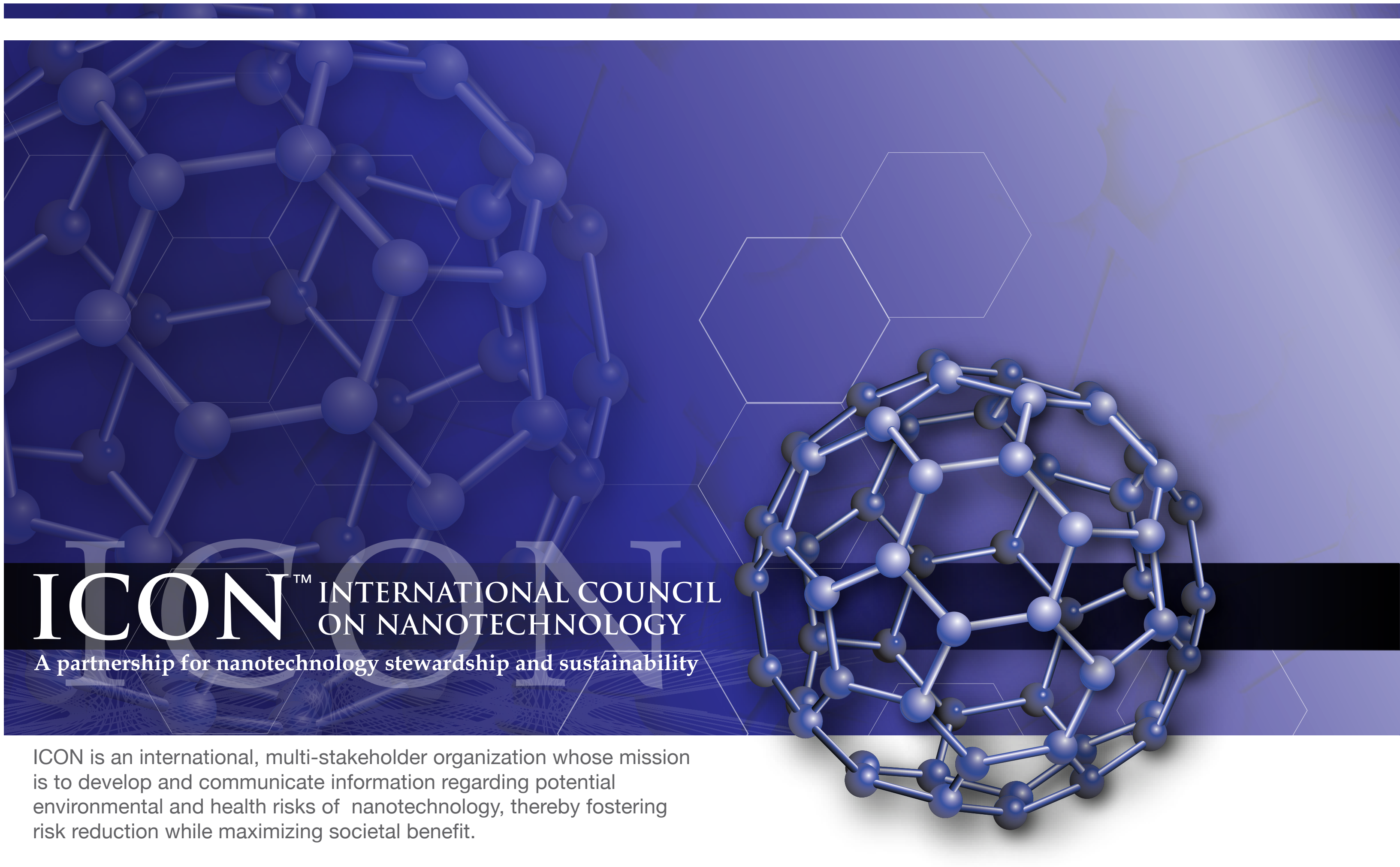

ICON is an international, multi-stakeholder organization whose mission is to develop and communicate information regarding potential environmental and health risks of nanotechnology, thereby fostering risk reduction while maximizing societal benefit.

A Review of Current Practices in the Nanotechnology Industry

PHASE TWO REPORT: SURVEY OF CURRENT PRACTICES IN THE NANOTECHNOLOGY WORKPLACE

Produced for the International Council on Nanotechnology

By the University of California, Santa Barbara
Researchers: Gina Gerritzen, Li-Chin Huang, Keith Killpack, Maria Mircheva, Joseph Conti
Advisors: Dr. Patricia Holden, PI, Dr. Magali Delmas, Co-PI, Dr. Barbara Herr Harthorn, Co-PI, Dr. Rich Appelbaum, Co-PI

November 13, 2006

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I. Executive Summary

This report presents the findings of an international survey of current environmental health and safety (EHS) and product stewardship practices in the global nanotechnology industry. Of the 337 organizations that were invited to participate, 64 companies, research labs, and university labs from four continents responded, which constitutes a response rate of 19%. The survey was administered between June and September, 2006 through telephone interviews and written and web-based surveys. The questionnaire was designed specifically for the study and inquired about current practices related to research, use and manufacture of nanomaterials (< 100 nm size) in the following areas: environmental health and safety training, use of engineering controls, personal protective equipment (PPE) and clothing recommendations, exposure monitoring, waste disposal, product stewardship practices, and risk characterization. All information was self-reported and no direct verification was performed.

In general, surveyed organizations reported that they believe there are special risks related to the nanomaterials they work with, that they are implementing nano-specific EHS programs and that they are actively seeking additional information on how to best handle nanomaterials. Actual reported EHS practices, however, including selection of engineering controls, PPE, cleanup methods, and waste management, do not significantly depart from conventional safety practices for handling chemicals. This is the primary finding of this report. In fact, practices were occasionally described as based upon the properties of the bulk form or the solvent carrier and not specifically on the properties of the nanomaterial. Additionally, few organizations reported monitoring the workplace for nanoparticles or providing formal guidance to downstream users on the safe disposal of nanomaterials. When asked, organizations generally recommended disposal of nano-products as hazardous waste, though they did not frequently report conveying this information to their customers. Reported practices in the handling of nanomaterials, with some exceptions, are based on criteria unrelated to any perceived risks stemming specifically from working with nano-scale materials. The “by-default” use of conventional practices for handling nanomaterials appears to stem from a lack of information on the toxicological properties of nanomaterials and nascent regulatory guidance on EHS practices. Indeed, most organizations reported that the biggest impediment to improving their nano-specific EHS program is a lack of information and nearly half of the organizations that reported implementing a nano-specific EHS program described it as a precaution against unknown hazards. Organizations reported seeking new information from scientific literature and governmental guidelines for help in assessing the risks related to their nanomaterials and the appropriate steps that should be taken to address them. This suggests that there is a strong demand for both more toxicological research on nanomaterials and additional industry and governmental guidance in risk assessment and EHS practices.

The relative dearth of regulatory guidance and uncertain risks associated with nanomaterials may contribute to the significant variance reported in EHS practices amongst organizational type and size. Nano-specific EHS programs and training were more often reported by organizations that have been working with nanomaterials longer, have more employees handling nanomaterials, and who believe there are risks related to their nanomaterials. Larger organizations that handle a number of different nanomaterials in a variety of phases and engage in a variety of nano-related operations reported the use of all engineering controls in higher numbers, and in particular cleanrooms, separate HVAC systems for lab areas, and closed piping systems. Smaller companies more frequently reported using "disposable" PPE, such as dust masks, disposable body coverings, and lower cost controls such as respirators, as well as glove boxes and glove bags. The organizations that indicated that either part or all of their nanomaterial operations are enclosed to prevent worker exposure were mostly companies rather than academic or purely research labs. While most organizations acknowledged that toxicological data on nanomaterials are needed, university labs specifically reported cost concerns and a lack of prioritization of EHS practices as the most significant impediments.

In addition to organizational type and size, there appear to be geographical variations in reported practices. North American organizations more frequently reported administering nano-specific EHS programs including training, and monitoring the work environment than organizations in other parts of the world. Similarly, North American organizations more often reported using high capital cost engineering controls such as cleanrooms, closed piping systems and separate HVAC systems, compared to organizations from Asia that indicated more widespread use of glove boxes, glove bags and respirators. More than European organizations, North American and Asian organizations reported that a lack of information is the primary impediment to improving nano-specific EHS. On the other hand, a relatively higher percentage of European organizations reported either conducting or funding toxicological research. In addition, respondents in Europe and Australia more frequently reported thinking that there are specific risks related to the nanomaterials they handle.

Few reported EHS practices appear to be determined solely by type and amount of nanomaterial handled. However, dust masks are reportedly widely used with nanopowders, while fume hoods are reportedly less frequently used with nanopowders because they can result in a loss of expensive material through ventilation. Very few organizations reported monitoring the workplace for nanoparticles, although those that handle larger volumes of nanomaterials are more likely to do so.

