or the environment, or what levels of exposures are likely to be harmful (Nowack and Bucheli 2007).

Scientist question whether or not we should heed lessons learned from past, the asbestos legacy as it relates to the similarities to nanomaterials. Researchers are reporting similarities between the elongated fibers of asbestos and the elongated shapes found in carbon nanotube. It wasn't until the mid-20th century that researchers officially established the connection between asbestos exposure and serious respiratory conditions (although evidence was presented as early as the 1920s), but by then, millions of workers had already been exposed to asbestos fibers in the workplace and in other locations. While federal asbestos exposure limits were imposed in 1972, an estimated 10,000 people in the United States continue to pass away each year from asbestos-related illnesses (Accessed Abestos.com May, 2011).

The October 29, 2009, issue of the European Respiratory Journal, a well-respected medical peer-reviewed periodical, reported an obvious relationship between nanomanufacturing exposure and acute respiratory disease (Song, Li, & Du, 2009). Specifically, in this study, investigators at China's Capital University of Medical Science related unusual and progressive lung disease in seven Chinese workers, two of whom died, to nanoparticle exposures in a print plant where a polyacrylic ester paste containing nanoparticles was used. This linkage was made by the study investigators despite a general lack of exposure data for the workers. Researcher's state:

> There are cellular and laboratory animal studies that suggest the enhanced toxicity of some engineered nanoparticles (ENP) relative to larger sized particles of the same chemical composition (e.g., carbon nanotubes versus graphite, nano-sized titanium dioxide versus conventional titanium dioxide), until recently, there were little or no undeviating human evidence of the health risks posed by ENP. . . . The lack of any epidemiology or medical case studies investigating potential ENP exposures and undesirable health effects among either the workforce or consumers is likely a result of several factors (Song et al., 2009).

These factors include the fairly recent intensification in ENP manufacturing and commercial application, as well as the fact that relatively small amounts are typically manufactured and handled. The Song et al. (2009) study is a medical case report that claims to provide the first human evidence of "nanomaterial-related disease" following long-term nanoparticle exposure. Investigators credited abnormal and progressive lung disorders in seven Chinese employees, two of whom died of respiratory failure, to workplace nanoparticle exposures in a print plant where a polyacrylic ester paste containing nanoparticles were sprayed onto a polystyrene substrate, with consequent heat-curing. (Song et al 2009).

According to the October 29, 2009, issue of the European Respiratory Journal, for a period of five-to-thirteen months' duration:

- All seven female staff members (ages 18–47) worked in the same department of the print facility

- All seven female staff members worked in a room with little to no ventilation due to the failure of the mechanical ventilation system.
- All seven female staff members wore cotton mask over their faces while working
- All seven female staff members presented with shortness of breath and pleural effusions were admitted to hospital.

Despite the absence of any quantitative data of actual human workforce exposures, Researchers concluded, based on the detection of 30-nm nanoparticles in the paste material as well as in accumulated dust in the workplace, that these workers were exposed to polyacrylate nanoparticles. Reporting the presence of similarly-sized nanoparticles in the chest fluid and lung cells of the diseased workers, Song et al. (2009) highlighted the emerging body of nanotoxicological evidence from animal and in vitro studies to support their conclusion that the observed health effects were due to polyacrylate nanoparticle exposures.

To help place the study in context, Dr. Andrew Maynard, Chief Science Advisor to the Woodrow Wilson International Center for Scholars Project on Emerging Nanotechnologies (PEN), has posted a blog item entitled "<u>New study seeks to link seven cases of occupational lung disease with nanoparticles and nanotechnology</u>" on the SAFENANO and 2020 Science websites (Maynard, 2009). Maynard notes that the seven women were all working for some months, in an enclosed space with little natural ventilation, in a facility spraying a polyacrylic ester paste onto a polystyrene substrate that was subsequently heat-cured. Five months before the lung disease was identified, the local exhaust ventilation in the facility broke down, and apparently was never repaired. Maynard states that the issues discussed in the aforementioned paper and the *Journal's* press release, including nanoparticle safety, worker deaths, and parallels with asbestos, these subjects will attract attention.

Dr. Andrew Maynard's review of the study yields important factors to consider (2009). Most importantly, the facility lacked even the most basic industrial hygiene and worker protection safeguards. Additionally, Dr. Maynard cautions that it is imperative to understand specific limitations of the study:

- It was a clinical study rather than a toxicology study
- It is not possible to draw any general conclusions on the safe use of nanotechnologies from it
- Interpretation of the study is hampered by a lack of exposure data
- There are no electron microscope images of the nanoparticles found in the workplace
- There is no chemical analysis of the particles found in the workplace or biological samples
- There is no assessment of other plausible causes of the symptoms seen
- In discussing the relevance of the study, the authors make no distinction between different types of nanomaterials and their potential impacts.

According to Maynard (2009), despite these limitations, this is a strong clinical study, and if viewed appropriately, will most likely help avoid similar incidents in the future." His final observation is that "the illnesses and deaths observed would most likely not have occurred if long-accepted occupational practices had been followed. The tragedy here is that, irrespective of the presence of nanoparticles, the illnesses and deaths could have been prevented if simple steps had been taken to reduce exposures.

An assessment of a variety of industries in the United Kingdom which produced or handled nanoparticles or materials was conducted by Wake (2001). High particle count concentrations were observed for carbon black and nickel powder. Unfortunately, analyses of

U.S. federal regulatory statutes conclude that existing federal regulations are inadequate to address potential nanotechnology risks in proactive ways (Davies 2006). The lack of toxicological data for many emerging nanomaterials is also a critical gap. Most environmental statutes cannot be enacted unless materials are first designated as ‘‘hazardous’’. Further, although the potential for human exposures to engineered nanomaterials could be significant in workplaces or via consumer products, there is little to no specific information about exposures to engineered nanomaterials (Powell et al, 2008).

The Occupational Safety and Health Act were enacted by the United States Congress on December 29, 1970. The objective of these federal laws were to protect employees by providing workers with a safe work environment, free from known hazards such as mechanical dangers, unsanitary conditions, toxic chemicals and excessive heat, cold, noise and vibrations. However, according to the November 13, 2006 survey conducted by the International Council on Nanotechnology (ICON), nanotechnology presents new challenges for measuring, monitoring, managing, and minimizing contaminants in the workplace and the environment. Further, measuring worker perceived frustration, effort, performance and mental, physical, temporal demands when wearing PPE is important. Sanders and McCormick (1993) state that measuring mental workload could be used for:

- Allocating functions and tasks between humans and machines based on predicted mental workload
- Comparing alternative equipment and designs in terms of the workloads imposed
- Monitoring operators of complex equipment to adapt the task difficulty or allocation of function in response to increases and decreases in mental workload.
- Choosing operators who have higher mental workload capacity for demanding tasks.

Currently, there are no standardized regulations for safe work practices with engineered nanosubstances. Manufactured nanoparticles may pose risk to human health due to their composition, size, and ability to cross cell membranes. Every aspect of nanotechnology is catching the attention of governments and business organizations worldwide. The proposed National Nanotechnology Initiative (NNI) budget for fiscal year (FY) 2011 of $1.76 billion will bring the cumulative investment since the inception of the National Nanotechnology Initiative in fiscal year 2001 to nearly $14 billion, reflecting the consistent, strong support of the United States government (Subcommittee on Nanoscale Science, Engineering, and Technology, 2010). In fiscal year 2010 requests include $80.44 million for discovery of novel nanoscale and nanostructured materials and improving the comprehensive understanding of the properties of nanomaterials (ranging across length scales and including interface interactions (NSF, 2010). Additionally, investigators have discovered evidence that indicates that nanoparticles can dissolve in the cell membranes, pass into cells, cross the blood–brain barrier, then reform as particles and alter the cell function(s) (University of Calgary, 2008).

2.1.2 Inhalation and Nanomaterials

The National Institute for Occupational Safety and Health (NIOSH, 2009) states that inhalation is the most common route of exposure to airborne particles in the workplace. Ultrafine nano particulate matter could be inhaled by workers if they do not wear protective breathing equipment. Humans have several defense methods to eradicate unwanted foreign objects. One process involves chemical decomposition for soluble particles and the other mechanism is physical translocation (i.e., transport from one place to another, for insoluble or low-solubility particles). Soluble ultrafine dusts will dissolve; however, they will not be discussed here, since the effects are highly variable depending on the dust composition and identical to those of larger dusts particles that are also solubilized. By translocation, insoluble or low-solubility particles deposited in the pulmonary system are eliminated from the respiratory system by transporting them elsewhere in the body. The mucociliary escalator eliminates the coarsest particles, which normally are deposited in the upper lungs, mainly in the tracheobronchial region. The tracheobronchial mucous membranes are covered with ciliated cells that form an escalator and expel the mucus containing the particles into the digestive system. Normally this is an efficient mechanism that eliminates particles from the respiratory tract in less than 24 hours, even ultrafine particles (Kreyling et al., 2002). In the alveolar region, the macrophages will take up the insoluble particles by phagocytosis, a mechanism whereby the macrophages will surround the particles, digest them if they can and proceed slowly to the mucociliary escalator to eliminate them. This is a relatively slow process, with a half-life of about 700 days in humans (Oberdörster et al., 2005). However, the efficiency of phagocytosis is heavily dependent on particle shape and size. Several studies seem to show that unagglomerated ultrafine particles deposited in the alveolar region are not phagocyted efficiently by the macrophages (particularly particles with a diameter of less than 70 nm; Bergeron & Archambault, 2005). However, the macrophages are very efficient for coarser particles in the one to three micrometer range (Tabata & Ikada, 1988). The often inefficient uptake of ultrafine and nanometric dusts by macrophages can lead to a major accumulation of particles if exposure is continued and to greater interaction of these particles with the alveolar epithelial cells. Studies have shown that some ultrafine particles can pass through the epithelium and reach the interstitial tissues (Borm, Schins, & Albrecht, 2004; Ferin, Oberdörster, & Penney, 1992; Kreyling & Scheuch, 2000, Kreyling et al., 2002; Oberdörster, Ferin, Gelein, Soderholm, & Finkelstein, 1992; Oberdörster, Ferin, & Lehnert, 1994). This phenomenon seems more prevalent in higher species, such as dogs and monkeys, compared to rodents (Kreyling & Scheuch, 2000; Nikula et al., 1997).

With a reduction of their size, nanoparticles reveal unique properties. A size reduction results in a substantial increase in the specific surface and the surface Gibbs free energy. This physical parameter of free energy reflects the fact that chemical reactivity increases rapidly as particle size diminishes. For example, water has a specific surface of 12.57x10-3 m2/g at a diameter of one millimeter but the surface expands to 12.57x10+3 m2/g at a diameter of one nanometer. Surface energy also rises by a factor of one million as size decreases from millimeters to nanometers (Zhao & Nalwa, 2006).

However, insoluble or low-solubility nanoparticles in biological fluid are the greatest cause for concern for the workforce. Due to their minuscule size, scientists have found that nanoparticles possess unique properties. Certain types of nanoparticles can pass through the body's natural defense systems and be transported through the body in insoluble form. Therefore, random nanoparticulate matter can terminate in the bloodstream after penetrating the respiratory or gastrointestinal membranes. These particles circulate to different organs and then collect at specific sites. Certain particles journey along the olfactory nerves and enter the brain, while others types, penetrate through cell walls and reach the nucleus of the cell. These unusual characteristics could be beneficial as vectors to transmit medication to specific body systems, including the brain (Tabata, Y and Ikada, Y 1988). The aforementioned scenario could be repeated and have toxic effect on the health of workers not utilizing personal protective equipment (PPE). Usually, in the field of toxicology, the detrimental effects are normally associated with the amount of the substance to which organism, animals or humans are exposed.

The greater the mass absorbed, the greater the effect. When investigators studied nanoparticle behavior, it has been evident, that the measured effects are not related to the mass of the product, which contradicts the classical interpretation of toxicity measurement. Study results are unambiguous, and demonstrate that at equal mass, nanoparticles are more toxic than products of the same chemical composition but of greater size.

2.1.3 Dermal Exposure to Nanomaterials

Further, Toyama, T. et al, (2008) described a case study involving a twenty-two year old student who was involved in laboratory work leading to synthesis of dendrimers. This student developed toxic epidermal necrolysis evolving from dermatitis of the hands associated with exposure to nanomaterials. Despite treatment with topical steroids and antihistamines, the disease progressed to other areas of the body. The student required hospitalization for more than three weeks. Afterwards, the symptoms reoccurred when he reentered the office and laboratory where he worked.

Although several studies find a good correlation between the specific surface and the toxic effects, a consensus seems to be emerging in the scientific community that several factors can contribute to the toxicity of these products and that it is currently impossible, with our limited knowledge, to weigh the significance of each of these factors or predict the precise toxicity of a new nanoparticle.

Nanotechnology and nanosciences is a dynamic and rapidly growing field that offer the promise of technologically based innovations that will substantially improve the quality life for all human kind. The data currently available on some products reveal various information that, while preliminary, already allows us to conclude that engineered nanoparticles must be handled with care and that workers' exposure must be minimized, since these effects are extremely variable from one product to another. Boffetta et al., 2004, examined respirable TiO_2 dust exposure. This observation occurred in Europe at eleven different production factories. Borretta's results found that no carcinogenic effect and no increased mortality due to TiO_2 exposure. Therefore, a comprehensible, understanding of the possible drawbacks of nanotechnology is critical to realizing the significant benefits of nanotechnology. The majority of the initial nanomaterials research has focused on the probable hazards and risks of nanotechnology-based manufacturing. Although, toxicological research for nanotechnology is in its formative years, concerns about potential risks to the health and safety of workers, will require definitive answers. Questions will be focused on manufacturing practices, procedures and controls for the present and future uses of nanotechnology. Yet another area of interest is the environment. What is the fate of the environment when nanomaterials are disposed? What does "appropriate" disposal mean as it related to the field nanotechnology? What is obvious; however, is that the nanotechnology manufacturing industry must identify, develop and implement the optimum approach for protecting its employees, and the public at large. One promising option indicates that researchers may be able to "engineer out" unacceptable levels of toxicity in nanomaterials. If this undertaking comes to fruition, then the industry will be able to minimize the potentially negative implications to its worker and the environmental impact of nanomaterial-based manufacturing and products. In the meantime, the best option to protect workers may be to wear personal protective equipment when working in nanomanufacturing.

2.1.4 Personal Protective Equipment (PPE)

In the late 1980s, Universal Precautions Guidelines were recommended by the Centers for Diseases Control in response to the risk of transmission of Human Immunodeficiency Virus (HIV) to Health Care Workers (HCW) from patients whose infection status was unknown (Centers for Disease Control, 1987). Precautions are based on the risk of contact with body fluid and are to be adopted regardless of whether or not the patients' blood borne virus status is known (Centers for Disease Control, 1987; Department of Health, 1998). These measures have been shown to reduce viral and microbial infections transmission from patients to staff (Department of Health, 2003). They include the use of appropriate personal protective equipment such as gloves, waterproof gowns or aprons, eye protection and mask for all patients whenever contact with blood or other bodily fluid is anticipated (Cutter and Jordan, 2004). Universal Precaution guidelines require contact precautions to be taken to minimize the risk of exposure to blood and body fluid.((Department of Health, 2003).

A 2004 Health Protection Agency Report confirms that compliance to Universal Precautions and safe disposal of clinical waste could prevent a large number of reported injuries and reduce the cost associated to those injuries. However, medical professionals despite years of education, knowledge of Universal Precautions, and the increased possibility of exposure to blood borne pathogens and viruses, choose not to use gloves when working with patients. Bennett and Mansell (2004) showed a statistically significant relationship between nurses having received training and compliance to glove use. Perceived reduced dexterity and lack of personnel protective equipment were stated as the reasons for not using gloves. Shibata and Howe (1999) studied the effects of gloves on performance of perceptual and manipulation tasks. It was found that on average, completion times were best when barehanded and were poorest while wearing gloves of thickness 1.91 mm. Krausman and Nussbaum (2007) conducted a study to determine the effects of glove thickness and masks on task performance and user preference. The results suggested that thinner protective gloves were more suitable than thicker gloves when using input devices, and that the use of masks did not affect task performance (Krausman and Nussbaum, 2007).

2.1.5 PPE and Worker Performance

Protective clothing can negatively impact the users‘ performance in several ways including increasing heat stress on the body, reducing task efficiency, and reducing the individual‘s range of motion (Adams, Slocum, & Keyserling, 1994). OSHA regulations recommends, Level A suits (affords maximal protection against harmful vapors and liquids) are to be selected ―when the maximum level of skin, respiratory, and eye protection is necessary (Occupational Safety and Health Standards, Standard Number 1910.120 App B, 1994). It typically includes a fully encapsulating chemical-resistant suit, gloves and boots, and a pressure-demand, self-contained breathing apparatus (SCBA) or a pressure-demand supplied air respirator (air hose) and escape SCBA. Another research project carried out by Bensel (1997) studied the effects of chemical protective uniform, used by the US Army, on soldier performance. They found that the clothing imposed a thermal as well as a mechanical burden. Bensel (1997) concluded that body movements are limited by the personal protective clothing, manual dexterity capabilities, communication, endurance and psychomotor performance can also be negatively impacted and it can induce psychological stress. Symptoms observed included breathing distress, tremors, and claustrophobia. Further, respirators restricted the visual field and affected speech.

The trade-off between performance and protection from PPE can be seen in studies of firefighters. Firefighting is a strenuous and potentially perilous occupation which required use of personal protective equipment. The biomechanical effects of personal protective equipment on this population of workers have been studied extensively. Research conducted Krueger (2001) suggests that chemical-biological protective clothing (CBC) imposes significant physiological, psycho-physiological, and biomechanical effects on the performance of individuals. Smith et al. conducted field studies investigating firefighter fatalities in conjunction with the role of personal protective equipment. The results revealed that donning of firefighting personal protective equipment caused significant detriments in gait and balance parameters regardless of which configuration of personal protective equipment was worn (Smith et al, 2008). This study found that wearing firefighting personal protective equipment significantly impairs dynamic functional balance. After strenuous firefighting activities, performance time increased slightly, but the number of errors decreased slightly, suggesting that participants were more cautious.

2.2 Summary of Reviewed Literature

The literature reviewed here reveals an absence in epidemiological knowledge regarding the impact of nano particles on operators from an ergonomic, attitudes, or performance perspective. Few studies have explored the ergonomic or health related effects of PPE, and no studies to date have explored the attitudes of nano workers regarding PPE. From the preceding introduction and literature reviewed in chapter two, the following research gaps were identified:

1. Absence of clarity as it relates to perceived cognitive human factors and ergonomics associated with wearing personal protective equipment when working with nanoparticles.

2. The need to identify perceived cognitive load and performance levels associated with PPE in the nano workplace, towards making recommendation(s) for the occupational setting.
3. No studies to date have investigated the possible effects of Personal protective equipment (PPE) on the mental demand, physical demand, temporal demand, performance, effort, and frustration in nanotechnology workers.

The present study was designed to fill this gap in the literature. The Methodology chapter follows, including the participants, instrumentation, procedures, and analysis plan that lead to the results of the present study and the discussion that ends this dissertation.

CHAPTER 3: METHODOLOGY

3.1 Compliance with Ethical Guidelines

The on line questionnaire and the field study were administered in compliance with the rules, regulations and policies for safe and ethical research mandated by the University of Central Florida. Each participant was informed of their rights as a research volunteer, then read and signed informed consent certifications. Based on conversations with management and staff, I signed a confidentiality agreement which stated that I could not disclose any specific information about the company or employees that may have be disclosed during the field study process. Both male and female workers of all ethnicities and cultures will be invited to participate in the study. Participating workers were informed that participation was voluntarily and would not affect their employment. Additionally, workers had the option to withdraw from the study at any time without consequence. All study participants have remained anonymous.

3.2 Introduction

The present study was designed to determine the differences in mental demand, physical demand, temporal demand, performance, effort, and frustration in nanotechnology workers when using PPE compared to when not using PPE. Six research questions were addressed, each reflecting potential differences when performing nanotechnology work in PPE and no-PPE conditions.

- Research Question 1 asked, *Is Perceived Mental Demand significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE?*
- Research Question 2 asked, *Is Perceived Physical Demand significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE?*

- Research Question 3 asked, *Is Perceived Temporal Demand significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE?*
- Research Question 4 asked, *Is Perceived Performance significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE?*
- Research Question 5 asked, *Is Perceived Effort significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE?*
- Research Question 5 asked, Is Perceived Effort is not significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.
- Research Question 6 asked, *Is Perceived Frustration significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE?*

The purpose of this chapter is to delineate the research approach used to test the hypothesis derived from the research questions. Following this introduction, this methodology chapter is divided into these sections:

- Online survey of nanotechnology subject matter experts (SME) and nanotechnology operators.
- Field study that evaluates the cognitive (mental workload) HFE risk factors in nanotechnology worker task performance while wearing PPE.

Overall, the remainder of this chapter is organized as follows:

- Tests of Power
- Research Gaps
- Section I. Preliminary On-Line Survey
- Conclusions from Preliminary On-Line Survey

- Section II. Field Study
- Field Study Setting
- Field Study Participants
- Field Study Materials tools
- Field Study Procedures
- Field Study Design and Analysis
- Compliance with Ethical Guidelines

3.2.1 Research Gaps

There have been a number of valuable studies about mental workload, nanotechnology and workplace ergonomics, however it remains a serious concern there is little or no research on nanotechnology worker from a human factors and ergonomics prospective. Outlined below are some of the research gaps found.

- There is a need for the understanding of the human factors and ergonomic implications that nanotechnology will bring to the workplace.
- An absence of clarity as it relates to potential health effects of occupational exposure to nanoparticles from a HFE prospective.
- There is a need to create a centralized HFE- nanotechnology knowledgebase in conjunction with other occupational health and safety organizations.
- A need to increase scientifically based research regarding ergonomic risk factors impacting workers in the nanotechnology industry.
- The need to identify a nanotechnology work place research framework which identifies processes and systems with human involvement.

- A need to determine whether or not occupational exposure to nanomaterials while wearing personal protective equipment (PPE) is or is not potentially frustrating to the workers. No one to date has researched or considered workers during work task performance and measures cognitive experience.
- Previous research found that there is no consensus about the most effective method in which to protect nanotechnology workers who are exposed to nanomaterials.
- The need for more research to determine if ergonomic risk factors are identifiable, measurable and manageable.
- A need to investigate effective controls (engineering controls, administrative controls, personal protective equipment (PPE), and training ect.) is useful in mitigating the risk – if they exist?
- Absence of clarity as it relates to perceived cognitive human factors and ergonomic associated with occupational exposure to nanoparticles when wearing personal protective equipment.
- The need to identify perceived cognitive and perceived performance levels as inferred by NASA - TLX associated with ongoing occupational nanoparticle exposure and determines its recommendation(s) for the occupational setting.
- Determining if adverse performance shaping factors are present in the nanotechnology workplace which can significantly impact human safety and errors.

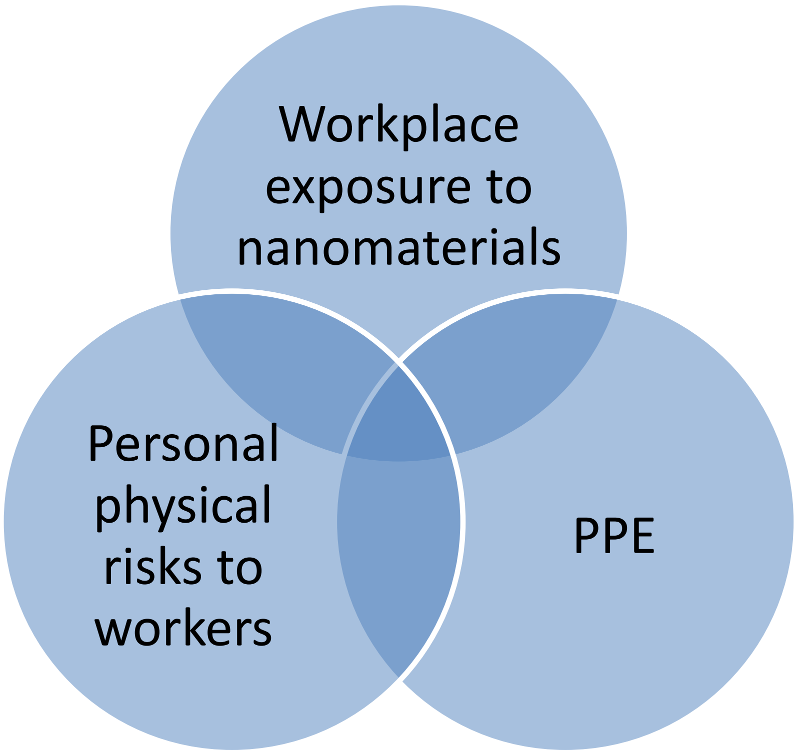


Figure 1. Venn Diagram Showing Research Gaps

3.2.2 Tests of Power

Power is the ability to detect a significant difference if one exists. An *a priori* power analysis was performed to determine the sample size for the field study. Assuming of statistical significance threshold of alpha = 0.05, and assuming a large effect (.80 standard deviations) by the criteria of Cohen (1992), statistical significance would be achieved 80% of the time (Power = .80) with as few as 26 participants in a repeated-measures design (Cohen, 1992). If effects are very large (1 full standard deviation or larger), power of .80 could be conferred with fewer than 19 participants (Decision Support Systems, 2011). Additionally, in research designs of comparable studies and literature review, sample size ranged from 21 to 64 respondents, but the level of statistical significance was not provided for any of the studies. For these reasons, an overall sample size of 60 participants, spread across three nano-worker job types (sorters, repetitive motion mixers, and loaders; n = 20 each) was considered a priori adequate for confer adequate power for the present study. This target sample size was used to inform the exploratory survey detailed above towards choosing an appropriate establishment to conduct the field study.

3.2.3 Section I. Exploratory Online Survey

The location of the Field Study (Section II below) was not predetermined; an exploratory on-line survey was conducted to determine an appropriate nanotechnology work environment with the necessary qualities to foster the goals of the field study portion of this dissertation. Towards identifying the qualities of nanotechnology work environments for the field study, the on-line survey was conducted using nanotechnology subject matter experts (SME) and nanotechnology operators.

3.3 Survey Instrument Participants

Survey participants were solicited from within the nanotechnology industry. Survey participants were identified by:

- Emailing Nanowerk's Nanotechnology Company and laboratory directory
- Emailing Academia web sites
- Creating a web site relating to the study and advertising the website on line
- Nanotechnology social networks (i.e. Facebook and Linked in)
- Recruiting nanotechnology conference attendees

3.4 Survey Materials

A survey questionnaire (see appendix) was developed (modified from the International Council on Nanotechnology (ICON 2006) to survey nanotechnology organizations in an effort to learn about current practices in nanomaterials handling in the workplace. This survey instrument was administered in the form of an online questionnaire (Appendix A), administered by utilizing a survey collection web site called Survey Monkey. Forty- eight questions were asked of the respondent such as:

- Respondent information
- Organizational information
- Company sponsored environmental health and safety programs
- Engineering controls
- Personal protective equipment
- Employee and area exposure
- Containment and exposure
- Waste management
- Work place monitoring
- Closing questions

Sample questions from the online survey are found below.

13. Please describe all the different types of nanomaterial that your organization manufactures, utilizes and/or handles.

	Response Percent	Response Count
Nanopowders	**38.5%**	**10**
Nanocrystals	26.9%	7
Quantum Dots	11.5%	3
Colloidal dispersions	23.1%	6
Fullerenes (Buckyballs)	11.5%	3
Nanotubes	30.8%	8
Nanowires	19.2%	5
Nanohorns	0.0%	0
Dendrimers	3.8%	1
Flakes	7.7%	2
Platelets	11.5%	3
Rods	11.5%	3
Polymers	26.9%	7
Carbon black	11.5%	3
Other (please specify)	34.6%	9
	answered question	**26**
	skipped question	**14**

Figure 2. Sample Questions from Survey (1)

14. Are the nanomaterials you described

	Response Percent	Response Count
in solid form and mobile	**65.4%**	**17**
in a liquid suspension	57.7%	15
Other (please specify)	26.9%	7
answered question		**26**
skipped question		**14**

15. Has your organization implemented a health and safety program?

	Response Percent	Response Count
Yes	**80.8%**	**21**
No	19.2%	5
answered question		**26**
skipped question		**14**

16. Has your organization implemented a nano-specific health and safety program?

	Response Percent	Response Count
Yes	24.0%	6
No	**76.0%**	**19**
answered question		**25**
skipped question		**15**

Figure 3. Sample Questions from Survey (2)

17. Does your organization offer health and safety training for your employees on the handling of nanomaterials?

	Response Percent	Response Count
Yes	40.0%	10
No	60.0%	15
answered question		25
skipped question		15

18. Do all employees who handle nanomaterials receive this training?

	Response Percent	Response Count
Yes	52.2%	12
No	47.8%	11
answered question		23
skipped question		17

Figure 4. Sample Questions from Survey (3)

3.4.1 Exploratory Survey Conclusions

Findings from the exploratory survey are detailed below. The exploratory survey failed to identify any business or academic location that could provide the necessary sample size (most are too small) and reasonable proximity (most larger entities are in Europe) to be suitable for the field study portion of this research. For these reasons, a southwestern nanomanufacturing concern of appropriate size and location was contacted, and agreed to host the field study.

3.4.2 Section II. Field Study

A field study was conducted to answer the six research questions, contrasting the effects of PPE and no-PPE on nano-worker mental demand, physical demand, temporal demand, performance, effort, and frustration. This section details the participants, materials, procedure, design and analysis of the field study, along with steps taken to comply with ethical guidelines.

3.4.3 Field Study Setting

Data were collected at a nanotechnology manufacturing facility, located in the southwestern United States. This firm was chosen because it was regionally located, agreed to access, and because it had a large enough workforce to confer adequate power to test the hypotheses of the field study. This facility employs 450 overall, and employs 150 nanotechnology workers, including sorters, repetitive motion mixers, and loaders. This facility had no formal PPE requirements. Presently, the use of personal protective equipment when performing their daily work tasks is at the worker discretion. Management stated that protective goggles, coveralls, gloves and faces masks are available if worker request them. Nanotechnology workers at this facility typically spread an eight-hour shift work across two four-hour blocks, divided by a lunch hour, with a 15 minute break every two hours. That is, facility nano-workers typically work for two hours between breaks.

3.4.4 Field Study Participants

The sixty male participants volunteered to participate in this research (N = 60). Only males are included because only males are employed as nanoworkers in this nanomanufacturing facility. This research experiment was open to individuals 18 years of age or older regardless of the participant's race, creed, color, sex or nation of origin. Participants were excluded if:

- The worker chose not to sign the informed consent form.
- Worker was unfamiliar with the work tasks to be performed

Participants represented the full time, experienced employees of the firm, ranging between 18 and 53 years of age. To foster generalizability, these measures were assessed in sixty workers (N = 60) representing three job types which are common in nanomanufacturing: sorters (n = 20), repetitive motion mixers (n = 20), and loaders (n = 20). This sample was considered adequate to address the hypotheses of the field study, and reasonably representative of many nanotechnology workers in general.

3.4.5 Field Study Materials

The materials used during the field study to measure participant responses were as follows:

- Pre-procedure documents
    - Informed consent
    - Confidentiality agreement
    - NASA-TLX forms. The NASA –TLX analysis was used to assess the impact of personal protective equipment on the operators' perceived level of effort, performance, physical, mental or temporal demands during task performance.
- Pens (60)
- Clipboards (60)

To assess the effects of PPE on workers, the PPE used in the present study were as follows:

- Clear protective plastic goggles
- Latex gloves
- White light weight long sleeved coveralls

- Turtle shell type mask

Table 6. Rating Scale Definitions and Endpoints from the NASA-TLX

Title	**Endpoints**	**Descriptions**
Mental Demand	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking searching, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)?Was the Task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Using the six dimensions of the NASA-TLX, a nanoworkers' level of workload experienced during work task performance is described in the table above.

Table 7. Rating Scale Definitions from the NASA-TLX

Title	Endpoints	Descriptions
Mental Demand	Low/High	How much mental and perceptual activity was required to watch a knowledge nugget video or browse the LMS using the mobile device? Was viewing the presentation and content layout easy or demanding, simple or complex?
Physical Demand	Low/High	How much physical activity was required to view a message and/or send a response using the mobile device keyboard interface? Did the activity cause discomfort?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which message responses had to be sent? Was the pace slow and leisurely or rapid and frantic?
Performance	Good/Poor	How successful do you think you were in using the mobile device data entry interface to type, send and receive a message? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel while watching the knowledge nugget, browsing the LMS or sending/receiving a message?

3.4.6 Data Collection Procedures

Data were collected on-site. Participants were greeted in a utility room adjacent to the facility workspace. Participants were seated and given a pen and a clipboard with informed consent and the confidentiality agreement attached. After signing the informed consent and the confidentiality agreement, participants were randomly assigned to one of two sequences of either wearing or not wearing PPE. Participants were each measured for mental demand, physical demand, temporal demand, performance, effort, and frustration twice: after the first two 2-hours shift and after the second 2-hour shift.

3.5 Field Study Research Design and Analysis

This study employed a crossover (counter balance) design (Campbell & Stanley, 1963), such that half of participants wore PPE followed by no-PPE, while the other half of participants worked with no-PPE then worked with PPE. Figure 5 utilizes a timeline to display the design of the field study.