This project identified current practices in the nanotechnology workplace for a subset of nanomaterial organizations worldwide. The findings should be of great value for the continuing development of “best practices” in nanomaterial safety, disposal and product stewardship, as well as a basis for ongoing research. However, independent verification of self-reported practices was not performed, and thus future research to determine actual workplace safety and product stewardship practices in the nanomaterials industry should incorporate additional steps such as site visits. Additionally, this project did not consider practices beyond the research lab or manufacturing facility, such as consumer and waste management practices. To address practices used throughout the full life-cycle of nanomaterials including the products in which they are used, future research should include interviews and site visits with waste management companies and nanomaterials customers. Such approaches will become increasingly important as the volume of products containing nanomaterials reaching consumer markets continues to rise.

II. Introduction

Nanotechnology is the understanding and control of engineered materials at dimensions of 1 to 100 nanometers, i.e. at the "nanoscale".[1] Nanomaterials are designed to exhibit novel or enhanced properties that affect their physical and chemical behavior, in effect presenting opportunities to create new and better products. Consequently, nanotechnology has the potential to make significant contributions to many fields from semiconductors to biotechnology to energy, transportation, agriculture and consumer products. Nanomaterials currently are being used in the manufacture of cosmetics, clothing, sports equipment, coatings, and electronics. It is estimated that global sales of nanomaterials could exceed $1 trillion by 2015.[2]

However, nanotechnology also presents new challenges for measuring, monitoring, managing, and minimizing contaminants in the workplace and the environment. The properties for which novel nanoscale materials are designed may generate new risks to workers, consumers, the public, and the environment. While some of these risks can be anticipated from experiences with other synthetic chemicals and with existing knowledge of ambient and manufactured fine particles, novel risks associated with new properties cannot easily be anticipated based on existing data. In the absence of specific information concerning risks and hazards associated with new nanomaterials, nanotechnological manufacturing industries may be implementing workplace safety and product stewardship practices that are both inspired by existing knowledge and, in some cases, are in response to anticipated hazards. Such practices could lay the foundation for industry standards, either voluntary or regulated. A survey of current practices is critical for both assessing the maturity of practice development and for communicating practices throughout the many nanotechnological sectors.

In response to the need for a consolidated understanding of current health, environmental, and stewardship practices in nanomaterial manufacturing, the International Council on Nanotechnology (ICON) issued a request for proposals (RFP) in December 2005 for the performance of a survey of current practices. Subsequently, an interdisciplinary team of researchers at the University of California at Santa Barbara (UCSB) was selected to perform this study in two phases. In the first phase, the goal was to describe existing and planned efforts to discover and summarize current industrial practices in workplace safety, environmental protection and product stewardship.[3] In the second phase of research, the subject of this report, the charge was to survey the global nanotechnology industry about current practices in environmental, health and safety, waste handling, risk management, monitoring, and product stewardship. This study begins to fill the strong need for a global

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[1] National Nanotechnology Initiative (NNI). "What is Nanotechnology?" <http://www.nano.gov/html/facts/whatIsNano.html>. June 21, 2006.

[2] Roco, M.C. "Overview of the National Nanotechnology Initiative." Presentation to the National Research Council on March 23, 2005. <http://www.nsf.gov/crssprgm/nano/reports/nni_05-0323_nset@nrc.pdf >. June 11, 2006.

[3] Gerritzen, G., Huang. L, Killpack, K., Mircheva, M., Conti, J., Magali, D., Harthorn, B.H., Appelbaum, R.P. and Patricia Holden. 2006. A Report to ICON: "Review of Safety Practices in the Nanotechnology Industry." University of California, Santa Barbara.

review and analysis of nanomaterial safety practices in order to aid the development of effective safety standards.

This Phase Two Report presents the findings of an international survey of sixty-four organizations in the nanotechnology industry from four continents on current EHS and product stewardship practices. The report begins with an overview of the specific methodologies used for collecting data. The findings of the survey are then analyzed, focusing on trends in practices across organizational type and region, trends in practices based on material type and scale of production, trends in the uses of engineering controls and personal protective equipment, and significant gaps in safety practices. This is followed by a discussion of key findings as a broad depiction of current EHS and product stewardship practices in the nanotechnology industry. The report concludes with consideration of the limitations of this research and offers suggestions for follow-up research.

III. Methodology

Survey Instrument and Administration

A questionnaire (Appendix A) was developed to survey nanotechnology organizations worldwide to learn about current practices in nanomaterials handling in the workplace, worker safety and product stewardship. The questionnaire was organized around several question categories: respondent information, organization information, EHS programs, engineering controls, personal protective equipment (PPE), waste management, workplace monitoring, risk characterization and product stewardship. The choice of question categories, and to some degree question content, was informed by consulting with nanomaterials experts in industry and government, reviewing previous instruments that were publicly available, and benchmarking to the original goals of the project. For each question category, goals in questioning were defined, and questions were created in response to those goals. A spreadsheet (Appendix B) facilitated development of questions most closely-aligned with the stated goals. The spreadsheet is organized by survey question, and states the purpose of each question, expectations for the types of answers (e.g., yes/no, a number or range of numbers, a position title), the format of the answer (e.g., categorical, open ended), and the information expected from the answers. This approach enabled streamlining the questionnaire while ensuring goals were met.

The questionnaire contains both structured and unstructured questions. Unstructured questions were preferred where responses either were expected to be conversational or were not easily pre-defined. For example, identifying the best ways to categorize the organizations working with nanomaterials and the various types of nanomaterials proved challenging during the questionnaire development. Nanotechnology is a new commercial, as well as scientific research, field. Many organizations, in addition to performing in-house research, do business in many economic sectors and frequently are involved with a variety of nanomaterial applications important for many industries. In addition, nanomaterial types are not easily categorized, and new terms for nanomaterials were discovered throughout this study. The efforts of the National Institute of Occupational Safety and Health (NIOSH) to develop the Nanoparticle Information Library[4] and the Woodrow Wilson Center's Inventory of Nanotechnology Environment Health and Safety[5] attest to the multiplicity of nanomaterials and their applications. The lack of a developed nomenclature and the diversity of nanomaterials and nanotechnology organizations posed problems for constructing a concise interview instrument that would efficiently solicit information about EHS practices contextualized by the specific type of nanomaterials and their applications. That is why the survey instrument included unstructured (open-ended) questions that permitted respondents to self-identify the industries within which they work and the particular nanomaterials they handle. For instance, instead of a long list of potential types of nanoparticles, respondents were simply asked to describe the materials with which they work.

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[4] National Institute for Occupational Safety and Health. "Nanoparticle Information Library." <http://www2a.cdc.gov/niosh-nil/>. June 1, 2006.

[5] Project on Emerging Nanotechnologies. 2006. <http://www.nanotechproject.org/>. October 1, 2006.

The draft questionnaire was pre-tested internally at UCSB and externally with two members of industry. In addition, the questionnaire was reviewed by NIOSH and ICON. The final instrument reflects feedback from these pre-tests and reviews and was ultimately approved by ICON prior to the start of interviewing. During the period of June through mid-September 2006, surveys were administered by four methods: oral telephone interviews, written responses, web-based survey, and translated written responses provided through a third-party.

To elicit a higher response rate in Asia, the survey was translated into Chinese and Japanese. Chinese companies were solicited for participation through emails in Chinese, and telephone interviews were conducted in Chinese by a research team member. During the period of data analysis and writing of this report, 17 additional completed questionnaires were returned to the UCSB researchers through a third party in China. Since these data were submitted late, were collected outside of either UCSB or ICON, and were obtained from one geographically-consolidated pool of respondents in China, the results are included in a separate Appendix B of this report. An ICON member from Japan translated the survey instrument into Japanese and distributed it through the Nanotechnology Business Creation Initiative (NBCI) to 25 local companies in Japan. Subsequently, the Japanese responses were translated into English by the same ICON member.

Four USCB researchers administered the telephone interviews. Most telephone interviews were audio-recorded, although two organizations requested that the call not be recorded. Multiple researchers participated in the initial telephone interviews, with one researcher administering the survey and others monitoring the conversation while taking notes. This interview mechanism proved invaluable for quality and training purposes to ensure consistency across interviews. Following the interview, the audio recording was used to complete the interview notes, which then were entered into the web-based archive. Only one significant change was made to the questionnaire after the start of interviewing: Question 18b, which specifically asks how nanomaterial waste is disposed, was added after seven interviews had been performed because this critical information was not being adequately captured by the other questions.

A web-based survey was developed as an alternative to the telephone interview. It was anticipated that a web-based survey would increase the response rate by providing a potentially more convenient means of participation for some respondents. The web-based survey was modeled with the intent of reproducing the telephone interview using the developed questionnaire. Respondents also were allowed the option of filling out a written survey upon request, although this particular means of collecting responses was not routinely offered and was used only at the respondent’s request. The written survey format proved useful in a few instances when multiple employees representing an organization were unable to coordinate a time to conduct a telephone interview.