3.5.1 Field Study Design Timeline

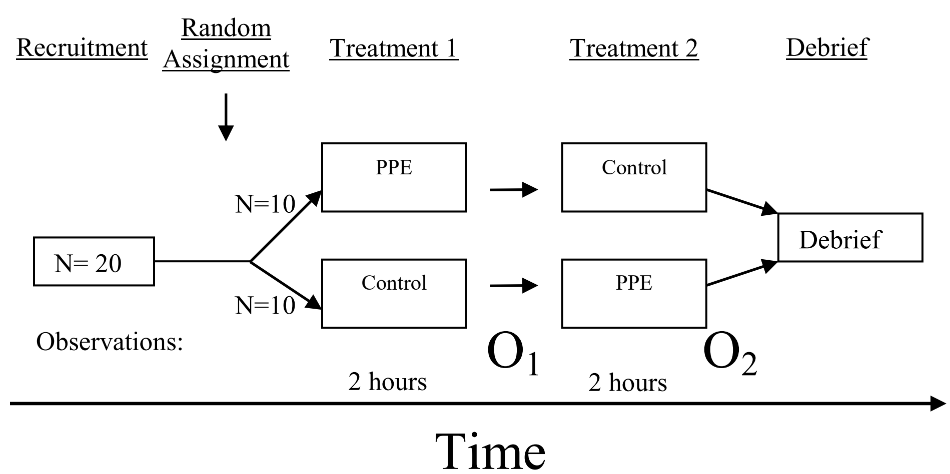


Figure 5. O_1 = Treatment 1 PPE and No PPE and O_2 = Treatment No PPE and PPE.

As shown in Figure 5, 60m participants were randomly assigned to either work with PPE first then without PPE (n = 30) (Figure XX, top sequence) or to work without PPR first and then work with PPE (n = 30). Sorters, repetitive motion mixers, and loaders were each tested in parallel analyses (n = 20 each, 10 per sequence). Measures from the NASA-TLX were acquired after the first 2-hour work shift (O_1) and after the second 2-hour work shift (O_2).

By using a counterbalance design, this field study reduced the effect of confounding personal variables that can drive results in between-groups designs, because each participant served as their own control in this counterbalanced design. The two hour time frame represented the continuous work time between breaks in the normal work cycle of this nanomanufacturing facility.

In the results chapter that follows, finding are presented in text, tables, and figures, representing means, standard deviations, minimum score, maximum score, and the standard error of the mean for mental demand, physical demand, temporal demand, performance, effort, and frustration per nanotechnology worker job type, with and without PPE.

For testing the hypotheses of the present study, differences between PPE and no-PPE conditions were assessed using paired t-tests, with each participant serving as their own control. Differences were considered statistically significant at a threshold of $p < .05$.

CHAPTER 4: RESULTS

The purpose of the present study was to determine the Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration of participants when 2 hours of nanotechnology work was performed with (PPE) or without (Control) protective equipment. Three job types were explored ($n = 20$ each): Job A were sorters, Job B were repetitive motion mixers, and Job C were loaders. Results are presented in text, in tables, and in figures. Differences were determined using the paired t-test. Differences were considered statistically significant at a threshold of $p < .05$.

4.1 Mental Demand

4.1.1 Overall: Mental Demand

Overall ($n = 60$), Table 8 shows that the Mental Demand wearing PPE was 17.05 (SD = 2.06) and the Mental Demand in the Control condition was 6.82 (SD = 2.00). This difference of 10.23 (SD = 2.97) was statistically significant, $t\ (59) = 26.8$, $p < .0001$.

4.1.2 Job A: Mental Demand

For Job A ($n = 20$), Table 8 shows that the Mental Demand wearing PPE was 17.00 (SD = 1.89) and the Mental Demand in the Control condition was 7.85 (SD = 1.87). This difference of 9.15 (SD = 2.83) was statistically significant, $t\ (19) = 14.4$, $p < .0001$ (Figure 1).

4.1.3 Job B: Mental Demand

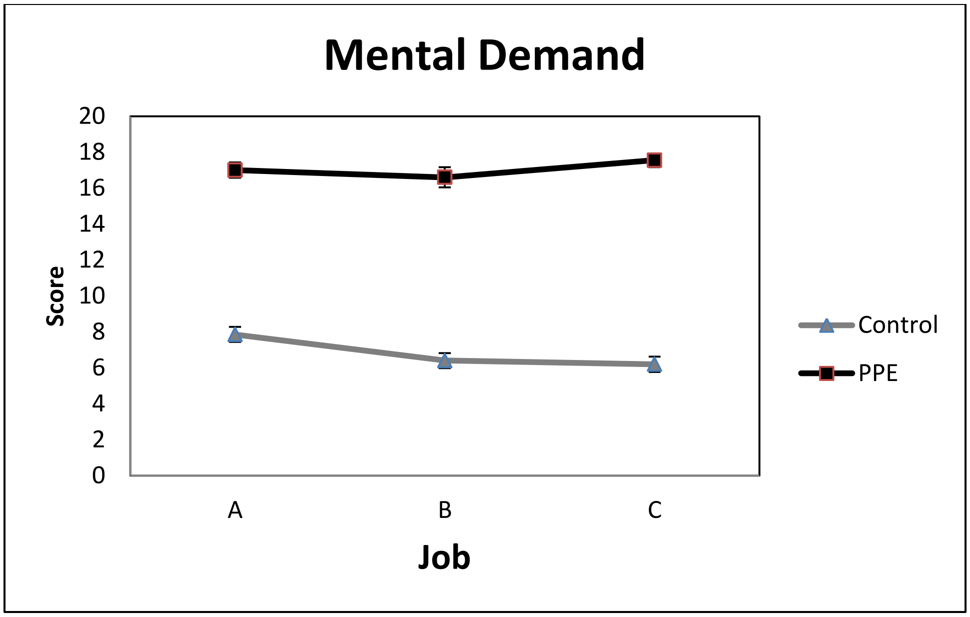
For Job B ($n = 20$), Table 8 shows that the Mental Demand wearing PPE was 17.00 (SD = 2.50) and the Mental Demand in the Control condition was 7.85 (SD = 1.87). This difference of 10.20 (SD = 3.22) was statistically significant, $t\ (19) = 14.2$, $p < .0001$ (Figure 1).

4.1.4 Job C: Mental Demand

For Job C (n = 20), Table 8 shows that the Mental Demand wearing PPE was 17.55 (SD = 1.70) and the Mental Demand in the Control condition was 6.20 (SD = 1.91). This difference of 11.35 (SD = 2.54) was statistically significant, t (19) = 20.00, $p < .0001$ (Figure 2).

Table 8. Mental Demand by Job

Job	Statistic	Control	PPE	Difference
A	Mean	7.85	17.00	-9.15
	N	20	20	0
	SD	1.87	1.89	-0.02
	Min	4	14	-10.0
	Max	11	19	-8.0
	SEM	0.42	0.42	0.
B	Mean	6.40	16.60	-10.20
	N	20	20	0
	SD	1.88	2.50	-0.62
	Min	4	12	-8
	Max	10	20	-10
	SEM	0.42	0.56	-1.12
C	Mean	6.20	17.55	-11.35
	N	20	20	0
	SD	1.91	1.70	0.21
	Min	3	15	-12.0
	Max	9	20	-11
	SEM	0.43	0.38	0.05
Total	Mean	6.82	17.05	-10.23
	N	60	60	0
	SD	2.00	2.06	-0.06
	Min	3	12	-9.0
	Max	11	20	-9.0
	SEM	0.26	0.27	-0.01



A= sorters, B = repetitive motion mixers, C = loaders. Icons represent mean scores. Error bars indicate standard error of the mean (SEM)

Figure 6. Mental Demand by Job

4.1.5 Summary of Mental Demand

PPE conferred significantly greater Mental Demand than Control. This significant effect was evident across Job A, Job B, and Job C.

4.2 Physical Demand

4.2.1 Overall: Physical Demand

Overall (n = 60), Table 9 shows that the Physical Demand wearing PPE was 18.72 (SD = 1.61) and the Physical Demand in the Control condition was 15.47 (SD = 2.35). This difference of 3.25 (SD = 2.91) was statistically significant, t (59) = 8.62, $p < .0001$.

4.2.2 Job A: Physical Demand

For Job A (n = 20), Table 9 shows that the Physical Demand wearing PPE was 18.75 (SD = 1.37) and the Physical Demand in the Control condition was 14.65 (SD = 2.08). This difference of 10.23 (SD = 2.97) was statistically significant, t (59) = 26.8, $p < .0001$ (Figure 3).

Table 9. Physical Demand by Job

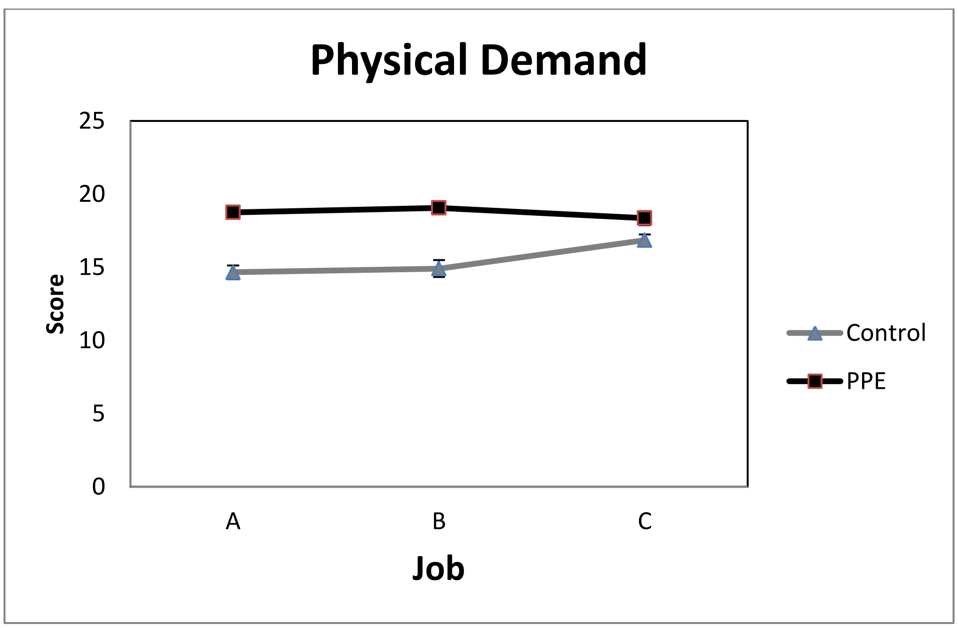
Job	Statistic	Control	PPE	Difference
A	Mean	14.65	18.75	-4.10
	N	20	20	0
	SD	2.08	1.37	0.71
	Min	12	16	-4
	Max	18	20	-2
	SEM	0.47	0.31	0.16
B	Mean	14.90	19.05	-4.15
	N	20	20	0
	SD	2.59	1.05	1.54
	Min	10	16	-6.0
	Max	19	20	-1.0
	SEM	0.58	0.23	0.35
C	Mean	16.85	18.35	-1.50
	N	20	20	0
	SD	1.73	2.18	-0.45
	Min	12	11	1.0
	Max	19	20	1
	SEM	0.39	0.49	-0.1
Total	Mean	15.47	18.72	-3.25
	N	60	60	0
	SD	2.35	1.61	0.74
	Min	10	11	-1.0
	Max	19	20	-1
	SEM	0.30	0.21	0.09

4.2.3 Job B: Physical Demand

For Job B (n = 20), Table 9 shows that the Physical Demand wearing PPE was 19.05 (SD = 1.05) and the Physical Demand in the Control condition was 14.90 (SD = 2.59). This difference of 4.15 (SD = 2.72) was statistically significant, t (19) = 6.82, $p < .0001$ (Figure 3).

4.2.4 Job C: Physical Demand

For Job C (n = 20), Table 9 shows that the Physical Demand wearing PPE was 18.35 (SD = 2.18) and the Physical Demand in the Control condition was 16.85 (SD = 1.73). This difference of 1.50 (SD = 2.80) was statistically significant, t (19) = 2.40, $p < .03$ (Figure 3).



A= sorters, B = repetitive motion mixers, C = loaders. Icons represent mean scores. Error bars indicate standard error of the mean (SEM)

Figure 7. Physical Demand by Job

4.2.5 Summary of Physical Demand

PPE conferred significantly greater Physical Demand than Control. This significant effect was evident across Job A, Job B, and Job C.

4.3 Temporal Demand

4.3.1 Overall: Temporal Demand

Overall (n = 60), Table 10 shows that the Temporal Demand wearing PPE was 17.80 (SD = 2.47) and the Temporal Demand in the Control condition was 16.03 (SD = 2.42). This difference of 1.77 (SD = 3.49) was statistically significant, t (59) = 3.92, $p < .001$.

4.3.2 Job A: Temporal Demand

For Job A (n = 20), Table 10 shows that the Temporal Demand wearing PPE was 17.75 (SD = 2.45) and the Temporal Demand in the Control condition was 15.00 (SD = 2.62). This difference of 2.75 (SD = 4.05) was statistically significant, t (59) = 26.8, $p < .01$ (Figure 4).

4.3.3 Job B: Temporal Demand

For Job B (n = 20), Table 10 shows that the Temporal Demand wearing PPE was 16.90 (SD = 2.90) and the Temporal Demand in the Control condition was 16.00 (SD = 2.10). This difference of 0.90 (SD = 3.51) was not statistically significant, t (19) = 1.15, $p = .27$ (Figure 4).

4.3.4 Job C: Temporal Demand

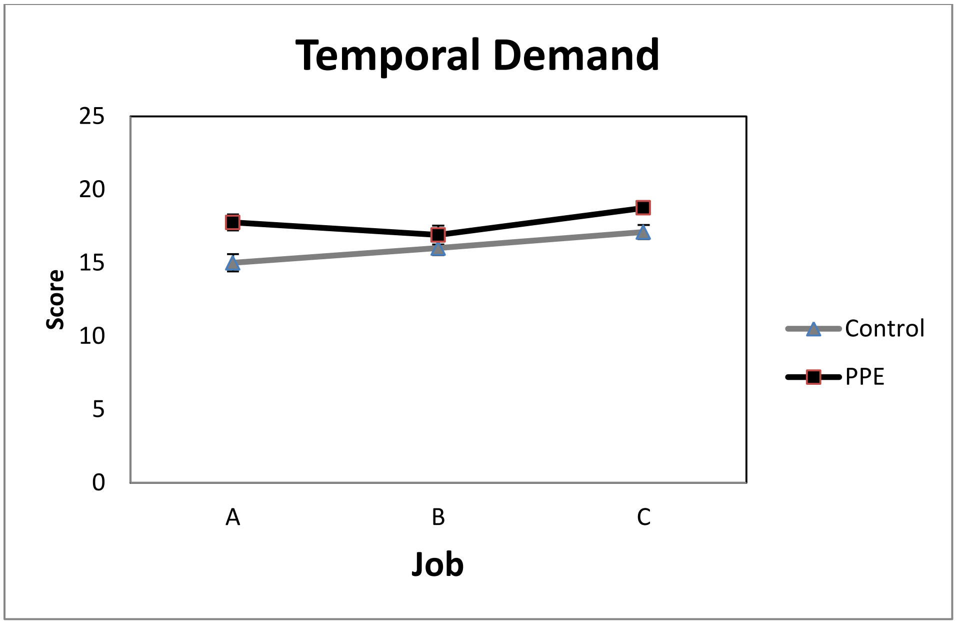
For Job C (n = 20), Table 10 shows that the Temporal Demand wearing PPE was 18.75 (SD = 1.65) and the Temporal Demand in the Control condition was 17.10 (SD = 2.15). This difference of 1.65 (SD = 2.70) was statistically significant, t (19) = 2.74, $p <.02$ (Figure 4).

Table 10. Temporal Demand by Job

Job	Statistic	Control	PPE	Difference
A	Mean	15.00	17.75	-2.75
	N	20	20	0
	SD	2.62	2.45	0.17
	Min	10	11	-1.0
	Max	20	20	0
	SEM	0.58	0.55	0.03
B	Mean	16.00	16.90	-0.90
	N	20	20	0
	SD	2.10	2.90	-0.8
	Min	10	10	0
	Max	19	20	-1.0
	SEM	0.47	0.65	-0.18
C	Mean	17.10	18.75	-1.65
	N	20	20	0
	SD	2.15	1.65	0.5
	Min	12	15	-3.0
	Max	20	20	0
	SEM	0.48	0.37	0.11
Total	Mean	16.03	17.80	-1.77
	N	60	60	0
	SD	2.42	2.47	-0.05
	Min	10	10	0
	Max	20	20	0
	SEM	0.31	0.32	-0.01

4.3.5 Summary of Temporal Demand

PPE conferred significantly greater Mental Demand than Control overall. This significant effect was evident for Job A and Job C, but the difference was not statistically significant for Job B.



A= sorters, B = repetitive motion mixers, C = loaders. Icons represent mean scores. Error bars indicate standard error of the mean (SEM).