Participant Development

Participants were developed from within the nanomaterials industry, including academia, research institutions, and manufacturing, with a major emphasis on the latter. The 337 possible subjects for the participant pool were identified using several sources. The Best Practices Subcommittee of ICON provided an initial contact list including 60 potential participants with contact information. Fifteen of those contacts were pre-contacted by an

ICON member regarding participation. As described above, 25 contacts were within the NBCI in Japan, and were developed by an ICON member. A majority of the organizations contacted were companies (282). Twenty five research labs and nineteen university labs were contacted worldwide.

Most prospective participants (252) for this research were mined from nano-related websites, articles, personal referrals, lists of conference participants and sponsors, nanotech news briefs, and internet search engine searches. Contacts obtained through the internet were the largest contributor to the list of potential participants. Sources used from the internet included, but were not limited to:

- *Conference abstracts.* Attendees and sponsors of several conferences were mined for potential participants, including Commercialization of NanoMaterials 2006,[6] NanoTX '06,[7] Nano & Bio in Society 2006 conferences[8] and the Lux Executive Summit '06[9].
- *Nanotechnology news briefs.* These were provided through email subscriptions to several outlets including Meridian Nanotechnology Development News,[10] Foresight Nanotech Weekly News Digest,[11] and ICON news[12].
- *Nanotechnology organization websites*. Websites such as NSTI,[13] Nanotechnology Now[14] and NanoVIP[15] provided lists of nanotechnology companies and links to their websites. To identify companies in Taiwan and China, several websites were used including the National Science and Technology Program for Nanoscience and Nanotechnology[16] and "Nano Pioneers."[17]

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[6] Commercialization of NanoMaterials 2006. TMS 2006. <http://www.tms.org/Meetings/Specialty/nano06/home.html> May 2006.

[7] nanoTX '06 <http://www.nanotx.biz/> June 2006.

[8] Nano & Bio in Society Conferences. NABIS 2006. <http://www.nabisconference.com/2006/> June 2006.

[9] Lux Executive Summit: Commercializing Nanotechnology. Lux Research, Inc. 2006. <http://www.luxexecutivesummit.com/Speakers/Speakers.php?spkr_id=thomas_theis> June 2006.

[10] Meridian Institute. Nanotechnology and Development News. 2006. <http://www.merid.org/NDN/> June 2006.

[11] Foresight Nanotech Insitute. Email List. 2006. < http://www.foresight.org/> October 2006.

[12] International Council on Nanotechnology. News Summaries. 2006. <http://icon.rice.edu/newssummaries.cfm> October 2006.

[13] Nanotechnology Company Directory. Nano Science and Technology Institute. 2006. <http://www.nsti.org/companies> July 2006.

[14] Nanotechnology Business Programs. Nanotechnology Now. 2006. <http://www.nanotech-now.com/business.htm> May 2006.

[15] NanoVIP Members List. Nanovip.com. 2006. <http://www.nanovip.com/forums/memberlist.php?> June 2006.

[16] National Science and Technology Program for Nanoscience and Nanotechnology. 2006. <http://nano-taiwan.sinica.edu.tw/newsbig5.asp> June 2006.

Participants were identified through a stratified purposive sampling frame, based on the identification of organizations in the nanotechnology industry by region. Initially, it was anticipated that participants would be solicited through referrals generated during the interview process, generating a “snowball” or chain sample pool.[18] In the end, 33 new and unique contacts were identified through this method, but of these only four resulted in participation. Furthermore, two organizations voluntarily contacted the research team regarding participation.

Participants were solicited primarily through email but, in some cases, telephone conversations with prospective participants were required prior to the actual interview in order to better explain the process and to secure participation. Potential participants were sent an email invitation to participate (Appendix D), accompanied by three documents. This included a letter of support from ICON (Appendix E), a letter of invitation from the University of California at Santa Barbara (Appendix F), and a one-page summary of the project, project scope, and goals (Appendix G). If the prospective participant did not respond to the initial email, another invitation was emailed one to two weeks later with the letter of support from ICON. In the event that the contact did not respond to either of these emails, they were emailed an invitation to participate using the web-based survey. If no response was received to any of the prior invitations, a final email invitation for participation in the web-based survey was sent one to two weeks later.

At the beginning of the survey period, invitations were mainly sent to European organizations due to the fact that many employees take vacation during August. Ultimately, this was not an issue because a slight majority of the European participants were interviewed in the month of August, 2006. In addition, contacts in all countries seemed to have many individuals taking vacations in August.

Human Subjects Requirements, Consent and Issues of Confidentiality

The survey was administered in compliance with regulations for safe and ethical research mandated by the State of California and United States federal laws and maintained by the Office of Research at the University of California, Santa Barbara. This included certification that each participant was informed of their rights as research participants. The form used to document the informed consent of participants in telephone interviews is attached in Appendix H.

Based on conversations with ICON and with individuals working within the nanotechnology industry, the research team anticipated that the confidentiality of information disclosed during interviews would be of paramount concern for participants. To address this, the research team, in consultation with ICON, developed an internal protocol for ensuring the confidentiality of all information disclosed as a part of the research. This protocol included rules and procedures to communicate with research participants, collect data, transmit participant information within the research team, store electronic data files containing,

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[17] “Nano Pioneers.” 2006. <www.nano.com.tw> July 2006.

[18] Biernacki, Patrick and Dan Waldorf. 1981. "Snowball Sampling: Problems and Techniques of Chain Referral Sampling." *Sociological Methods and Research* 10:2, 141-63.

aggregate raw data to protect the identity of participants in the final report, dispose of data at the conclusion of the project, and develop protocols to address any potential breaches of confidentiality. The confidentiality protocol is attached in Appendix I. The use of a non-disclosure agreement was discussed with ICON, but ultimately was not employed for this research since it was not requested by any respondent. In fact, very few actual and potential participants seemed strongly concerned about confidentiality; however, there were a significant number of non-responses to the interview invitation and the research process was not designed to discover the reasons, whether confidentiality-related or other, for those non-responses. The need for a non-disclosure agreement may have been precluded by the content of the questions (i.e., not requesting proprietary information) as well as the content of pre-contact documents and the pre-interview statements of confidentiality, which were intended to improve participants' confidence in the security of this process.

Included in the final data were responses from fourteen Japanese participants whose interviews were administered by an ICON member, outside of the UCSB research team, using the questionnaire developed by UCSB. While the results of these interviews were examined in the final reporting, the inclusion of this data implied neither informed consent of the third-party participants nor confidentiality of the respondents provided during the period preceding data transmittal to UCSB.

Data Analysis

All responses initially were organized into a database by question number. As indicated above, to protect the confidentiality of the participants, all identifying information was stripped from the responses prior to aggregation by question. Data analysis began by first generating descriptive statistics for each question. If the question was open-ended, the responses were coded based on dominant categories identified in the data. Each question was analyzed based on all responses provided, and in many cases the results were graphed. In addition, responses were examined for biases due to different means of data collection, and potential biases were recorded. Therefore, each response was identified by its origin – interview, web-survey or third-party administration, and each group of responses was compared to one another. Analyses then were performed using responses from multiple questions to uncover patterns that may exist based on factors, such as geographic location of the organization, organization size and age, nano-division size and age, and types of materials handled. These findings are reported in the results section.

Due to the small sample size, causal analyses such as regressions were not performed on this data set. The data set is non-probabilistic i.e., not a random sample, since participants volunteered participation and were not selected at random.

Incomplete responses were not included in the data analysis. A response was considered incomplete if the respondent did not answer a question beyond Section 3 of the survey. Sixteen incomplete web-based survey responses were discarded. One telephone interview was excluded from the results on the same basis. Another telephone interview was discarded because the respondent's organization did not handle materials smaller than 100 nanometers. This was selected as a criterion for participation based on the generally accepted size range of 1-100 nm as defining the nano scale.

IV. Results

Sample Characteristics

Geographic Location of Contacts and Respondents

Of the 337 organizations contacted, 64 responded to the survey for an overall response rate of 19% (Table 1). The response rate was highest in Asia (30%), while the response rates in the North America and Europe were similar (14% and 16%, respectively). The higher response rate in Asia was due primarily to the assistance of a Japanese ICON member who translated and distributed the survey through the Nanotech Business Creation Initiative (NBCI) to 25 Japanese companies. Of these 25 Japanese organizations, 14 completed the survey, which constituted a response rate of over 50%. The response rate of our Asian contacts outside of NBCI was only 20%. Therefore, the high response rate in Asia was due to the organizations' familiarity with NBCI. This stresses the importance of familiarity for obtaining a high response rate in any region. In addition, eight Australian organizations were contacted; of these, three Australian organizations participated producing a response rate of 38%.