Figure 8. Temporal Demand by Job

4.4 Performance

4.4.1 Overall: Performance

Overall (n = 60), Table 9 shows that the Performance wearing PPE was 1.78 (SD = 0.92) and the Performance in the Control condition was 1.00 (SD = 0). This difference of 0.78 (SD = 0.92) was statistically significant, t (59) = 6.58, $p < .0001$.

4.4.2 Job A: Performance

For Job A (n = 20), Table 11 shows that the Performance wearing PPE was 2.15 (SD = 1.04) and the Performance in the Control condition was 1.00 (SD = 0). This difference of 1.15 (SD = 1.04) was statistically significant, t (59) = 4.95, $p < .0001$ (Figure 5).

4.4.3 Job B: Performance

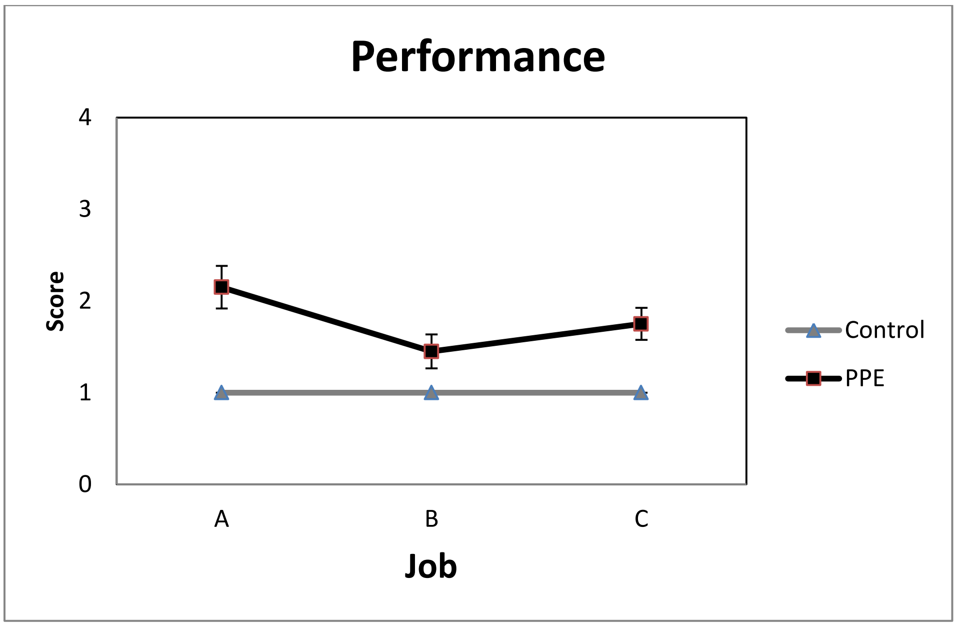
For Job B (n = 20), Table 11 shows that the Performance wearing PPE was 1.45 (SD = 0.83) and the Performance in the Control condition was 16.00 (SD = 2.10). This difference of 0.45 (SD = 0.83) was not statistically significant, t (19) = 2.44, $p < .03$ (Figure 5).

Table 11. Performance by Job

Job	Statistic	Control	PPE	Difference
A	Mean	1.00	2.15	-1.15
	N	20	20	0
	SD	0.00	1.04	1.04
	Min	1	1	0
	Max	1	4	-3
	SEM	0.00	0.23	0.23
B	Mean	1.00	1.45	-0.45
	N	20	20	0
	SD	0.00	0.83	0.83
	Min	1	1	0
	Max	1	4	-3
	SEM	0.00	0.18	0.18
C	Mean	1.00	1.75	-0.75
	N	20	20	0
	SD	0.00	0.79	0.79
	Min	1	1	0
	Max	1	3	-2
	SEM	0.00	0.18	0.18
Total	Mean	1.00	1.78	-0.78
	N	60	60	0
	SD	0.00	0.92	0.92
	Min	1	1	0
	Max	1	4	-3
	SEM	0.00	0.12	0.12

4.4.4 Job C: Performance

For Job C (n = 20), Table 11 shows Performance wearing PPE was 1.75 (SD = 0.75) and Performance in the Control condition was 17.10 (SD = 2.15). This difference of 0.75 (SD = 0.79) was statistically significant, t (19) = 4.37, p <.0001 (Figure 5).



A= sorters, B = repetitive motion mixers, C = loaders. Icons represent mean scores. Error bars indicate standard error of the mean (SEM).

Figure 9 Performance by Job

4.4.5 Summary of Performance

PPE conferred significantly higher (indicating worse) Performance scores than Control. This significant effect was evident across Job A, Job B, and Job C.

4.5 Effort

4.5.1 Overall: Effort

Overall (n = 60), Table 12 shows that the Effort wearing PPE was 1.78 (SD = 0.92) and the Effort in the Control condition was 1.00 (SD = 0). This difference of 0.78 (SD = 0.92) was statistically significant, t (59) = 6.58, $p < .0001$.

4.5.2 Job A: Effort

For Job A (n = 20), Table 12 shows that the Effort wearing PPE was 19.15 (SD = 1.09) and the Effort in the Control condition was 1.00 (SD = 0). This difference of 4.20 (SD = 2.02) was statistically significant, t (59) = 9.32, $p < .0001$ (Figure 6).

Table 12. Effort by Job

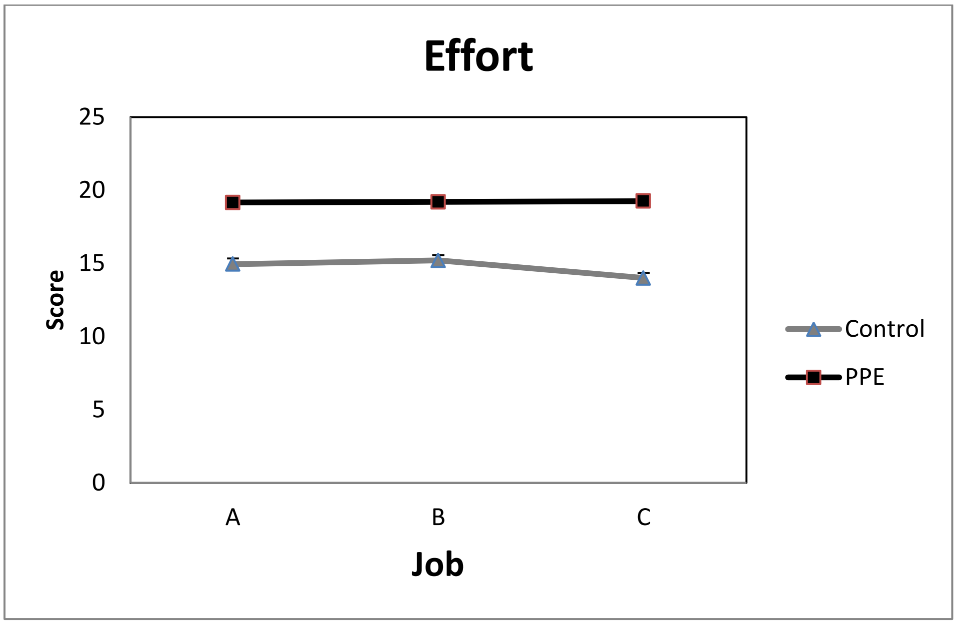
Job	Statistic	Control	PPE	Difference
A	Mean	14.95	19.15	-4.20
	N	20	20	0
	SD	1.67	1.09	0.58
	Min	12	17	-5
	Max	19	20	-1
	SEM	0.37	0.24	0.13
B	Mean	15.20	19.20	-4.00
	N	20	20	0
	SD	1.58	1.06	0.52
	Min	12	17	-5
	Max	18	20	-2
	SEM	0.35	0.24	0.11
C	Mean	14.00	19.25	-5.25
	N	20	20	0
	SD	1.56	0.85	0.71
	Min	12	18	-6.0
	Max	16	20	-4.0
	SEM	0.35	0.19	0.16
Total	Mean	14.72	19.20	-4.48
	N	60	60	0
	SD	1.66	0.99	0.67
	Min	12	17	-5.0
	Max	19	20	-1.0
	SEM	0.21	0.13	0.8

4.5.3 Job B: Effort

For Job B (n = 20), Table 12 shows that the Effort wearing PPE was 14.95 (SD = 1.67) and the Effort in the Control condition was 16.00 (SD = 2.10). This difference of 4.00 (SD = 2.08) was not statistically significant, t (19) = 8.61, p < .0001 (Figure 6).

4.5.4 Job C: Effort

For Job C (n = 20), Table 10 shows that the Effort wearing PPE was 19.25 (SD = 1.74) and the Effort in the Control condition was 14.00 (SD = 1.56). This difference of 5.25 (SD = 1.74) was statistically significant, $t\ (19) = 13.47$, $p < .0001$ (Figure 6).



A= sorters, B = repetitive motion mixers, C = loaders. Icons represent mean scores. Error bars indicate standard error of the mean (SEM)

Figure 9. Effort by Job

4.5.5 Summary of Effort

PPE conferred significantly greater Effort than Control. This significant effect was evident across Job A, Job B, and Job C.

4.6 Frustration

4.6.1 Overall: Frustration

Overall (n = 60), Table 13 shows that the Frustration wearing PPE was 19.17 (SD = 1.08) and the Frustration in the Control condition was 1.47 (SD = 0.60). This difference of 17.70 (SD = 1.17) was statistically significant, t (59) = 117.30, p < .0001.

Table 13. Frustration by Job

Job	Statistic	Control	PPE	Difference
A	Mean	1.45	18.85	-17.40
	N	20	20	0
	SD	0.60	1.35	-.75
	Min	1	16	-15
	Max	3	20	-17
	SEM	0.14	0.30	-0.16
B	Mean	1.25	19.50	-18.25
	N	20	20	0
	SD	0.44	0.69	-0.25
	Min	1	18	-17
	Max	2	20	-18
	SEM	0.10	0.15	-0.05
C	Mean	1.70	19.15	-17.45
	N	20	20	0
	SD	0.66	1.04	-0.38
	Min	1	17	-16
	Max	3	20	-17
	SEM	0.15	0.23	-0.08
Total	Mean	1.47	19.17	-17.70
	N	60	60	0
	SD	0.60	1.08	-0.48
	Min	1	16	-15
	Max	3	20	-17
	SEM	0.08	0.14	-0.06

4.6.2 Job A: Frustration

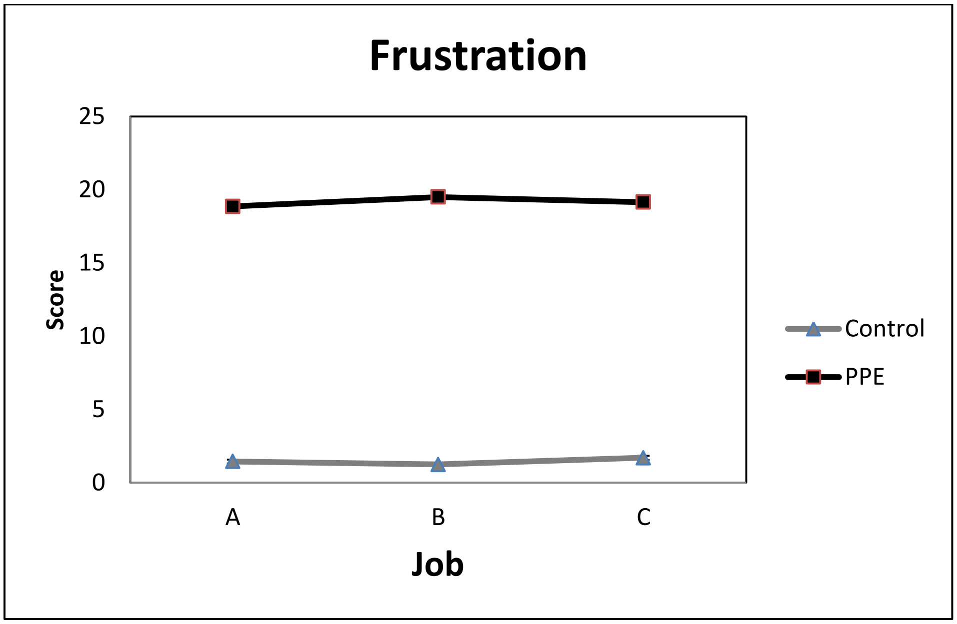
For Job A (n = 20), Table 13 shows that the Frustration wearing PPE was 18.85 (SD = 1.35) and the Frustration in the Control condition was 1.45 (SD = 0.60). This difference of 17.40 (SD = 1.35) was statistically significant, t (59) = 57.50, $p < .0001$ (Figure 7).

4.6.3 Job B: Frustration

For Job B (n = 20), Table 13 shows that the Frustration wearing PPE was 19.50 (SD = 0.69) and the Frustration in the Control condition was 1.25 (SD = 0.44). This difference of 18.25 (SD = 0.79) was not statistically significant, t (19) = 103.79, $p < .0001$ (Figure 7).

4.6.4 Job C: Frustration

For Job C (n = 20), Table 13 shows that the Frustration wearing PPE was 19.15 (SD = 1.04) and the Frustration in the Control condition was 1.70 (SD = 0.66). This difference of 17.45 (SD = 1.15) was statistically significant, t (19) = 68.10, $p < .0001$ (Figure 7).



A= sorters, B = repetitive motion mixers, C = loaders. Icons represent mean scores. Error bars indicate standard error of the mean (SEM)

Figure 10. Frustration by Job

4.6.5 Summary of Frustration

PPE conferred significantly greater Frustration than Control. This significant effect was evident across Job A, Job B, and Job C.

4.7 Summary of Major Findings

The present study of sixty (60) male nanotechnology workers revealed that PPE equipment conferred significant Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration of participants when 4 hours of nanotechnology work was performed with (PPE)for 2 hours or without (Control) protective equipment for two hours. This pattern was evident for Job A (sorters), Job B (repetitive motion mixers), and Job C (loaders). The one exception was Temporal Demand for Job B (repetitive motion mixers), where there was no significant difference was evident between PPE and Control. These findings highlight the burden on PPE in the nanotechnology industry.

4.8 Discussion and Research Implications

The aim of this research was to investigate and measure perceived mental demand, physical demand, temporal demand, performance, effort, and frustration in nanotechnology workers when using PPE and when not using PPE. Additionally, the ergonomic factors that impact worker's performance , provide insight into worker's needs, capabilities and limitations as it relates to the nanomanufacturing process and as well as evaluate the worker's cognitive and physical needs in this environment from HFE perspective. The research did reveal that PPE equipment conferred significant Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration of participants when 4 hours of nanotechnology work was performed with (PPE)for 2 hours or without (Control) protective equipment for two hours. This pattern was evident for Job A (sorters), Job B (repetitive motion mixers), and Job C (loaders). The one exception was Temporal Demand for Job B (repetitive motion mixers), where there was no significant difference was evident between PPE and Control. These findings highlight the burden on PPE in the nanotechnology industry.

4.9 Research Implications

The research implications for this study are:

- HFE community needs investigate & redesign PPE to enhance worker performance and comfort due to hampered performance of nano-workers

- HFE community needs to investigate/ recommend methods by which automation (robotics) can be introduced into the nanomanufacturing arena to perform hazardous work related task
- Develop PPE particularly suited for the nanotechnology community

The results of this study provide insights into capabilities and limitations of that PPE equipment conferred significant Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration of participants when 4 hours of nanotechnology work was performed with (PPE)for 2 hours or without (Control) protective equipment for two hours. This pattern was evident for Job A (sorters), Job B (repetitive motion mixers), and Job C (loaders). The one exception was Temporal Demand for Job B (repetitive motion mixers), where there was no significant difference was evident between PPE and Control.

These findings highlight the burden on PPE in the nanotechnology industry. Moreover, these results provide insight into capabilities and limitations of nanotechnology workers as it relates to the differences in mental demand, physical demand, temporal demand, performance, effort, and frustration in nanotechnology workers when using PPE compared to when not using PPE. The limitations identified:

- Limited sample size (only 60 male participants)
- Experienced and inexperienced workers should be measured
- Females were not included in the study
- Limited time frame of the study
- Longitudinal study needed
- Self- report by workers
- Only a single measure used (no physiological measures taken)

- More than one tool should be used to measure worker's experience
- Safety goggles continued to fog up while operators performed work task
- Latex gloves caused workers hands to perspire profusely
- Workers complained coverall were hot and limited their mobility
- Worker productivity was hampered with PPE

Uncovering factors hindering worker performance is pertinent. Below are suggestions to help facilitate closing the nano-worker PPE issues:

- PPE manufactures partner with ergonomist to create suitable, cost effective
- Ergonomic assessment of PPE to ensure the workers are being adequately protected
- Using Arousal theory as a theoretical foundation, derived a formal foundation to begin to understand cognitive and physical impacting nanotechnology workers from a HFE prospective

Unfortunately, the same equipment that is designed to support the user can potentially cause heat stress, reduced task efficiency, and reduced range-of-motion. (Grugle & Kleiner, 2006). The relationship between the operator and PPE presented a contradictory relationship between the operators wearing the PPE who are performing the work tasks. For this study, the worker tasks adversely affected participants' perceived mental workload. The Processing Efficiency Theory (PET) was specifically developed to account for how anxiety influences performance. This implies a performance – workload association (Burke, Szalma, Gilad, Duley, & Hancock, 2005; Yeh & Wickens, 1988). Performance decrements occurred because of competition for processing resources which lead to higher ratings of perceived mental workload from participants. PPE equipment conferred significant Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration of participants when 4 hours of nanotechnology work was performed with (PPE)for 2 hours or without (Control) protective equipment for two hours. This pattern was evident for Job A (sorters), Job B (repetitive motion mixers), and Job C (loaders). The one exception was Temporal Demand for Job B (repetitive motion mixers), where there was no significant difference was evident between PPE and Control. These findings highlight the burden on PPE in the nanotechnology industry.