Table 1: Response rate by geographic location

# Contacted	# Respondents	Response Rate (%)	Region of Origin
178	25	14%	**North America**
82	25	30%	**Asia**
69	11	16%	**EU**
8	3	38%	**Australia**
337	64	19%	**Total Contacts**

Origin of Contact for Respondents

Of the 64 respondents:

- Twenty seven were obtained through direct contact by UCSB, based on contact information derived from diverse sources including web searches, nano-industry web pages, and nano news briefs as described above.
- Fourteen were obtained through the NBCI
- Thirteen were referrals provided by members of ICON
- Four were ICON members
- Four were referred by other participants
- Two voluntarily contacted UCSB to participate

Organizations that Declined to Participate

Although 284 of the contacted organizations did not participate in the research, only 68 organizations overtly declined to participate. The remainder (216) did not respond to invitations to participate. Of the 68 declinations, 11 refusals resulted from the lack of manufacturing or application of nanomaterials. Three organizations stated they lacked the resources to participate. Two organizations believed their EHS program was not sufficiently developed to share. Due to some confusion with another UCSB research project being conducted in Asia at the same time, two respondents believed they had already participated in this study. In a phone call, one contact expressed fear that this research would lead to unnecessary regulation of the industry. Another potential respondent refused to participate because the wording in the survey did not distinguish between nanomaterials and fine or ultrafine particles. This particular concern was primarily about nomenclature and the possibility that the organization would be wrongly categorized as a nanotechnology organization. The remaining 38 contacts did not state a reason for declining to participate.

Methods of Data Collection: Sample Bias and Response Rate

Data were collected from respondents via three main methods: oral telephone interviews, web-based and/or written surveys, and surveys administered by a third-party. Two surveys were collected using a combination of the above methods. Consequently, data were analyzed for sample bias based on the survey administration method. In general, written/web-based surveys and surveys administered by a third-party indicated a greater non-response rate than those administered over the telephone. In addition, with written/web-based and third-party surveys unlike oral surveys, there is no opportunity to probe interviewees, or request clarification on responses, thus resulting in less detailed and sometimes unclear responses. For instance, one third-party respondent, when asked about recommended PPE for working with nanomaterials, simply stated “special clothing” and “skin gloves.” There was no opportunity to request clarification for such responses, such as there would have been if the interview were administered either over the telephone or in person. In summary, responses provided for non-verbal surveys were less detailed and had higher non-response rates than those from telephone interviews.

Summary of Sample Characteristics

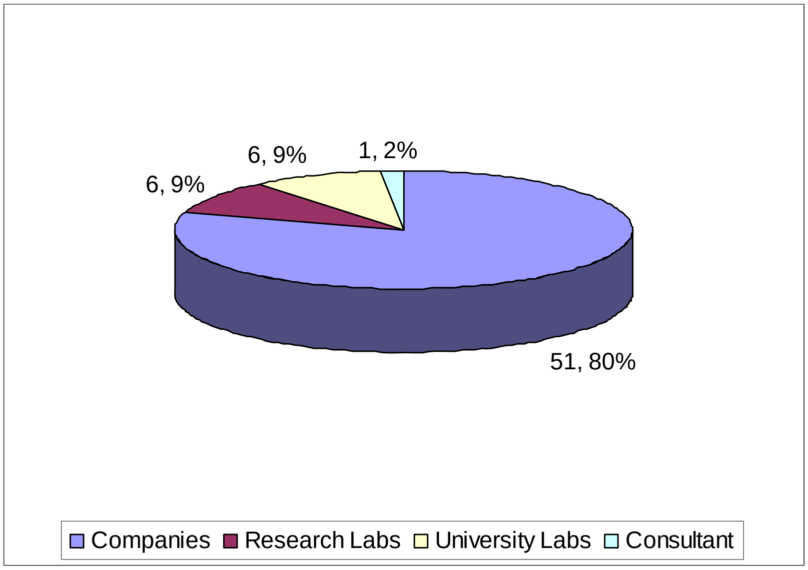
The majority of surveyed organizations were companies that handle nanomaterials. Most of the job titles and responsibilities of individuals representing organizations could be classified as management, EHS-related, or scientist. Management was the largest represented segment of these categories. Organizations handled diverse types of nanomaterials, with nanopowders, carbon nanotubes, and colloidal dispersions being the most frequently cited. Most of the respondents described handling nanomaterials as a dry powder only or as both a dry powder and in suspension.

Respondent Characteristics

Types of Respondent Organizations

A large majority of the respondents (80%) was from private sector companies (Figure 1). This category included for-profit entities that were developing or had developed a product involving nanomaterials. An equal share of research and university labs (9% each) also participated. Research labs were characterized as being non-academic organizations involved in nanomaterials research and funded either by the government or private sources. University labs are research organizations within university settings. In addition, one consultant who specialized in the nanotechnology industry was interviewed.

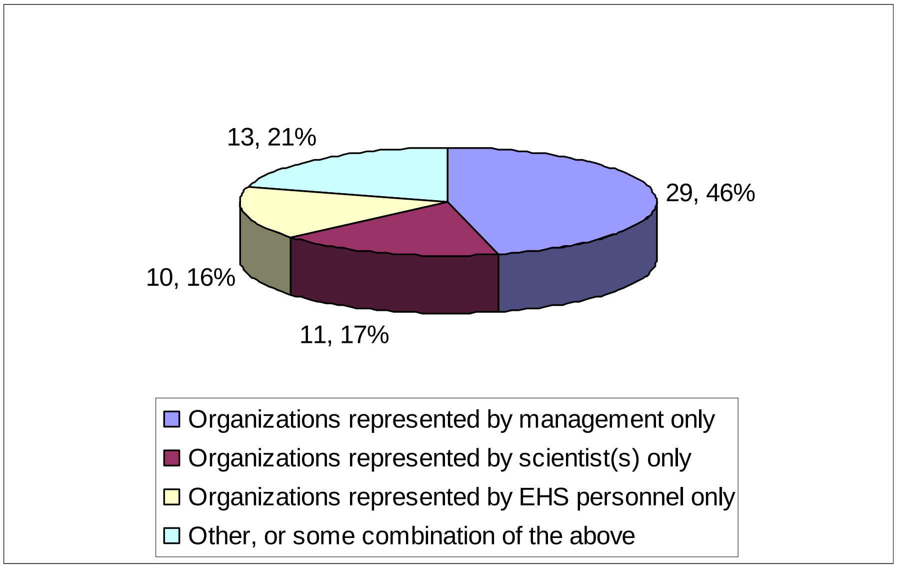
Figure 1: Types of responding organizations



Job Titles of Respondents

Respondent organizations were represented in interviews of one to five representatives. While the unit of analysis was the organization, an organization could select as many representatives as it deemed necessary to participate in the interview. These representatives were classified into at least one of three categories based upon job title and job responsibilities. These categories included executive administration or management, scientists who were involved in nanomaterials research, and EHS personnel (including industrial hygienists). Of the respondent organizations, 46% were represented by executive administration or management (Figure 2), 17% were represented by scientists, and 16% were represented by EHS personnel. In addition, 21% of organizations were represented by an “other” category, which included consultants and a combination of the above mentioned three categories.

Figure 2: Roles of respondents based upon job titles and responsibilities



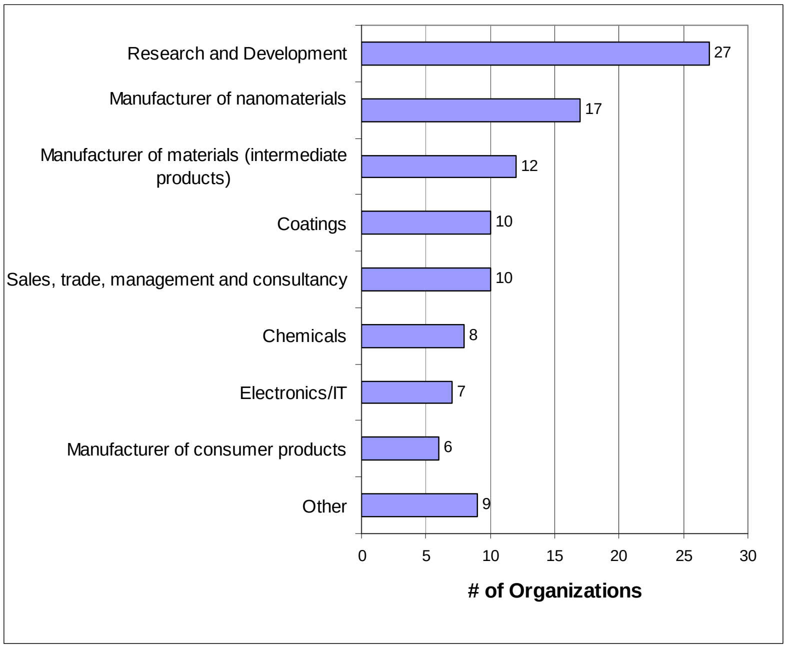
Business Description of Participating Organizations

The survey contained two questions about the business activities of participating organizations. The first was an open-ended question requesting the line of business of the participant companies, since nanotechnology lines of business were not clearly delineated. Based on the responses, eight business categories were identified, which were not mutually exclusive such that an organization may fall into multiple categories. The categories were:

- Research and Development of nanomaterials, which included organizations involved in research only and toxicological research.
- Manufacturer of nanomaterials. For instance, manufacture of metal oxides, carbon nanotubes, fullerenes or others.
- Manufacturer of materials such as plastics, textiles, and ceramics.
- Manufacturer of consumer products such as cosmetics and appliances.
- Electronics/Information Technology mostly referred to producers of electronic components.
- Chemicals.
- Coatings.
- Sales, trade, management and consultancy organizations.
- The “Other” category included developing nanotechnology measurements and standards, manufacturing technologies, environmental remediation and various applications.