CHAPTER 5: CONCLUSION

The purpose of this research was to examine the perceived mental workload issues nanotechnology workers experience while using personal protective equipment while performing work tasks. This research examined the cognitive issues facing workers and how it affects worker performance and mental work load perception namely:

- Mental demand
- Physical demand
- Temporal demand
- Performance
- Effort
- Frustration

The aim of the research to examine the ergonomic factors that impact nano workers performance while donning PPE and offer insight into worker perceived capabilities and limitations in their use of personal protective equipment for safety purposes during occupational activities exposing workers to nanomaterials. Moreover, understand cognitive and performance issues impacting the nanotechnology workplace environment. The table below captures the results of the research questions and hypotheses posited for this study.

Table 14. Results of Research Questions and Hypotheses

Research Questions/Hypotheses	**Research Answer**	**Accept H_o**	**Reject Ho**
Research Question 1: Is Perceived Mental Demand significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE? $H1_0$: Perceived Mental Demand is not significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE $H1_a$: Perceived Mental Demand is significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.	PPE conferred significantly greater mental demand than Control. This significant effect was evident across Job A, Job B, and Job C.		X
Research Question 2: Is Perceived Physical Demand significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE? $H2_0$: Perceived Physical Demand is not significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE. $H2_a$: Perceived Physical Demand is significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.	PPE conferred significantly greater Physical Demand than Control. This significant effect was evident across Job A, Job B, and Job C.		X

Research Questions/Hypotheses	Research Answer	Accept H_o	Reject Ho
Research Question 3: Is Perceived Temporal Demand significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE? $H3_0$: Perceived Temporal Demand is not significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE. $H3_a$: Perceived Temporal Demand is significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.	PPE conferred significantly greater Mental Demand than Control overall. This significant effect was evident for Job A and Job C, but the difference was not statistically significant for Job B.	X For sorters & loaders	X*for mixers
Research Question 4: Is Perceived Performance significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE? $H4_0$: Perceived Performance is not significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE. $H4_a$: Perceived Performance is significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.	PPE conferred significantly higher (indicating worse) Performance scores than Control. This significant effect was evident across Job A, Job B, and Job C.		X

Research Questions/Hypotheses	Research Answer	Accept H_o	Reject Ho
Research Question 5: Is Perceived Effort significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE? $H5_0$: Perceived Effort is not significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE. $H5_a$: Perceived Effort is significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.	PPE conferred significantly greater Effort than Control. This significant effect was evident across Job A, Job B, and Job C.		X
Research Question 6 asked, Is Perceived Frustration significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE? $H6_0$: Perceived Frustration is not significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE. $H6_a$: Perceived Frustration is significantly different in nanotechnology workers when wearing PPE compared to when not wearing PPE.	PPE conferred significantly greater Frustration than Control. This significant effect was evident across Job A, Job B, and Job C.		X

Six research questions were addressed, each reflecting potential differences between donning PPE and doffing PPE conditions in performing work in a nanotechnology environment. For each research question, the null (H_0) and alternative hypotheses (H_a) are presented. The present study of sixty (60) male nanotechnology workers revealed that PPE equipment conferred significant Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration of participants when 4 hours of nanotechnology work was performed with (PPE) for 2 hours or without (Control) personal protective equipment for two hours. This pattern was evident for Job A (sorters), Job B (repetitive motion mixers), and Job C (loaders). The one exception was Temporal Demand for Job B (repetitive motion mixers), where there was no significant difference was evident between PPE and Control. These findings highlight the burden of PPE in the nanotechnology industry.

5.1 Future Research

Future research could explore whether or not PPE protects the workers who are utilizing PPE during nanotechnology related work tasks. Is PPE effective when working with nanomaterials? Why expose humans to cognitively and ergonomically unfavorable work environment? Automation of the nanotechnology worker present tasks maybe a more feasible solution than exposing human nanotechnology operators to potentially dangerous work environments. The worker population researched in this study was all male, future worker populations should include female nanotechnology workers too. A longitudinal study should be investigated also. Using Arousal Theory as a theoretical framework, future research can examine other contradictions theories to analyze cognitive and physical ergonomic issues affecting nanotechnology research laboratory workers.

The research discovered from the manufacturing nanotechnology environment will provide researchers with an understanding of the physical and cognitive issues faced by workers in other nanotechnology related industries. The significance of extending ICON Review of

Current Practices in the Nanotechnology Industry (2006) research was to examine cognitive and ergonomic issues preventing workers from maximizing their work performance. Extending the ICON study allowed the current study not to be focused on just current work practices but to explore the relationship between the nanotechnology workers, PPE and the effects on worker cognitive and physical performance while performing work tasks.

APPENDIX A: SURVEY QUESTIONNAIRE

Nanotechnology HFE Survey

SurveyMonkey

1. What is your job title?

		Response Count
		40
	answered question	40
	skipped question	0

2. Please identify what your responsibilities are within your organization.

		Response Count
		40
	answered question	40
	skipped question	0

3. How long have you been in this current position?

		Response Count
		40
	answered question	40
	skipped question	0

4. Please provide a basic description of your company. (For instance, my company is a university research laboratory, my company is a nanotechnology research and development firm, my company manufactures nanomaterials for the pharmaceutical industry or a medical diagnostics company.)

	Response Count
	29
answered question	**29**
skipped question	**11**

5. Which of the following best describes your organizations business as it relates to engineered nanomaterials (please check all that apply)?

	Response Percent	Response Count
Your company manufactures nanomaterials	37.9%	11
Your company uses nanomaterials	24.1%	7
Your organization performs nanomaterials research and development	**55.2%**	**16**
Your company is a medical facility or hospital	3.4%	1
Other (please specify)	17.2%	5
answered question		**29**
skipped question		**11**

6. Which industry or industries are your nanomaterials' customers? Please mark that apply.

	Response Percent	Response Count
Agricultural	20.7%	6
Automotive	27.6%	8
Coatings	37.9%	11
Construction	10.3%	3
Cosmetics or other personal care products	27.6%	8
Defense	20.7%	6
Electronics	31.0%	9
Energy	20.7%	6
Medical	31.0%	9
Nanomaterial Manufacturer	27.6%	8
Plastics	24.1%	7
Sensing	17.2%	5
Research and development	**51.7%**	**15**
Retail	10.3%	3
Other (please specify)	24.1%	7
	answered question	**29**
	skipped question	**11**

7. What year was your organization formed?

	Response Count
	25
answered question	25
skipped question	15

8. How long has your organization been working with nanomaterials?

	Response Count
	29
answered question	29
skipped question	11

9. How many employees are in your entire organization?

	Response Percent	Response Count
1 - 9 employees	28.6%	8
10 - 49 employees	**32.1%**	**9**
50 - 99 employees	3.6%	1
100 - 249 employees	3.6%	1
250 - 500 employees	3.6%	1
501 or more employees	14.3%	4
Other (please specify)	14.3%	4
answered question		28
skipped question		12

10. How many employees are in your organizations work directly with engineered nanomaterials? (For instance, handle, research or produce nanomaterials)

	Response Percent	Response Count
1 - 9 employees	**55.2%**	**16**
10 - 49 employees	17.2%	5
50 - 99 employees	6.9%	2
100 - 249 employees	6.9%	2
250 - 500 employees	0.0%	0
501 or more employees	3.4%	1
Other (please specify)	10.3%	3
	answered question	**29**
	skipped question	**11**

11. How long has your organization been working with engineered nanomaterial?

	Response Count
	29
answered question	**29**
skipped question	**11**

12. Where does your company produce nanomaterials? Please indicate the Country, State, City and or Province.

		Response Count
		29
	answered question	29
	skipped question	11

13. Please describe all the different types of nanomaterial that your organization manufactures, utilizes and/or handles.

	Response Percent	Response Count
Nanopowders	38.5%	10
Nanocrystals	26.9%	7
Quantum Dots	11.5%	3
Colloidal dispersions	23.1%	6
Fullerenes (Buckyballs)	11.5%	3
Nanotubes	30.8%	8
Nanowires	19.2%	5
Nanohorns	0.0%	0
Dendrimers	3.8%	1
Flakes	7.7%	2
Platelets	11.5%	3
Rods	11.5%	3
Polymers	26.9%	7
Carbon black	11.5%	3
Other (please specify)	34.6%	9
	answered question	**26**
	skipped question	**14**

14. Are the nanomaterials you described

	Response Percent	Response Count
in solid form and mobile	65.4%	17
in a liquid suspension	57.7%	15
Other (please specify)	26.9%	7
answered question		26
skipped question		14

15. Has your organization implemented a health and safety program?

	Response Percent	Response Count
Yes	80.8%	21
No	19.2%	5
answered question		26
skipped question		14

16. Has your organization implemented a nano-specific health and safety program?

	Response Percent	Response Count
Yes	24.0%	6
No	76.0%	19
answered question		25
skipped question		15

17. Does your organization offer health and safety training for your employees on the handling of nanomaterials?

	Response Percent	Response Count
Yes	40.0%	10
No	60.0%	15
answered question		25
skipped question		15

18. Do all employees who handle nanomaterials receive this training?

	Response Percent	Response Count
Yes	52.2%	12
No	47.8%	11
answered question		23
skipped question		17

19. How often do employees receive nano-specific health and safety training?

	Response Percent	Response Count
Daily	4.3%	1
Weekly	0.0%	0
Monthly	13.0%	3
Annually	17.4%	4
Upon starting employment	13.0%	3
When standard health and safety training is offered	8.7%	2
When new nano materials are introduced	4.3%	1
Other (please specify)	**39.1%**	**9**
	answered question	**23**
	skipped question	**17**

20. Who provides the nano-specific training?

	Response Percent	Response Count
Internal resources	**65.2%**	**15**
External resources	0.0%	0
Both internal and external resources	17.4%	4
Other (please specify)	17.4%	4
	answered question	**23**
	skipped question	**17**

21. To better understand the potential for engineered nanomaterial exposure in your work environment, what amount of nanomaterials do your employees typically work with at a time? Is it on a scale of: (Note if the answer is in "volume" units please provide concentration information so that so that your answer can be converted to mass units.)

	Response Percent	Response Count
Micrograms to less than one milligram	16.7%	3
Milligrams to less than one gram	**27.8%**	**5**
One gram to less than one kilogram	22.2%	4
Greater than one kilogram	**27.8%**	**5**
Other (please specify)	16.7%	3
	answered question	**18**
	skipped question	**22**

22. Are "nano-specific" facility design and engineering controls used to safely manage worker exposure to engineered nanomaterials? If the answer is yes, please identify which of the following methods are used?

	Response Percent	Response Count
Clean room	35.3%	6
Fume hood	47.1%	8
Biological safety cabinet	17.6%	3
Laminar flow clean bench	17.6%	3
Glove box	**52.9%**	**9**
Glove bag	11.8%	2
HVAC system	5.9%	1
Pressure differentials	0.0%	0
Closed piping systems	5.9%	1
Other (please specify)	29.4%	5
	answered question	**17**
	skipped question	**23**

23. Do you have recommendations for your employees regarding personal protective equipment and or clothing that should be worn while working with engineered nanomaterials?

	Response Percent	Response Count
Yes	**68.4%**	**13**
No	15.8%	3
Other (please specify)	15.8%	3
	answered question	**19**
	skipped question	**21**

24. Please describe the types of personal protective equipment worn by your employees when working with engineered nanomaterials.

	Response Percent	Response Count
Lab coats	78.9%	15
Special shoes	26.3%	5
Gloves	**84.2%**	**16**
Eye protection (ie.,goggles, Full face coverage,side shields)	78.9%	15
Face masks	57.9%	11
Hair bonnets	31.6%	6
Respiratory protection	15.8%	3
Other (please specify)	15.8%	3
	answered question	**19**
	skipped question	**21**

25. Is the use of personal protective equipment and clothing required of employees while working with engineered nanomaterials?

	Response Percent	Response Count
Yes	52.6%	10
No	31.6%	6
Other (please specify)	15.8%	3
answered question		19
skipped question		21

26. How does your organization dispose of waste containing engineered nanomaterials?

	Response Count
	18
answered question	18
skipped question	22

27. Are separate disposal containers for nanomaterials used either in the laboratory or in waste storage areas?

	Response Percent	Response Count
Yes	47.4%	9
No	36.8%	7
Other (please specify)	15.8%	3
answered question		19
skipped question		21

28. Does your organization monitor the work environment for nanoparticles?

	Response Percent	Response Count
Yes	15.8%	3
No	**63.2%**	**12**
Other (please specify)	21.1%	4
	answered question	**19**
	skipped question	**21**

29. How frequently do you perform the monitoring of nanoparticles?

	Response Percent	Response Count
At initiation of the work	5.6%	1
When a change occurs in the work	16.7%	3
Continuous monitoring	5.6%	1
More than once per week	0.0%	0
Less than once per week, more than once per month	0.0%	0
Less than once per month, more than once per year	5.6%	1
Never	**50.0%**	**9**
Other (please specify)	16.7%	3
	answered question	**18**
	skipped question	**22**

30. Do you think there are any special risks associated with the nanomaterials handled or produced in your organization? If yes, what do you think those risk are?

	Response Count
	14
answered question	14
skipped question	26

31. Does your organization perform its own toxicological research?

	Response Percent	Response Count
Yes	36.8%	7
No	**42.1%**	**8**
Other (please specify)	21.1%	4
answered question		19
skipped question		21

32. Is there anything that we have not covered in this questionnaire that you think is relevant and we need to understand and included in this survey?

	Response Count
	10
answered question	10
skipped question	30

33. Can you recommend other organizations that you think we should invite to participate in our survey?

	Response Count
	8
answered question	8
skipped question	32

Page 1, Q1. What is your job title?		
1	dsad	May 23, 2011 4:02 PM
2	Director	Mar 17, 2011 5:25 PM
3	R&D engineer	Feb 7, 2011 8:53 AM
4	Manufacturing Engineer Application Support Specialist	Feb 4, 2011 2:56 PM
5	President	Feb 4, 2011 2:44 PM
6	Senior Vice President	Feb 4, 2011 10:26 AM
7	Research engineer	Feb 2, 2011 6:53 AM
8	John V. Stone, Ph.D. Co-Director & Senior Research Scientist Center for the Study of Standards in Society (CS3, formerly IFAS) Berkey Hall, #425-A Michigan State University East Lansing, MI 48824 517-355-2384 (office); 517-432-2856 (FAX) jvstone@msu.edu http://cs3.msu.edu/	Feb 1, 2011 3:31 PM
9	hhhhhh	Jan 31, 2011 12:59 PM
10	President	Jan 28, 2011 8:29 PM
11	Assistant Professor	Jan 26, 2011 1:16 PM
12	Founding Director Center of Nanotechnology King Abdul Aziz University Jeddah Saudi Arabia	Jan 25, 2011 3:44 PM
13	Rr	Jan 25, 2011 3:23 PM
14	Owing to company restructuring I am at present seeking a new position. My previous role was in a nanopowder production company where I Principal Scientist/technical Manager for the past 8years up to October 2010.	Jan 25, 2011 2:12 PM
15	Graduate Student	Jan 23, 2011 12:18 PM
16	Research Scholar (Full time PhD)	Jan 23, 2011 12:13 PM
17	President & Member	Jan 22, 2011 1:41 PM
18	assistant professor of electrical & computer eng.	Jan 22, 2011 12:20 PM
19	Research Fellow	Jan 22, 2011 9:48 AM
20	Executive Director of Business Development	Jan 20, 2011 10:41 AM
21	Researcher	Jan 17, 2011 6:40 PM
22	Postdoctoral associate	Jan 15, 2011 11:50 AM
23	Director of Marketing and Sales	Jan 14, 2011 1:55 PM
24	Senior Research Scholar and Director of E-Spin Nanotech Pvt. Ltd. Company	Jan 14, 2011 11:07 AM

Page 1, Q1. What is your job title?		
25	Research Assistant	Jan 14, 2011 10:03 AM
26	Technology Analyst	Jan 14, 2011 9:31 AM
27	Resesrch associate in NDDS dept.	Jan 14, 2011 5:29 AM
28	Group Leader-NDDS	Jan 14, 2011 3:02 AM
29	Director of Engineering	Jan 11, 2011 3:09 PM
30	Product development engineer	Jan 11, 2011 2:31 PM
31	Safety Director	Jan 11, 2011 8:39 AM
32	Cheif Technology Officer	Jan 11, 2011 4:31 AM
33	vice-rector for research	Jan 11, 2011 1:10 AM
34	OFFICER , PRODUCT DEVELOPMENT AND RESEARCH	Jan 10, 2011 11:38 PM
35	w	Jan 10, 2011 5:00 PM
36	df	Nov 21, 2010 10:39 AM
37	Postdoctoral Research Associated	Nov 19, 2010 2:43 PM
38	CEO	Nov 19, 2010 10:44 AM
39	Vice President Fleet and Logistics	Nov 19, 2010 8:59 AM
40	Research associate, postdoc.	Nov 16, 2010 12:34 PM

Page 1, Q2. Please identify what your responsibilities are within your organization.		
1	das	May 23, 2011 4:02 PM
2	management	Mar 17, 2011 5:25 PM
3	Project manager	Feb 7, 2011 8:53 AM
4	Nano powder deposition and coating with CVD infiltration for application toward the cutting tool industry.	Feb 4, 2011 2:56 PM
5	Technology Development and Pre-Commercialization	Feb 4, 2011 2:44 PM
6	Business Development for Hyperspectral Microscope technology supporting researchers at the nano-scale	Feb 4, 2011 10:26 AM
7	R&D; test planning and pilot runs, some laboratory analytics.	Feb 2, 2011 6:53 AM
8	John V. Stone is Co-Director and Senior Research Scientist at the Center for the Study of Standards in Society (CS3) at Michigan State University. He holds a Ph.D. in Applied Anthropology from the University of South Florida. As an applied anthropologist, Dr. Stone's research centers on ethnographic approaches to public participation and standards in emerging technologies, through which he seeks to promote more equitable social access to and outcomes of those processes. He directs and assists with numerous activities at CS3, including building a diverse portfolio of standards-related research, education and outreach; research conception and grant development; project research and management; administration and staff and student supervision; and graduate course development and occasional instruction. Prior to joining CS3 in 2002, Dr. Stone held notable positions with Formative Evaluation Research Associates, the International Association for Great Lakes Research, the Great Lakes Environmental Research Laboratory, and the Great Lakes Commission. Earlier in his career Dr. Stone participated in social impact assessment studies conducted through Oak Ridge National Laboratory and later at the University of Michigan's Institute for Social Research, where he helped develop the 'Risk Perception Mapping' (RPM) methodology for social assessment of controversial facilities and technologies. He is presently leading a multi-year effort supported by the USDA to develop RPM capacity within the Cooperative Extension System to link local knowledges with public policies for agrifood nanotechnologies. Dr. Stone holds a seat on the Nanotechnology Standards Panel of the American National Standards Institute, co-founded the Risk Assessment and Policy Association, is a Fellow of the Society for Applied Anthropology, and holds occasional membership in the International Association for Public Participation and the International Association for Impact Assessment. He was awarded the Environmental Protection Agency's Environmental Anthropology Fellowship in 1999, served as the Inaugural Fellow to the Great Lakes Commission Fellowship Program, and as an invited participant to the Enivronmental Protection Agency's National Dialogue on Public Involvement in EPA Decisions. Dr. Stone has 25+ years experience in applied social research, authored more than 30 scientific publications and technical reports, and delivered more than 85 presentations to professional and scientific societies and government agencies.	Feb 1, 2011 3:31 PM
9	hhhhhh	Jan 31, 2011 12:59 PM

Page 1, Q2. Please identify what your responsibilities are within your organization.		
10	Owner, Technical Visionary	Jan 28, 2011 8:29 PM
11	Conduct research, supervise students, teach classes, help run the department.	Jan 26, 2011 1:16 PM
12	Providing Leadership to CNT at KAU	Jan 25, 2011 3:44 PM
13	*****	Jan 25, 2011 3:23 PM
14	Health and safety. Development of novel materials and processes. Characterisation of nanopowders. Post processing of nanopowders. Project management of internal and external projects. Technical manager of a 4 year programme funded by the EU - Nanosafe	Jan 25, 2011 2:12 PM
15	Research nanotechnology related subjects as it relates to occupational safety and health	Jan 23, 2011 12:18 PM
16	Preformulation studies for the drug under development. Analytical and bioanalytical method development and validation as per ICH and USFDA guidelines. Formulation development of novel carriers to achieve progress in the existing therapy. Characterization of the developed novel drug carriers. Interpret the output from various analytical instruments like HPLC, UV, GC, IR, DSC, etc. Monitoring of the formulation stability as per ICH guidelines. Reporting research findings to the principal investigator. Preparation and submission of research reports to the government and various funding agencies. Preparation of the standard operating procedures for the institutional formulation development department. Demonstration and imparting training on the high end instruments to the candidates from various organizations.	Jan 23, 2011 12:13 PM
17	General Management	Jan 22, 2011 1:41 PM
18	teaching, research	Jan 22, 2011 12:20 PM
19	Device fabrication, project management, lecturing, training, CAD engineering	Jan 22, 2011 9:48 AM
20	I Implement markting materials, Tradeshows, Getting new markets globally etc	Jan 20, 2011 10:41 AM
21	HFE	Jan 17, 2011 6:40 PM
22	Nanoparticle-toxicity relationship research, writing reports, writing proposals	Jan 15, 2011 11:50 AM
23	We are a small start up (8 employees). CEO of the company and I split our marketing and sales roles. Primarily I do these: Represent the company at industry conferences, seminars organize and coordinate company representation at conferences and exhibits prepare and facilitate meetings with shareholders and prospective investors and weekly lunches. availing myself to you, the team, and prospective clients 24/7, except during my vacation to assist and answer questions maintain company website write and distribute company newsletters and press releases; achieving highest profile possible for press releases seek high profile news and market analysis, such as Frost and Sullivan, WSJ represent and strengthen relationships with local and state agencies, and local and state representatives, identify, propose, facilite, perform booth duties, and make presentations at conferences and exhibits identify and create relationships with external technical experts in our application areas, such as	Jan 14, 2011 1:55 PM

Page 1, Q2. Please identify what your responsibilities are within your organization.		
	Bob, Graeme, and Mike Miller cold call and/or create business prospects maintain and strengthen ties with existing partners/collaborators research and disseminate market data review and inform the team of federal funding opportunities achieve and negotiate corporate discount rates with local merchants and shipping carriers communicate and motivate sales and distribution channels invoice, ship, and communicate with customers on shipments and deliveries track royalties, accounts receivables identify and develop new sales and distributors	
24	I am the head in our group, I preferably do a instrument design work which basically related to our research. My research area is basically focused on structural adhesion. The structures are created on adhesive surface by fracture of thin polymer films by speed controlled root in order to generate micro-nano structure on fracture polymer surface. The generated structures was useful for adhesion tuning properties. Apart from this, I also do work on nanofibers and nanomaterail fabrication by electrospinning machine which I have developed in my lab currently.	Jan 14, 2011 11:07 AM
25	I am working on Nanosphere lithography. I am a student. I do sputtering, AFM and SEM scans, RIE etching at lab levels. I need to maintain my lab notes and need to write my thesis docs.	Jan 14, 2011 10:03 AM
26	Analysis of the development of nanotechnologies across the world, particularly in Electronics, semiconductors, displays, and other ICT applications. Also in thin films and coatings, and sensors applications.	Jan 14, 2011 9:31 AM
27	Literature survey. Design & development of nanocarrier based drug delivery systems for oral & parenteral route. Evaluation of Nano based drug products & there stability studies. Planning of animal pharmacokinetic & cell line studies of developed formulations.	Jan 14, 2011 5:29 AM
28	Generation of novel drug delivery based platform technologies. This will mostly involve preparation of nanoparticulate formulations to address various therapeutic, pharmaceutical problems.	Jan 14, 2011 3:02 AM
29	Equipment and process design of nano manufacturing of pharmaceutical products. Scale up and commercialization of nanomedicine products.	Jan 11, 2011 3:09 PM
30	Research and development of applications for nanoparticles, Scale-up, technical support	Jan 11, 2011 2:31 PM
31	Responsible for site safety on a 227mw coal fired power plant (new construction)	Jan 11, 2011 8:39 AM
32	Build strategic partners for the Nano business Aquire technologies by working with reasearch centres Development of Nano materials and technologies Development of Textile finishing chemistries Innovations in Silicone polymer and its applications	Jan 11, 2011 4:31 AM
33	coordination of R&D	Jan 11, 2011 1:10 AM
34	DEVELOPMENT OF NANOMATERIALS RESEARCH & COMMERCIAL APPLICATIONS OF THE DEVELOPED PRODUCT	Jan 10, 2011 11:38 PM

Page 1, Q2. Please identify what your responsibilities are within your organization.		
35	w	Jan 10, 2011 5:00 PM
36	df	Nov 21, 2010 10:39 AM
37	Research / Teaching	Nov 19, 2010 2:43 PM
38	Leading the company	Nov 19, 2010 10:44 AM
39	Aquisition, maintenance and disposal of rolling fleet assets. Efficiency and maagement of materials movement.	Nov 19, 2010 8:59 AM
40	Theoretical description of dynamics of many-body excitations in semiconductors from the perspective of nonlinear optical response.	Nov 16, 2010 12:34 PM

Page 1, Q3. How long have you been in this current position?		
1	dfg	May 23, 2011 4:02 PM
2	1 year	Mar 17, 2011 5:25 PM
3	6 years	Feb 7, 2011 8:53 AM
4	6 months	Feb 4, 2011 2:56 PM
5	8	Feb 4, 2011 2:44 PM
6	six years	Feb 4, 2011 10:26 AM
7	1 year	Feb 2, 2011 6:53 AM
8	Nine years	Feb 1, 2011 3:31 PM
9	hhhhh	Jan 31, 2011 12:59 PM
10	1.5years	Jan 28, 2011 8:29 PM
11	2.5 years	Jan 26, 2011 1:16 PM
12	4 years	Jan 25, 2011 3:44 PM
13	E	Jan 25, 2011 3:23 PM
14	8years up to Oct 2010	Jan 25, 2011 2:12 PM
15	Since 2008	Jan 23, 2011 12:18 PM
16	1 year 8 months	Jan 23, 2011 12:13 PM
17	11 yrs.	Jan 22, 2011 1:41 PM
18	4 yrs	Jan 22, 2011 12:20 PM
19	15 months	Jan 22, 2011 9:48 AM
20	7 years	Jan 20, 2011 10:41 AM
21	5	Jan 17, 2011 6:40 PM
22	6 years	Jan 15, 2011 11:50 AM
23	1.5 years	Jan 14, 2011 1:55 PM
24	4.5 years	Jan 14, 2011 11:07 AM
25	from past 2 years	Jan 14, 2011 10:03 AM
26	14 months	Jan 14, 2011 9:31 AM
27	8 months (+ 12 months of project during postgraduation)	Jan 14, 2011 5:29 AM

Page 1, Q3. How long have you been in this current position?		
28	2 months	Jan 14, 2011 3:02 AM
29	2 years 11 years with my nanoproduct company	Jan 11, 2011 3:09 PM
30	3 years	Jan 11, 2011 2:31 PM
31	2 years	Jan 11, 2011 8:39 AM
32	3 years	Jan 11, 2011 4:31 AM
33	3 years	Jan 11, 2011 1:10 AM
34	6 MONTHS	Jan 10, 2011 11:38 PM
35	w	Jan 10, 2011 5:00 PM
36	df	Nov 21, 2010 10:39 AM
37	2.5 years	Nov 19, 2010 2:43 PM
38	15 years	Nov 19, 2010 10:44 AM
39	3 years	Nov 19, 2010 8:59 AM
40	4 years	Nov 16, 2010 12:34 PM

Page 2, Q1. Please provide a basic description of your company. (For instance, my company is a university research laboratory, my company is a nanotechnology research and development firm, my company manufactures nanomaterials for the pharmaceutical industry or a medical diagnostics company.)		
1	My company is a nanotechnology research and development firm along with manufacturing for specific end users.	Feb 4, 2011 3:01 PM
2	long-life, self-recharging batteries	Feb 4, 2011 2:46 PM
3	ZZZ is the biggest multitechnological applied research organisation in Northern Europe. ZZZ provides high-end technology solutions and innovation services.	Feb 2, 2011 6:58 AM
4	University research & policy center	Feb 1, 2011 3:37 PM
5	hhhh	Jan 31, 2011 1:00 PM
6	Industrial ink jet fluids and print process - ink jet nano metals to fabricate devices	Jan 28, 2011 8:32 PM
7	University research laboratory.	Jan 26, 2011 1:18 PM
8	It is a nanotechnology research center with the vision : To be partener in the sustainable devlopment of Saudi Arabia via transfer and indeginous growth of nanotechnology	Jan 25, 2011 3:56 PM
9	The company manufactured metal and inorganic nanopowders for a range of industries includingdefence, electronics and health. >48 different material variants were manufactured.	Jan 25, 2011 2:16 PM
10	My organization is a university research laboratory.	Jan 23, 2011 12:31 PM
11	My company is a university research laboratory which is mainly engaged in development of novel drug delivery systems for pharmaceutical compounds.	Jan 23, 2011 12:21 PM
12	Polymer R&D Consulting company	Jan 22, 2011 1:44 PM
13	University research nanotechnology centre	Jan 22, 2011 9:50 AM
14	FDA facility manufacturing RxTopicals, OTC, Nutriceuticals and Cosmeceuticals all using our patented Nano technology delivery system.	Jan 20, 2011 10:45 AM
15	R&D	Jan 17, 2011 6:42 PM
16	My company is Interdisciplinary Center for Nanotoxicity at Jackson State University	Jan 15, 2011 11:54 AM
17	The company develops and manufactures environmentally friendly high surface area nanomaterials for pollution control, catalysis, composites and sensory technologies. The company's patent-pending nanomaterials provide a scalable, industry compatible, low cost platform for highly efficient solutions.	Jan 14, 2011 1:58 PM
18	My company deals with nano-material fabrication from polymer solutions	Jan 14, 2011 11:12 AM
19	My company is a university research Lab.	Jan 14, 2011 10:04 AM
20	independent institute and registered charity.	Jan 14, 2011 9:34 AM

Page 2, Q1. Please provide a basic description of your company. (For instance, my company is a university research laboratory, my company is a nanotechnology research and development firm, my company manufactures nanomaterials for the pharmaceutical industry or a medical diagnostics company.)		
21	Elan Delivery Technology which develops nanomedicine products	Jan 11, 2011 3:12 PM
22	My company is a manufacturer of nanomaterials	Jan 11, 2011 2:33 PM
23	we are a specilty chemical company with focus on nanomaterials and silicone materaials for textiles and other applications check www.resil.com www.n9worldtechnology.com	Jan 11, 2011 4:37 AM
24	My company is university R&D department	Jan 11, 2011 1:16 AM
25	THIS COMPANY IS BASICALLY STRENGTHENED IN TEXTILE CHEMICALS AND FINISHES MANUFACTURING .. IT HAS A NANOTECHNOLOGY WING WHICH FOCUSSES ON NANOMATERIALS DEVELOPMENT AND APPLICATION IN TEXTILE AND NON TEXTILE FIELDS.	Jan 10, 2011 11:38 PM
26	my institution focuses on combinations of biology and (computer-)technology	Nov 19, 2010 2:47 PM
27	manufacturing of nanomaterials for differen purposes	Nov 19, 2010 10:46 AM
28	Refuse disposal, renewable energy production, environmential services.	Nov 19, 2010 9:03 AM
29	University research laboratory	Nov 16, 2010 12:35 PM

Page 2, Q2. Which of the following best describes your organizations business as it relates to engineered nanomaterials (please check all that apply)?		
1	Research on the social and ethical dimensions of nanotechnologies in agriculture and food systems.	Feb 1, 2011 3:37 PM
2	A pharmaceutical novel drug delivery development laboratory	Jan 23, 2011 12:21 PM
3	From a HF engineering impacts.	Jan 17, 2011 6:42 PM
4	we are a membership organisation, and charity that promote the responsible use of nanotechnology across the world	Jan 14, 2011 9:34 AM
5	Calculates properties of nanomaterials	Nov 16, 2010 12:35 PM