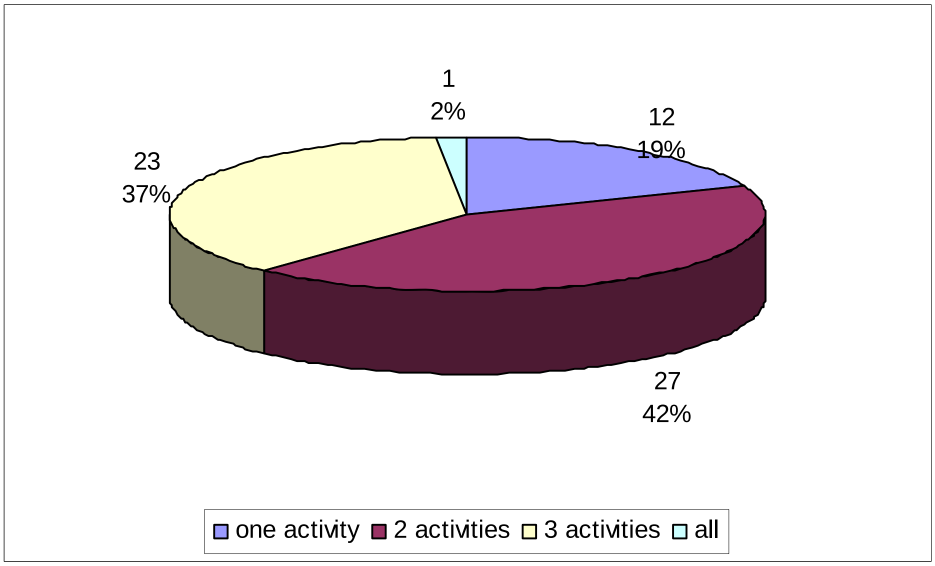
Most respondents (27) indicated that they were involved in R&D, followed by nanomaterial manufacturing (17), and then various categories of applications (Figure 3).

Figure 3: Respondent business description



A second question asked participant organizations to describe their business as it related specifically to nanomaterials: were they a manufacturer, user, and/or researcher and developer of nanomaterials? Over 90% of the respondents indicated they were involved in R&D activities related to nanomaterials, while 67% used or applied nanomaterials and 56% manufactured nanomaterials (Figure 4). In addition, four respondents (6%) were involved in other activities such as consulting, supply and oversight of the nanotechnology industry. These activities were not mutually exclusive and, in fact, 81% of the respondents were involved in more than one of the three activities.

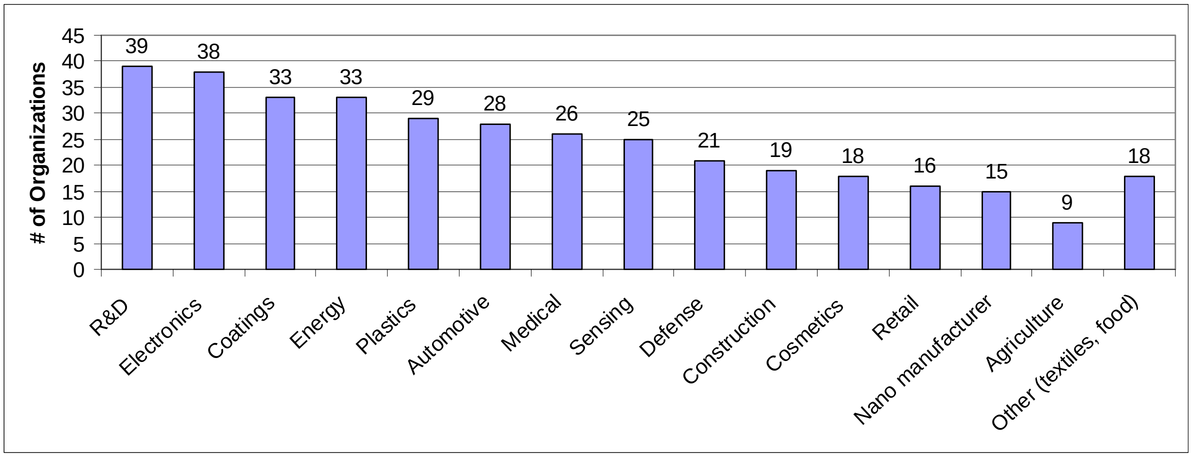
Figure 4: Number of nanomaterial-related activities per respondent – manufacturing, use/application, R&D, and other



Respondent Customer Industries

Respondent customers operated in a number of different industries (Figure 5). On average, respondents maintained customers in six different industries. The most common customer industries included R&D, electronics, energy, coatings, plastics, automotive, and medical.

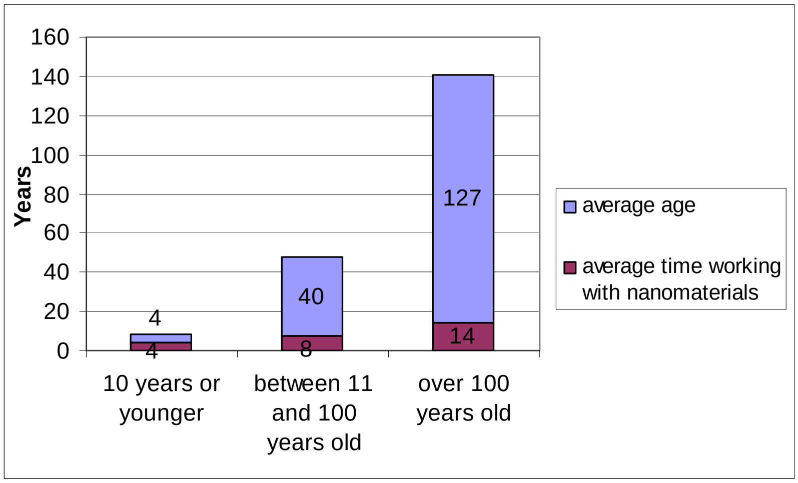
Figure 5: Industries of respondents' nanomaterial customers



Age of Respondent Organizations and Duration of Involvement with Nanotechnology

Most of the responding organizations (56%) were less than ten years old. However, the survey sample also included organizations between 11 and 100 years old (30%) and organizations over 100 years old (14%). Despite the differences in age, most respondents (86%) indicated they had been working with nanomaterials for less than 10 years. About 44% of the respondents had been working with nanomaterials since the inception of their organization, and all but two had existed for less than 10 years. While the average time working with nanomaterials generally increased with age of the company, this trend was not particularly strong (Figure 6). For organizations ten years old or less, the average time working with nanomaterials (4.2 years) was almost as much as the average age (4.4 years). For organizations between 11 and 100 years old, the average time working with nanomaterials was eight years while the average age was 40 years. The difference was greatest in organizations over 100 years old, where the average age was 127 years and the average time working with nanomaterials was 14 years.

Figure 6: Age of respondent and length of time working with nanomaterials



Geographic Location of Respondents

Headquarter locations of the respondents were located in 14 different countries on four continents. Only seven respondents had one or more location where nanomaterials were handled (nanomaterial activity) in a country different from their headquarter location (Table 2).

Table 2: Country location of headquarters vs. nano-lab locations of respondents

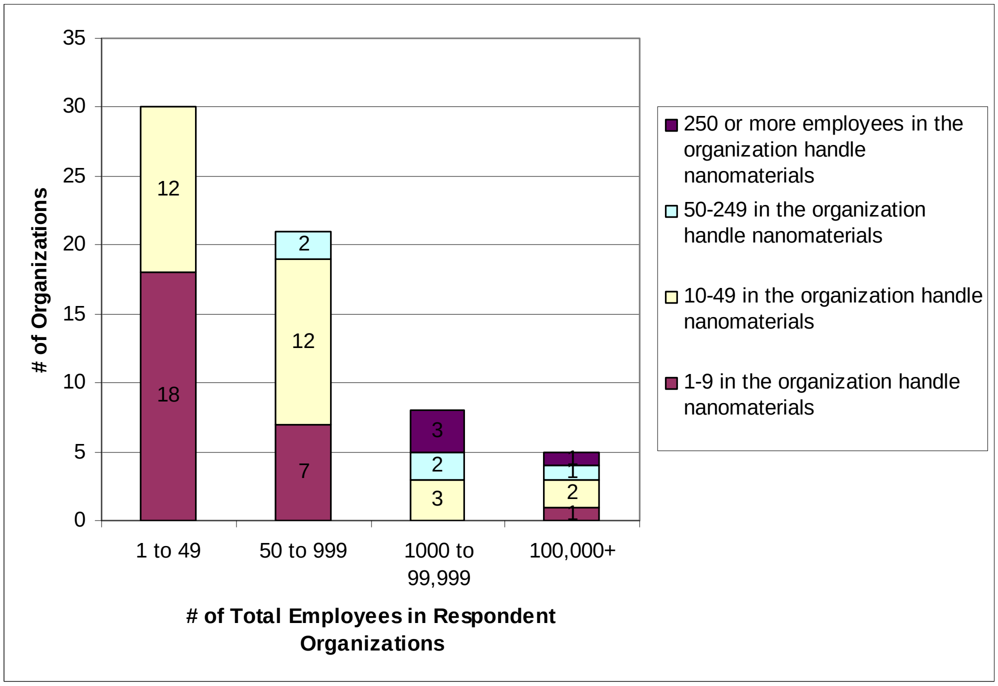
Region or Country	Headquarters (#)	Nanomaterial Activity (#)
United States	25	25
North America Total	**25**	**25**
Japan	15	15
China	3	6
India	3	3
Taiwan	3	3
Hong Kong	1	2
Israel	0	1
Asia Total	**25**	**30**
Switzerland	2	4
United Kingdom	4	4
Germany	3	3
Ireland	0	1
Belgium	1	1
France	1	1
Unidentified European country	0	1
Europe Total	**11**	**15**
Australia	**3**	**3**
Grand Total	**64**	**73**

Size of Respondent Organizations

Most of the participant organizations were small in size. Thirty organizations had one to 49 employees and twenty one had 50 to 999 employees. However, some large organizations participated in the survey as well – eight reported 1,000 to 99,999 employees and five had more than 100,000 employees.

A majority of the organizations had fewer than 50 employees handling nanomaterials, whereas 26 had one to nine employees and 29 had 10 to 49 employees handling nanomaterials. Only four of the respondents had more than 250 employees handling nanomaterials. Although larger organizations had many employees, only a small percentage of them handled nanomaterials (Figure 7). Of the organizations with more than 100,000 employees, one had 1-9 employees handling nanomaterials, two had 10 to 49, one had 50 to 250 and only one had 250 or more employees handling nanomaterials.

Figure 7: Total number of employees compared with number of employees handling nanomaterials

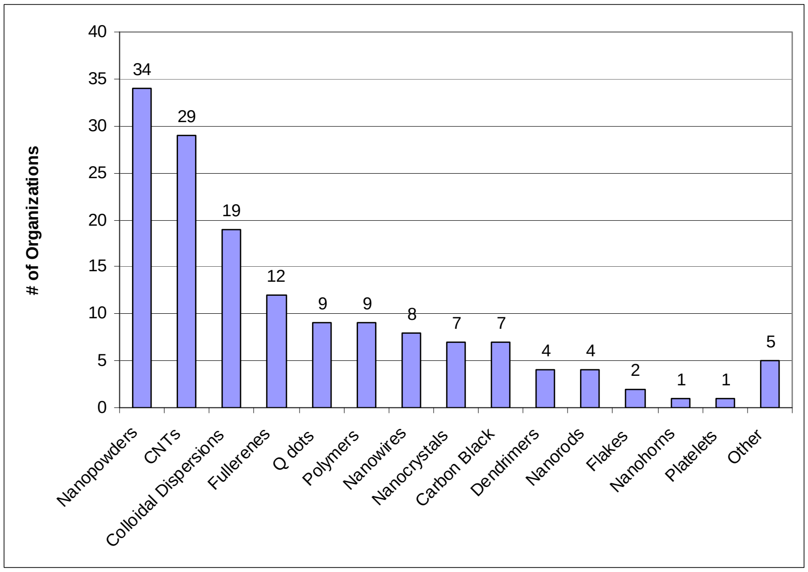


Respondent Description of Nanomaterials

Respondents were asked to describe the nanomaterials that were handled or produced at their organization. Respondents were provided with the categories in Figure 8. Occasionally, the issue of differences in nomenclature used to describe the forms of nanomaterials was raised during interviews. These questions were resolved through discussion, but this emphasizes the lack of standardized nomenclature.

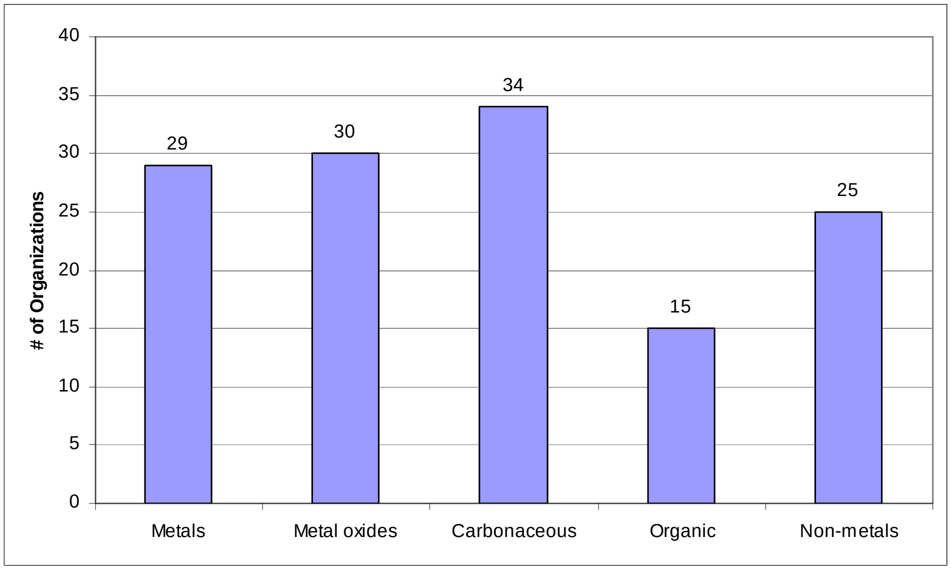
Almost all (61) respondents provided data describing the form(s) of nanomaterials handled or produced at their organization. The most commonly handled or produced forms were nanopowders (34), carbon nanotubes (29), and colloidal dispersions (19).

Figure 8: Number of respondents handling various types of nanomaterials



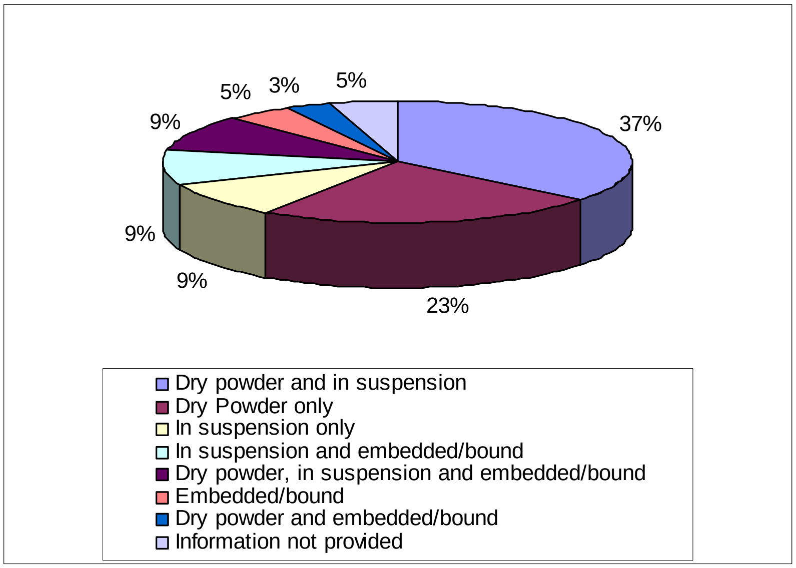
Furthermore, respondents were asked to describe the elemental constituents of the nanomaterials handled or produced at their organization (Figure 9). Responses were provided as elemental or molecular compounds and were categorized as metals (pure metals or metal containing molecules, but not including metal oxides), metal oxides, carbonaceous (nanotubes, fullerenes, and carbon black), organic, and non-metals (both pure non-metals and non-metal containing compounds).

Figure 9: Elemental characterization of nanomaterials handled by participants



Respondents indicated whether the nanomaterials handled were in suspension or in solid form. Materials in solid form were differentiated from freely mobile nanomaterials, and nanomaterials that are fixed in a solid matrix or embedded on a surface. Based upon the 61 responses, most respondents (37%) handled nanomaterials as both a dry powder and in suspension (Figure 10). Twenty three percent of respondents only handled the dry powder form.