Page 2, Q3. Which industry or industries are your nanomaterials' customers? Please mark that apply.		
1	Any machining and manufacturing companies.	Feb 4, 2011 3:01 PM
2	The nature of the technologies in question necessarily crosses sectoral and disciplinary boundaries, so 'agrifood' nanotechnology is a bit of a misnomer. I have it checked above as it is the organizing motivation for our work, but the technologies of application in agrifood also have application across numerous other sectors.	Feb 1, 2011 3:37 PM
3	Not at a company.	Jan 26, 2011 1:18 PM
4	Pharmaceutical	Jan 23, 2011 12:21 PM
5	We do only research, we academic institution	Jan 15, 2011 11:54 AM
6	Chemical	Jan 14, 2011 1:58 PM
7	Textiles, leather	Jan 11, 2011 4:37 AM

Page 2, Q4. What year was your organization formed?		
1	2008?	Feb 4, 2011 3:01 PM
2	2002	Feb 4, 2011 2:46 PM
3	1942	Feb 2, 2011 6:58 AM
4	MSU = 1855; CS3 = 2010 (although that was when it was renamed; previously it was known as the Institute for Food and Agricultural Standards, which was founded in 1998).	Feb 1, 2011 3:37 PM
5	2009	Jan 28, 2011 8:32 PM
6	Don't know	Jan 26, 2011 1:18 PM
7	2007	Jan 25, 2011 3:56 PM
8	2001	Jan 25, 2011 2:16 PM
9	January 2008	Jan 23, 2011 12:31 PM
10	1999	Jan 22, 2011 1:44 PM
11	1980	Jan 22, 2011 9:50 AM
12	1999	Jan 20, 2011 10:45 AM
13	1960's	Jan 17, 2011 6:42 PM
14	2008	Jan 15, 2011 11:54 AM
15	2007	Jan 14, 2011 1:58 PM
16	2010	Jan 14, 2011 11:12 AM
17	1997	Jan 14, 2011 9:34 AM
18	1992	Jan 11, 2011 3:12 PM
19	2003	Jan 11, 2011 2:33 PM
20	1994	Jan 11, 2011 4:37 AM
21	1965	Jan 11, 2011 1:16 AM
22	1991	Jan 10, 2011 11:38 PM
23	2004	Nov 19, 2010 2:47 PM
24	1993	Nov 19, 2010 10:46 AM
25	1968	Nov 19, 2010 9:03 AM

Page 2, Q5. How long has your organization been working with nanomaterials?		
1	?	Feb 4, 2011 3:01 PM
2	8	Feb 4, 2011 2:46 PM
3	I don't know	Feb 2, 2011 6:58 AM
4	Nano-related research since 2004.	Feb 1, 2011 3:37 PM
5	hhhh	Jan 31, 2011 1:00 PM
6	1.5 years	Jan 28, 2011 8:32 PM
7	Don't know	Jan 26, 2011 1:18 PM
8	4	Jan 25, 2011 3:56 PM
9	2002	Jan 25, 2011 2:16 PM
10	I have studied nanomaterials since January 2008	Jan 23, 2011 12:31 PM
11	last one decade	Jan 23, 2011 12:21 PM
12	11 yrs.	Jan 22, 2011 1:44 PM
13	30 years	Jan 22, 2011 9:50 AM
14	15 years	Jan 20, 2011 10:45 AM
15	n/a	Jan 17, 2011 6:42 PM
16	4 years	Jan 15, 2011 11:54 AM
17	3 years; the technology is exclusively licensed to us from the University of Idaho and Washington State University. The two universities collaborated for nearly ten years prior to setting up the company.	Jan 14, 2011 1:58 PM
18	from last 3 month	Jan 14, 2011 11:12 AM
19	Last 10 years	Jan 14, 2011 10:04 AM
20	1997	Jan 14, 2011 9:34 AM
21	19 years	Jan 11, 2011 3:12 PM
22	8	Jan 11, 2011 2:33 PM
23	3 years	Jan 11, 2011 4:37 AM
24	12 years	Jan 11, 2011 1:16 AM
25	3 YEARS	Jan 10, 2011 11:38 PM
26	ever since	Nov 19, 2010 2:47 PM

Page 2, Q5. How long has your organization been working with nanomaterials?		
27	since 1995	Nov 19, 2010 10:46 AM
28	10 years	Nov 19, 2010 9:03 AM
29	4 years	Nov 16, 2010 12:35 PM

Page 2, Q6. How many employees are in your entire organization?		
1	2 900	Feb 2, 2011 6:58 AM
2	I'm not sure which organization you're referring to here -- MSU or CS3. CS3 associates span much of MSU but aren't necessarily tied to CS3 beyond any particular research or policy collaboration.	Feb 1, 2011 3:37 PM
3	My research team headed by my Institute dean and some research scholars.	Jan 23, 2011 12:21 PM
4	42,000	Nov 19, 2010 9:03 AM

Page 2, Q7. How many employees are in your organizations work directly with engineered nanomaterials? (For instance, handle, research or produce nanomaterials)		
1	See question above.	Feb 1, 2011 3:37 PM
2	Don't know	Jan 26, 2011 1:18 PM
3	none	Jan 14, 2011 9:34 AM

Page 2, Q8. How long has your organization been working with engineered nanomaterial?		
1	?	Feb 4, 2011 3:01 PM
2	8	Feb 4, 2011 2:46 PM
3	?	Feb 2, 2011 6:58 AM
4	Nano-related research since 2004.	Feb 1, 2011 3:37 PM
5	hhh	Jan 31, 2011 1:00 PM
6	1.5 years	Jan 28, 2011 8:32 PM
7	Don't know	Jan 26, 2011 1:18 PM
8	4	Jan 25, 2011 3:56 PM
9	8years	Jan 25, 2011 2:16 PM
10	We do not handle engineered nanomaterials.	Jan 23, 2011 12:31 PM
11	Lat one decade	Jan 23, 2011 12:21 PM
12	11 yrs.	Jan 22, 2011 1:44 PM
13	20 yeasrs	Jan 22, 2011 9:50 AM
14	we don't engineer, we use nautral plant based nano material	Jan 20, 2011 10:45 AM
15	-	Jan 17, 2011 6:42 PM
16	3 years	Jan 15, 2011 11:54 AM
17	3 years	Jan 14, 2011 1:58 PM
18	form last three month	Jan 14, 2011 11:12 AM
19	10 years	Jan 14, 2011 10:04 AM
20	0	Jan 14, 2011 9:34 AM
21	17 years	Jan 11, 2011 3:12 PM
22	8	Jan 11, 2011 2:33 PM
23	3 years	Jan 11, 2011 4:37 AM
24	10 years	Jan 11, 2011 1:16 AM
25	2 YEARS	Jan 10, 2011 11:38 PM
26	since 2005	Nov 19, 2010 2:47 PM
27	since 1995	Nov 19, 2010 10:46 AM

Page 2, Q8. How long has your organization been working with engineered nanomaterial?		
28	10years	Nov 19, 2010 9:03 AM
29	4 years	Nov 16, 2010 12:35 PM

Page 2, Q9. Where does your company produce nanomaterials? Please indicate the Country, State, City and or Province.		
1	USA Arkansas Springdale	Feb 4, 2011 3:01 PM
2	not applicable	Feb 4, 2011 2:46 PM
3	Finland	Feb 2, 2011 6:58 AM
4	NA	Feb 1, 2011 3:37 PM
5	hhhh	Jan 31, 2011 1:00 PM
6	Buy from the US and UK	Jan 28, 2011 8:32 PM
7	Montreal, Quebec, Canada	Jan 26, 2011 1:18 PM
8	Fabrication of nanomaterials	Jan 25, 2011 3:56 PM
9	UK	Jan 25, 2011 2:16 PM
10	We are a research laboratory only. Engineered nanomaterials are not handled here.	Jan 23, 2011 12:31 PM
11	Dept. of Pharmaceutics Manipal College of Pharmaceutical Sciences, Manipal University, Manipal, Karnataka, India	Jan 23, 2011 12:21 PM
12	R7D for clients only	Jan 22, 2011 1:44 PM
13	in house	Jan 22, 2011 9:50 AM
14	St. Petersburg, Florida, USA	Jan 20, 2011 10:45 AM
15	-	Jan 17, 2011 6:42 PM
16	no production, only research	Jan 15, 2011 11:54 AM
17	Moscow, Idaho	Jan 14, 2011 1:58 PM
18	India Uttar Pradesh Kanpur-208016	Jan 14, 2011 11:12 AM
19	Ohio, United states	Jan 14, 2011 10:04 AM
20	n/a	Jan 14, 2011 9:34 AM
21	Philadelphia area	Jan 11, 2011 3:12 PM
22	USA	Jan 11, 2011 2:33 PM
23	bangalore, India	Jan 11, 2011 4:37 AM
24	city	Jan 11, 2011 1:16 AM
25	BANGALORE,KARNATAKA	Jan 10, 2011 11:38 PM
26	we do not produce them, but use them	Nov 19, 2010 2:47 PM

Page 2, Q9. Where does your company produce nanomaterials? Please indicate the Country, State, City and or Province.		
27	Germany, Berlin	Nov 19, 2010 10:46 AM
28	Unclear	Nov 19, 2010 9:03 AM
29	N/A	Nov 16, 2010 12:35 PM

Page 3, Q1. Please describe all the different types of nanomaterial that your organization manufactures, utilizes and/or handles.		
1	engineered nano/micro cavities in silicon	Feb 4, 2011 2:47 PM
2	This does not apply to our nano-related research/policy portfolio (i.e., 'NA')	Feb 1, 2011 3:38 PM
3	We do not utilize any nanomaterials directly only literature research.	Jan 23, 2011 12:38 PM
4	Plant based from soy lecithin	Jan 20, 2011 10:46 AM
5	Nanosprings(TM), consisting of 5 to 8 individual nanowires	Jan 14, 2011 2:00 PM
6	nano material	Jan 14, 2011 10:04 AM
7	none	Jan 14, 2011 9:34 AM
8	molequles	Nov 19, 2010 2:48 PM
9	None	Nov 16, 2010 12:36 PM

Page 3, Q2. Are the nanomaterials you described		
1	solid	Feb 4, 2011 2:47 PM
2	NA	Feb 1, 2011 3:38 PM
3	We do not utilize any nanomaterials directly only literature reviews and literature searches	Jan 23, 2011 12:38 PM
4	Nanosprings can be coated on a variety of substrates or sold as powders.	Jan 14, 2011 2:00 PM
5	n/a	Jan 14, 2011 9:34 AM
6	in Polymers	Jan 11, 2011 4:38 AM
7	N/A	Nov 16, 2010 12:36 PM

Page 4, Q5. How often do employees receive nano-specific health and safety training?		
1	as needed	Feb 4, 2011 2:48 PM
2	This question, as with 1-4 above, pertain to MSU more generally, as CS3 is not directly involved in the production or manufacture of nano-related materials	Feb 1, 2011 3:39 PM
3	There is no specific training given - employees learn on the job. I was in-house expert on Nanosafety	Jan 25, 2011 2:17 PM
4	as needed	Jan 22, 2011 1:45 PM
5	since we only use nautral no extra training needed	Jan 20, 2011 10:48 AM
6	n/a	Jan 14, 2011 9:35 AM
7	Not provided	Jan 11, 2011 2:35 PM
8	PEOPLE HAVING GOOD KNOWLEDGE IN NANOTECHNOLOGY ONLY ARE ALLOWED TO HANDLE NANOMATERIALS	Jan 10, 2011 11:42 PM
9	nothing	Nov 19, 2010 10:48 AM

Page 4, Q6. Who provides the nano-specific training?		
1	n/a	Jan 14, 2011 9:35 AM
2	Not provided	Jan 11, 2011 2:35 PM
3	PEOPLE HAVING GOOD KNOWLEDGE IN NANOTECHNOLOGY ONLY ARE ALLOWED TO HANDLE NANOMATERIALS	Jan 10, 2011 11:42 PM
4	no	Nov 19, 2010 10:48 AM

Page 5, Q1. To better understand the potential for engineered nanomaterial exposure in your work environment, what amount of nanomaterials do your employees typically work with at a time? Is it on a scale of: (Note if the answer is in "volume" units please provide concentration information so that so that yo...		
1	You need to add 'not applicable' and 'don't know/unsure' options to your scale.	Feb 1, 2011 3:41 PM
2	not applicable	Jan 23, 2011 1:56 PM
3	materials are not in nano form until exfoliated and dispersed into polymers. no handling problems are we handle large quantities of nano reinforced compounds.	Jan 22, 2011 1:48 PM

Page 5, Q2. Are "nano-specific" facility design and engineering controls used to safely manage worker exposure to engineered nanomaterials? If the answer is yes, please identify which of the following methods are used?		
1	see above	Feb 1, 2011 3:41 PM
2	vacuum cleaning systems and laminar flow booths	Jan 25, 2011 2:18 PM
3	not applicable	Jan 23, 2011 1:56 PM
4	conventional clays and talcs until exfoliated into polymers	Jan 22, 2011 1:48 PM
5	normal exhausters	Nov 19, 2010 10:49 AM

Page 6, Q1. Do you have recommendations for your employees regarding personal protective equipment and or clothing that should be worn while working with engineered nanomaterials?		
1	NA	Feb 1, 2011 3:42 PM
2	Not applicable	Jan 23, 2011 2:00 PM
3	we don't engineer	Jan 20, 2011 10:50 AM

Page 6, Q2. Please describe the types of personal protective equipment worn by your employees when working with engineered nanomaterials.		
1	NA	Feb 1, 2011 3:42 PM
2	Not applicable	Jan 23, 2011 2:00 PM
3	we have to do to FDA regulations not because we use Nano	Jan 20, 2011 10:50 AM

Page 6, Q3. Is the use of personal protective equipment and clothing required of employees while working with engineered nanomaterials?		
1	NA	Feb 1, 2011 3:42 PM
2	The company did not have any specific rules but it was impressed on the employees that PPE should be worn to prevent inhalation and skin contact	Jan 25, 2011 2:20 PM
3	Not applicable	Jan 23, 2011 2:00 PM

Page 7, Q1. How does your organization dispose of waste containing engineered nanomaterials?		
1	not applicable	Feb 4, 2011 2:50 PM
2	Does this refer to wastes associated with ENP production/manufature, or in use of products containing ENPs manufactured elsewhere? If the former, then NA; if the latter, then, sadly, in the conventional solid waste stream, even assuming one knows a given product contains ENPs.	Feb 1, 2011 3:45 PM
3	Trash	Jan 28, 2011 8:36 PM
4	University waste management handles it.	Jan 26, 2011 1:20 PM
5	Via a regulated waste company	Jan 25, 2011 2:21 PM
6	Not applicable	Jan 23, 2011 2:07 PM
7	Yes they have the separate provision..	Jan 23, 2011 12:24 PM
8	nano materials are completely encapsulated in polymer and are handled as normal polymer waste	Jan 22, 2011 1:52 PM
9	there is no waste	Jan 20, 2011 10:50 AM
10	Don't know	Jan 15, 2011 11:57 AM
11	We use a disposal service.	Jan 14, 2011 2:03 PM
12	Collect and burn, or collect and chemically degrade nanostructure	Jan 11, 2011 3:16 PM
13	Deep well injection	Jan 11, 2011 2:37 PM
14	yes	Jan 11, 2011 4:44 AM
15	Collects at special waste storage	Jan 11, 2011 1:21 AM
16	DISPOSAL IS HANDLED BY TRAINED ENGINEERS	Jan 10, 2011 11:52 PM
17	that depends: normal trash only if covalently bound	Nov 19, 2010 2:51 PM
18	Through diaposal companies the same as other chemical wastes	Nov 19, 2010 10:51 AM

Page 7, Q2. Are separate disposal containers for nanomaterials used either in the laboratory or in waste storage areas?		
1	NA	Feb 1, 2011 3:45 PM
2	not applicable	Jan 23, 2011 2:07 PM
3	no need	Jan 20, 2011 10:50 AM

Page 8, Q1. Does your organization monitor the work environment for nanoparticles?		
1	Not CS3 per se; not sure about nano labs elsewhere on campus.	Feb 1, 2011 3:46 PM
2	While I was at the company I built up daily logs of particle counts. I believe this has been discontinued.	Jan 25, 2011 2:22 PM
3	not applicable	Jan 23, 2011 2:09 PM
4	no floating particles	Jan 20, 2011 10:51 AM

Page 8, Q2. How frequently do you perform the monitoring of nanoparticles?		
1	NA for CS3, unsure for MSU-wide efforts.	Feb 1, 2011 3:46 PM
2	it was daily.	Jan 25, 2011 2:22 PM
3	Not applicable	Jan 23, 2011 2:09 PM

Page 9, Q1. Do you think there are any special risks associated with the nanomaterials handled or produced in your organization? If yes, what do you think those risk are?		
1	not applicable	Feb 4, 2011 2:50 PM
2	I'm not sure what constitutes a 'special' risk, or distinguishes it from other risks. I suppose the question is more methodological than anything, bearing largely on standards governing the selection criteria for variables used to establish relative risk (see, e.g., http://www.foodproductiondaily.com/content/view/print/355781)	Feb 1, 2011 3:57 PM
3	No - they are all bought liquid suspensions - not particles.	Jan 28, 2011 8:37 PM
4	toxicology, fire and explosion. Metal nanopowders are extremely sensitive to ignition. On toxicology- copper, nickel and cobalt powders were found to be potentailly the most harmful from invitro tests.	Jan 25, 2011 2:25 PM
5	Not applicable	Jan 23, 2011 2:11 PM
6	During development and handling preparation of anticancer drugs	Jan 23, 2011 12:26 PM
7	no	Jan 22, 2011 1:53 PM
8	NO	Jan 20, 2011 10:51 AM
9	Yes. A very light and easy to get into air material. Dangerous if inhaled.	Jan 15, 2011 11:59 AM
10	No, our material is made of silica.	Jan 14, 2011 2:04 PM
11	Not with our technology.	Jan 11, 2011 3:17 PM
12	none as most of them are dispersions effluent treatment plant needs to be monitored as some of the materials are antimicrobials	Jan 11, 2011 4:45 AM
13	LONG TERM RISKS ARE NOT KNOWN	Jan 10, 2011 11:53 PM
14	Only for toxic elements containing particles like CdTe	Nov 19, 2010 10:52 AM

Page 9, Q2. Does your organization perform its own toxicological research?		
1	Not CS3	Feb 1, 2011 3:57 PM
2	We participated in a 4yr programme where we tested 28 different materials for toxicology using invitro tests. Tests were carried out by three different institutes.	Jan 25, 2011 2:25 PM
3	Not applicable	Jan 23, 2011 2:11 PM
4	ALL Natural	Jan 20, 2011 10:51 AM

Page 10, Q1. Is there anything that we have not covered in this questionnaire that you think is relevant and we need to understand and included in this survey?		
1	not applicable	Feb 4, 2011 2:51 PM
2	Nothing beyond which was covered in comments provided earlier. I might suggest including a section on regulation, standards, etc., and how these function together with lab and production/manufacture systems. Many of the considerations identified in your survey have their roots in standards and regulatory organizations and directly affect the direction and conduct of nano-technoscience. Best of luck!	Feb 1, 2011 4:01 PM
3	I believe that there owing to the uncertainty surrounding the hazardous nature of nanopowders minimum standards of protective equipment should be employed in manufacturing plants, environmental monitoring and sampling should be conducted and records kept. These minimu standards would also define what personal protective equipment should be used.	Jan 25, 2011 2:30 PM
4	No great survey	Jan 23, 2011 2:12 PM
5	We do not work with nano materials that are nano-scale before we use them.	Jan 22, 2011 1:54 PM
6	We are unique in the fact we only use Natural nano particles from soy based plants. Alot of your questions were not relevant to us.	Jan 20, 2011 10:52 AM
7	N/A	Jan 15, 2011 11:59 AM
8	Our nanoparticles do not exist by themselves. They have a very strong atraction to other particles. There is a misconception with our technology that nano particles float out of control into the environment. This is incorrect with our technology and we have data to back it up.	Jan 11, 2011 3:18 PM
9	No	Jan 11, 2011 1:22 AM
10	Important ground question is omitted: Do you think Nanomaterials per se present new danger? My answer would be "No". NOrmal atmospheric and room dust contain a lot of nanoparticles of very broad chemistry. It is normal environment fior humans.	Nov 19, 2010 10:56 AM

Page 10, Q2. Can you recommend other organizations that you think we should invite to participate in our survey?		
1	not applicable	Feb 4, 2011 2:51 PM
2	NIST, ANSI-NSP, ISO-TC229, etc.	Feb 1, 2011 4:01 PM
3	no	Jan 23, 2011 2:12 PM
4	Not at this time	Jan 20, 2011 10:52 AM
5	N/A	Jan 15, 2011 11:59 AM
6	quantum materials, Bangalore Tata chemicals, pune	Jan 11, 2011 4:47 AM
7	No	Jan 11, 2011 1:22 AM
8	no	Nov 19, 2010 10:56 AM

APPENDIX B: UCF IRB LETTER

University of Central Florida

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Exempt Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Wanda L. Greaves-Holmes**

Date: **September 29, 2011**

Dear Researcher:

On 9/29/2011, the IRB approved the following activity as human participant research that is exempt from regulation:

Type of Review:	Exempt Determination
Project Title:	A Retrospective Analysis and Field Study of Nanotechnology Related Ergonomic Risks
Investigator:	Wanda L Greaves-Holmes
IRB Number:	SBE-11-07518
Funding Agency:	
Grant Title:	
Research ID:	N/A

This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these changes affect the exempt status of the human research, please contact the IRB. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 09/29/2011 09:14:09 AM EDT

Joanne Muratori

IRB Coordinator

Page 1 of 1

APPENDIX C: INFORMED CONSENT

University of Central Florida

Summary Explanation for Exempt Research

EXPLANATION OF RESEARCH

Title of Project: A Retrospective Analysis and Field Study of Nanotechnology Related Ergonomic Risks

Principal Investigator: Wanda Holmes, Doctoral Graduate Researcher

Other Investigators:

Faculty Supervisor: Dr. Pamela McCauley Bush, Ph.D

You are being invited to take part in a research study. Whether you take part is up to you.

The purpose of this research is to study worker's ergonomics as it relates to the nanomaterials in a manufacturing environment.

While in the factory location, I will utilizing the Borg's Rated Perceived Exertion (RPE) scale, The WISHA outline (for musculoskeletal risks), and The NASA-TLX Scale (for frustration). I want to survey and measure:

- Workers perceived level of physical task exertion
- Workers perceived level of mental demands of the task
- Physically demanding aspects of the task

The expected duration of the participant's participation will be approximately 15 -30 minutes, (the time needed to complete questionnaires, etc.)

You must be 18 years of age or older to take part in this research study.

Study contact for questions about the study or to report a problem: If you have questions, concerns, or complaints talk to Wanda Holmes, Graduate Student, Industrial Engineering Department, by email at wlgh@knights.ucf.edu or 407 620-6202.

IRB contact about your rights in the study or to report a complaint: Research at the University of Central Florida involving human participants is carried out under the oversight of the Institutional Review Board (UCF IRB). This research has been reviewed and approved by the IRB. For information about the rights of people who take part in research, please contact: Institutional Review Board, University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246 or by telephone at (407) 823-2901.

APPENDIX D: CDC NIOSH RECOMMENDATIONS

The following voluntary workplace best practices which may decrease the risk of human exposure to nanomaterials has been are suggested below.

CDC/NIOSH Recommendations for Safe Nanotechnology in the Workplace
Worker Exposure to Nanoparticles

Workers may be exposed by three routes:

- Inhalation — The most common route of exposure is by inhalation.
- Ingestion — Workers can be exposed by unintentional hand-to-mouth transfer of materials or swallowing particles cleared from the respiratory tract.
- Skin — Some studies mention that nanoparticles may penetrate the skin. This possibility is being investigated.

Several factors affect worker exposure to nanoparticles:

- Concentration, duration, and frequency of exposure all affect exposure.
- The ability of nanoparticles to be easily dispersed as a dust (e.g., a powder) or an airborne spray or droplets may result in greater worker exposure.
- Use of protective measures such as engineering controls can reduce worker exposure.

Job-related activities may also influence worker exposure:

- Active handling of nanoparticles as powders in non-enclosed systems pose the greatest risk for inhalation exposure.
- Tasks that generate aerosols of nanoparticles from slurries, suspensions, or solutions pose a potential for inhalation and dermal exposure.
- Cleanup and disposal of nanoparticles may result in exposure if not properly handled.
- Maintenance and cleaning of production systems or dust collection systems may result in exposure if deposited nanoparticles are disturbed.

- Machining, sanding, drilling, or other mechanical disruptions of materials containing nanoparticles may lead to aerosolization of nanoparticles.

Inhalation exposure can occur during additional processing of materials removed from reactors; this processing should be done in fume hoods. In addition, maintenance on reactor parts that may release residual particles in the air should be done in fume hoods. Another process, the synthesis of particles using sol-gel chemistry, should be carried out in ventilated fume hoods or glove boxes. Good work practices will help minimize exposure to nanomaterials: These work practices are consistent with general good laboratory practice.

APPENDIX E: ERGONOMIC RISK FACTORS TO NANO WORKERS

Risk Factors	Author Citations	Study Synopsis
Personal Protective Equipment (PPE) Impact (i.e. gloves)	NIOSH	Suggested best practices guides
Repetition		Absence of data
Force		Absence of data
Posture		Absence of data
Dermal	Toyama, et. al., 2008	Investigates a case toxic epidermal necrolysis-like dermatitis from exposure to dendrimers nanoparticles
Respiratory (inhalation)/ olfactory structure	Song, et. al, 2009	Investigates occupational nanotechnology exposure
Respiratory (inhalation)/ olfactory structure	Boffetta et. al., 2004	Investigated respirable Titanium dioxide (TiO_2) dust exposure
Respiratory (inhalation)/ olfactory structure	Aitken et. al., 2004	Investigates potential occupational risk of engineered nanoparticles
Respiratory (inhalation)/ olfactory structure	Lam, et al 2004	Investigated nanoparticle that are deposited in the respiratory system
Ocular	Huczko & Lange 2001	Investigated limited ocular data in the workplace
Ocular	Bucolo, 2008	Investigated limited ocular data in the workplace
Ingestion	Song, et. al, 2009	Investigates occupational nanotechnology exposure

APPENDIX F: NANOTECHNOLOGY REGIONAL AND GLOBAL MARKET

Country/region	Year	Market	Amount (US dollars except where noted)	Source*
Worldwide	2003	Estimated turnover with nano products	double-digit billion	c
Worldwide	2003	Public research funding	3 billion (est.)	c
Worldwide	2005	Total investment in nanotechnology	5–7 billion (est.)	a
USA	2006	Money spent on nanotechnology	1.2 billion (est.)	a
USA	2008	Nanomaterials market	1.4 billion	a
Worldwide	2008	Global market for nano products	700 billion	b
Worldwide	2008	Global market for nano products	700 billion euro (est.)	d
Worldwide	2010	Estimated turnover with nano products	triple-digit billion	c
Worldwide	2010	Global market for nano products	148 billion (est.)	d
Worldwide	2011	World nanomaterials demand	4.1 billion	a
Worldwide	2015	Estimated turnover with nano products	four-digit billion	c

*Source key:

a. Hannah, W., & Thompson, P. B. (2008). Nanotechnology, risk and the environment: A review. *Journal of Environmental Monitoring, 10*, 291–300.

b. Hassan, E., & Sheehan, J. (2003). Scaling-up nanotechnology. Retrieved from http://www.oecdobserver.org/news/fullstory.php/aid/1005/Scaling-up_nanotechnology.html

c. Hett, A. (2004). Nanotechnology: Small matter, many unknowns. Retrieved from http://media.swissre.com/documents/nanotechnology_small_matter_many_unknowns_en.pdf

d. Luther, W., & Malanowski, N. (2004). Innovations- und Technikanalyse: Nanotechnologie als wirtschaftlicher Wachstumsmarkt. Retrieved from http://www.bmbf.de/pub/nanotech_als_wachstumsmarkt.pdf

APPENDIX G: MATRIX OF RESEARCH

	Research Subjects										
	Occupational disease and injury	Health and enviro impact of nano	Current workplace practices in nano workplace	Research gaps	Studies with ultra-fine particles	Ergonomic issues and nano	Human factors	Actual health ramifications of nano exposure respiratory	Nano product consumer inventory	PPE	Actual health ramifications of nano exposure dermal
Author											
Ashford, 1976	X	X		X							
Dreher, 2004											
ICON, 2006			X								
Iavicoli et al., 2009		X		X							
NIOSH, 2007	X	X	X	X						X	
NIOSH, 2009	X	X	X	X						X	

NSF, 2010	X	X	X	X							
Oberdorster, 1992, 1994, 2005, 2007					X						
Karwowski , 2003						X					
Maynard, 2009	X		X	X							
O'Donnell & Eggemeier, 1986						X					
ISST, 2008	X	X	X	X							
Roco, 2001, 2005& 2007		X	X								
Royal Society & Royal Acad Eng, 2007	X	X	X	X							
Sanders & McCormick, 1993							X				

Song, Li, & Du, 2009											
Toyama et al. 2008								X			
WWICS, Prjct EM Nano, 2009									X		
Tsang, 1997							X				X
University of Illinois, 2008		X						X		X	
Simon , 2010	X	X				X			X		

APPENDIX H: NASA TLX

NASA-TLX Mental Workload Rating Scale

INSTRUCTIONS: Please place an "X" along each scale at the point that best represents the magnitude of each factor in the task you just performed.

Mental Demand: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low High

Physical Demand: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low High

Temporal Demand: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low High

Performance: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low High

Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low High

Frustration: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low High

APPENDIX I: SWOT ANALYSIS

Most organizations are unenthusiastic about disclosing their commercial engineered nanomaterial uses and toxicity data voluntarily. The SWOT Analysis below outlines some of the reasons below.

Table 15. SWOT Analysis of the Ergonomic Ramifications of Nanotechnology

STRENGTHS	**WEAKNESSES**
• Proposed National Nanotechnology Initiative (NNI) budget for fiscal year (FY) 2011 of $1.76 billion, reflecting the consistent, strong support of the United States government • • In fiscal year 2010 requests include $80.44 million for discovery of novel nanoscale and nanostructured materials and improving the comprehensive understanding of the properties of nanomaterials (ranging across length scales and including interface interactions (NSF, 2010) • • The number of nano-related products has grown exponentially over the last twenty years. This fact is confirmed by the vast number of nano-related products produced and marketed as well as the huge monetary amounts dedicated to research and development by governmental agencies worldwide	• Engineered nanomaterials may exhibit higher toxicity due to their size compared to larger particles of similar composition • • Until more definitive information is available on the risks associated with nanomaterials it is advisable that precautionary work practices should be established and followed collectively • • Challenges lies in implementation of a universally safe handling framework in the face of insufficient scientific understanding of the toxic profiles of novel nanoparticle manufacturing and an ever-changing market for products based on these substances • • There have been scores of research from bioengineering, medical, physiological, behavioral, and clinical standpoints, but there is limited information from an occupational or ergonomic perspective

OPPORTUNITIES	THREATS
• Nanotechnology and nanosciences are global technologies that can possible transform the world’s economy and its workforce • • Every aspect of nanotechnology is catching the attention of governments and business organizations worldwide • • Nanotechnology and nanosciences present vast opportunities for economic growth and development in multiple areas. These areas include but are not limited to manufacture of and access to clean water, energy production, medical therapies and diagnostics, agriculture and food production, and information technology • • The number of nano-related products has grown exponentially over the last twenty years. This fact is confirmed by the vast number of nano-related products produced and marketed as well as the huge monetary amounts dedicated to research and development by governmental agencies worldwide • • A scientific approach to the identification, assessment, and mitigation of the risks posed by nanomaterial manufacturing and commercialization will protect the public, the environment and industry, thereby ensuring that the benefits of nanotechnology are shared by all	• Countless studies have illustrated that appropriate universally accepted standards, guidelines, or legislation does not presently exist for nanomanufacturing, handling, and safety utilization of nanomaterials • • Absence of scientific clarity about the potential health effects of occupational exposure to nanoparticles • • The Song et al. (2009) study is a medical case report that claims to provide the first human evidence of “nanomaterial-related disease” following long-term nanoparticle exposure • • Insoluble or low-solubility nanoparticles in biological fluid are the greatest cause for concern for the workforce

Table 16. The California Department of Toxic Substance Control (DTSC) Carbon Nanotube Survey 2010 SWOT Analysis

STRENGTHS	**WEAKNESSES**
• Manipulating materials at the molecular level result in materials that exhibit desired properties, including: increased strength, improved catalysis, improved mechanical properties, improved optical properties, increased electrical conductivity, water remediation, medical innovations and enhanced energy efficiency and storage properties	• Urgent need for extensive ongoing testing for potential ill effects of nanomaterials • Ongoing monitoring needed of all research for potential hazards and abuse • • Nanoscale materials and devices are sensitive to electro static discharges and humidity extremes, and possess explosive properties
OPPORTUNITIES	**THREATS**
• Nanotechnology and nanosciences are global technologies that can possible transform the state of California's economy and its workforce • • The financial aspects of nanotechnology is catching the attention of California government agencies and business organizations worldwide	• Workplaces such as research laboratories, production or operation facilities at which nanomaterials are engineered, processed, used, disposed or recycled are areas of concern because these are areas where workers are initially exposed to nanomaterials • • Currently, guiding principles on personal protective equipment for workers who come in contact with nanomaterials have not been standardized universally • • Manufactured nanoparticles may pose risk to human health due to their composition, size, and ability to cross cell membranes • • Countless studies have illustrated that appropriate universally accepted standards, guidelines, or legislation does not presently exist for nanomanufacturing, handling, and safety utilization of nanomaterials.

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