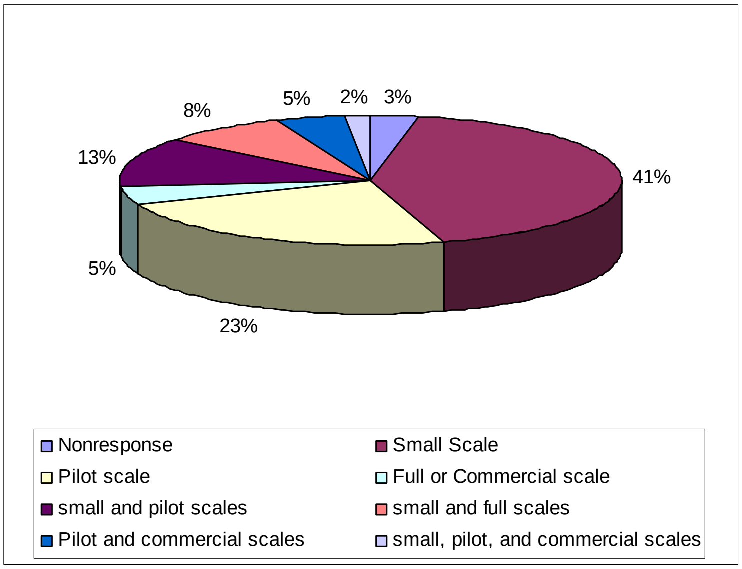
Figure 10: Phases of nanomaterials handled by participants



Information regarding the scale of production or handling of nanomaterials also was elicited from respondents (Figure 11). Options included: small scale, pilot scale, and full or commercial scale. The definitions of these categories were not provided and the interpretation was left to the respondent. Instances where an organization had multiple scales of production were attributed to multiple products.

A large number of respondents (41%) said they handled or produced nanomaterials at a small scale. In addition to production, this category included research and development activities. About 23% of respondents claimed to be producing nanomaterials at a pilot scale. Only 15% of respondents indicated that they produced at least one nano-containing product at the full or commercial scale.

Figure 11: Scales of production or use of nanomaterials described by respondents



Summary of Respondent Characteristics

Sixty four organizations participated in this survey, including twenty five organizations from Asia, twenty five from North America, eleven from Europe, and three from Australia. Three hundred and thirty seven organizations were contacted, resulting in an overall response rate of 19%.

Environmental Health and Safety Program

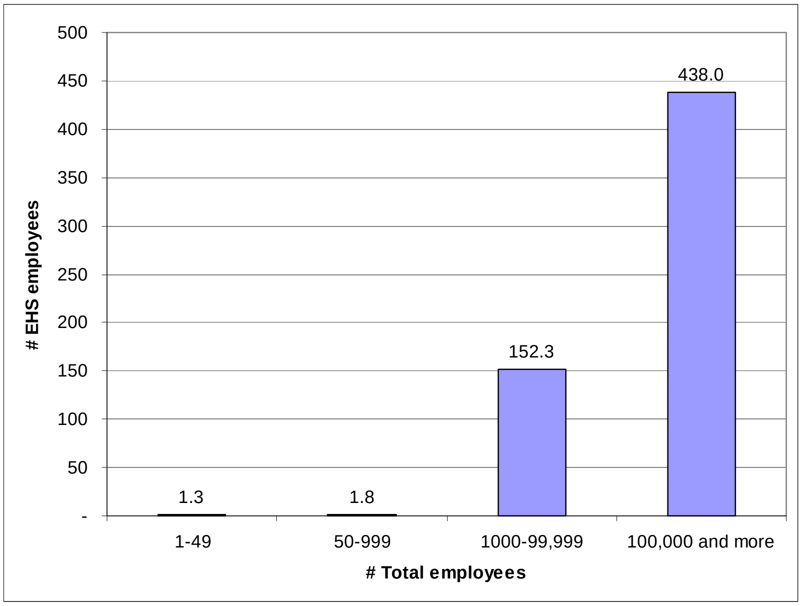
Through a set of questions, respondents were asked to describe their organization's general environmental health and safety programs, any "nano-specific" EHS programs and health and safety training for employees handling nanomaterials. The following section details the responses to these questions in combination with organizational characteristics.

General EHS Program

A majority of respondent organizations (59) indicated they had an EHS program and five indicated they did not have an EHS program. Of the five respondents with no EHS program, three are in Asia and two were in Europe; all five organizations had less than 200 employees, were less than six years old, and had less than 10 employees handling nanomaterials.

Of the 59 respondents who had an EHS program, only two indicated that their EHS program was executed by a consultant. Forty five respondents indicated they had five or fewer FTE EHS employees. Overall, the number of FTE EHS employees increased with company size. While organizations with 1-49 employees had an average of 1.3 FTE EHS employees, organizations with 50-999 employees had an average of 1.8 FTE EHS employees, organizations with 1,000-99,999 employees had an average of 152.3 FTE EHS employees, and organizations with 100,000 and more employees had an average of 438 FTE EHS employees. However, the number of FTE EHS employees increased at a decreasing rate commensurate with organization size. In other words, the percentage of FTE EHS employees decreased from 7.21% in organizations with 1 to 49 employees to 1.37% in organizations with 50 to 999 employees, to 0.37% in organizations with 1,000 to 99,999 employees 0.19% in companies with 100,000 or more employees.

Figure 12: Number of EHS employees according to respondent size



Nano-Specific EHS Program

More than two-thirds of the respondent organizations with an EHS program (59) reported that they also had a nano-specific EHS program (37) or that one was being developed (3). Of the respondents without a nano-specific EHS program, eight indicated they had an EHS program that addressed hazardous materials or fine particles that was used for nanomaterials. Four other respondents claimed that a nano-specific program was not necessary because employees handled nanomaterials either in suspensions, agglomerations, or within a closed system.

Characteristics of Respondents with a Nano-Specific EHS Program

Respondents from the US reported the highest percentage of nano-specific EHS programs, followed by Asian, European and Australian respondents, respectively (Table 3).

Table 3: Nano-specific EHS programs by geographic region

Region	Yes	No	% Yes
USA	18	7	72%
Asia	13	12	52%
Europe	5	6	45%
Australia	1	2	33%

Companies reported higher percentage of nano-specific EHS programs than other organizations (Table 4). However, it was difficult to draw conclusions since the sample population was skewed heavily toward the private sector.

Table 4: Nano-specific EHS programs according to type of respondent

Type of Respondent	Yes	No	% Yes
Company	33	18	65%
Research Lab	1	5	17%
University lab	3	3	50%
Consultant	0	1	0%

The relationship between company size and the likelihood of administering a nano-specific EHS program was not clear, since a smaller percentage of medium sized companies (50-999 employees) had a nano-specific EHS program than small companies (1-49 employees, Table 5). At the same time, a larger percentage of large companies (over 1000 employees) had a nano-specific EHS program than small companies (1-49 employees).

Table 5: Nano-specific EHS programs according to company size

Company Size	Yes	No	% Yes
1 to 49 employees	17	13	57%
50 to 999 employees	9	12	43%
1000 to 99,999 employees	6	2	75%
100,000+ employees	5	0	100%

Respondents with a greater number of employees handling nanomaterials were more likely to administer a nano-specific EHS program (Table 6).

Table 6: Nano-specific EHS programs according to nano-division size

# of Employees working with nanomaterials	Yes	No	% Yes
1 up to < 10 employees	13	13	50%
10 up to < 50 employees	15	12	56%
50 up to < 250 employees	5	1	83%
250 and more employees	4	1	80%

The relationship between company age and the likelihood of administering a nano-specific EHS program was not clear, since a smaller percentage of medium-age companies (11 to 100 years old) had a nano-specific EHS program than the younger companies (10 years or younger, Table 7). At the same time, a larger percentage of older companies (over 100 years old) had a nano-specific EHS program than the youngest companies in the survey sample (10 years or younger).

Table 7: Nano-specific EHS programs according to company age

Age of Organization	Yes	No	% Yes
10 years or younger	21	14	60%
11 to 100 years old	9	11	45%
Over 100 years old	7	2	78%

Respondents that had been handling nanomaterials longer appeared to be more likely to administer a nano-specific EHS program (Table 8).

Table 8: Nano-specific EHS programs according to nano-division age

Number of years working with nanomaterials	Yes	No	% Yes
1 year or less	2	3	40%
1 to 10 years	28	20	58%
Over 10 years	7	4	64%

The data suggested that respondents who believed there were special risks associated with the nanomaterials handled in their organizations were more likely to administer a nano-specific EHS program than both those who did not know and those who believed there was no special risk (Table 9).

Table 9: Nano-specific EHS programs according to the beliefs of risk

Is there risk associated with your nanomaterials	Yes	No	% Yes
There is a risk	18	4	82%
Unknown	12	8	60%
There is NO risk	7	15	32%

There was no apparent relationship between scale of production and the likelihood of administering a nano-specific EHS program (Table 10).

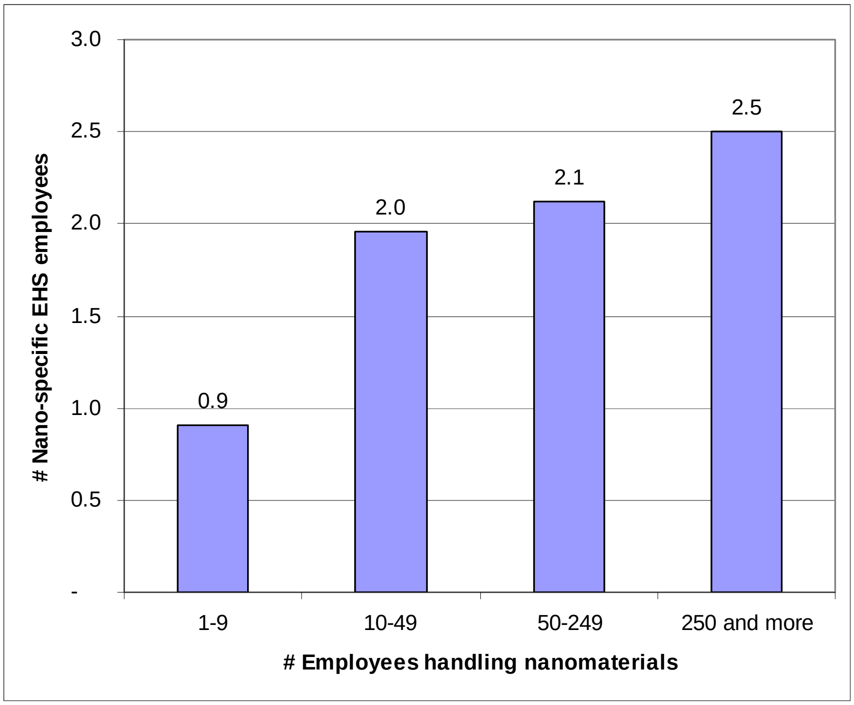
Table 10: Nano-specific EHS programs according to production scale

Scale of Production	Yes	No	% Yes
Small Scale	12	15	44%
Pilot scale	17	6	74%
Full or Commercial scale	7	5	58%
Non response	1	1	50%

Similarly, no relationship was apparent between the quantity of nanomaterial handled by workers at an organization and the likelihood of that organization administering a nano-specific EHS program. An equal percentage (58%) of organizations whose employees worked with more than one kilogram of nanomaterial at a time and those working with less than one kg reported their organization had a nano-specific EHS program.

Nano-specific EHS programs were executed by an average of 1.6 full-time equivalent (FTE) EHS personnel and a maximum of seven FTE EHS personnel. Data showed the number of nano-specific EHS personnel increased modestly with the number of employees handling nanomaterials (Figure 13).

Figure 13: Number of nano-specific EHS employees compared with number of employees handling nanomaterials



Nano-specific EHS Program Description

When asked to describe their nano-specific EHS program, ten respondents mentioned having a guideline document, nine respondents mentioned using a risk assessment approach, four mentioned modeling after a fine particles or hazardous waste program, and two based their program on monitoring actual exposure to nanoparticles. Respondents indicated that their guideline documents included a definition of nanotechnology, employee responsibilities and training, medical monitoring, equipment maintenance, material storage and disposal, procedures for handling nanomaterials in different forms (liquid, suspension and dry powder), handling of spills containing nanomaterials, and personal protective equipment and clothing (PPE). Those respondents that reported a risk assessment approach described a similar program, although controls were designed specifically for each task or project. Risk assessments included a description of the specific nanomaterial, its form and toxicity, and how to minimize exposure and environmental hazards through engineering controls and PPE. Two respondents indicated they followed the same guidelines for nanomaterials as for fine particles and dust. Two other respondents emphasized that they attempted to “engineer out” exposure by using an enclosed system, fume hoods and PPE so that their employees do not touch nanomaterials directly. Further, two respondents indicated their programs focused on monitoring employee exposure and the release of nanoparticles into the air and water.

The type of EHS program used to some extent depended on organizational characteristics. While our data did not show a link between the number of nanomaterials handled and the type of nano-specific EHS program administered, it did reveal a relationship between the number of employees handling nanomaterials within an organization and the type of program. Organizations with 1-9 employees working with nanomaterials most frequently described their nano-specific EHS program as a guideline document. The safe work practice guideline document typically included: a definition of nanotechnology, employee responsibilities and training, medical monitoring, equipment maintenance, material storage and disposal, procedures for handling nanomaterials in different forms (suspension vs. dry powder), the handling of spills containing nanomaterials, and personal protective equipment and clothing. Respondents with more than 10 employees working with nanomaterials often described a risk assessment approach for each particular task or on a project basis. Each risk assessment was stated in a written document that included a description of the specific nanomaterial, its form and toxicity, and how to minimize exposure and environmental hazards through the use of engineering controls and PPE. Subsequently, the risk assessment was reviewed and approved by the appropriate level of management.

Several respondents with backgrounds in industrial hygiene described a four-tier system for minimizing worker exposure to hazards. They explained how this same scheme could be used to reduce exposure to nanomaterials. The first tier emphasizes either substitution or elimination of the material being handled. According to the respondents, replacing a hazardous material or more hazardous form of any material, such as nanomaterials in the dry powder form, with a material recognized to be safer, such as the same material in solution, would be the highest level of deterrence to exposure. They stated that the effect of this substitution or elimination would more effectively prevent exposure to the material than the remaining three tiers: engineering controls, work practices, and personal protective equipment and clothing (PPE). The second tier of the scheme describes effective use of engineering controls. According to the respondents, the use of proper engineering controls is more effective at reducing worker exposure than implementing safe work practices and proper PPE because the latter approaches are subject to worker compliance and education. The third tier of this scheme is changing work practices. Although this is subject to worker compliance, the respondents indicated it is more effective than PPE because PPE only acts as a barrier of protection, while work practices, if selected carefully, can deter potential exposure. Respondents indicated that the lowest level of control is PPE. Although the importance of PPE should not be minimized, this only acts as a barrier of protection. Gloves and lab coats can be permeable to solvents. Respirators are only “fully” effective if the user is fitted and instructed in its use by a trained professional. That is why respondents who use this scheme emphasize the importance of first and second tier controls.

Reasons for a Nano-specific EHS Program

The reasons cited for administering a nano-specific EHS program revolve around precaution and safety. Twelve respondents indicated they administer a nano-specific EHS program as a safety precaution against unknown hazards, including potential toxicity. Four respondents indicated the main reason is to minimize employee exposure. Two respondents said they are taking a proactive approach to address potential risks from nanomaterial exposure. Two other respondents stated they have a nano-specific EHS program to address the unique hazards related to nanomaterials. One respondent mentioned compliance with safety regulations for fine particles.

In order to understand the nature of their nano-specific EHS programs, respondents were asked if the programs varied by location or type of nanomaterial. Of the 37 respondents with a nano-specific EHS program, 18 indicated that their guidelines do not vary by location. Four of the eighteen respondents explained that this is because their organization has only one location. Nine respondents indicated their program varies by location, where four explained it is based on a risk assessment approach for each task, whereas tasks vary by location. Another three reported that their practices were different between R&D and manufacturing facilities. An equal number of respondents indicated that their program varied or their program did not vary by the type of material handled. Fifteen respondents indicated their program did not vary according to the type of nanomaterial handled within their organization because there is only one location (3) or all nanomaterials are treated as hazardous (1). Another fifteen respondents indicated their program varied by the type of material handled or more specifically, the material form (powder, in suspension or embedded in a matrix) and specific known hazards (such as flammability, toxicity, carcinogenicity or high reactivity).

Use of Outside Contractors for Nano-specific EHS Programs

The majority (24) of respondents who had a nano-specific EHS program (37) did not use an outside contractor for development and/or implementation. Five respondents used contractors for performing various audits (e.g., risk assessment, electrical equipment), monitoring, and training. Further, two respondents have consultants administer their entire nano-specific EHS program because as small companies, they do not have the resources to hire and train full-time employees on nano-specific EHS issues.

Summary- Nano-specific EHS Programs

Most organizations reported having a nano-specific EHS program. Organizations with larger numbers of employees handling nanomaterials more frequently reported the existence of nano-specific EHS programs, as well as higher numbers of nano-specific EHS employees. North American organizations also exhibited the greatest number of nano-specific EHS programs. Respondents whose employees have been working with nanomaterials longer and those who believe there are special risks associated with nanomaterials handled or produced in their organization more often reported administering a nano-specific EHS. On the other hand, larger scale of production and larger amounts handled did not necessarily lead to the development of nano-specific EHS programs. Respondents described their nano-specific EHS programs most often as guideline documents or risk assessments. Some respondents treat nanoparticles either as fine particles or as hazardous materials and use EHS practices appropriate for handling those materials.

Nano-specific Health and Safety Training

More than half of the respondents (61%) indicated their organization offers “health and safety” training to employees on handling nanomaterials. The most frequently cited reason organizations train their employees are to protect them from exposure and potential hazards. The top two reasons why respondents did not offer training were that they did not have the resources or information to design a training program, or their employees did not handle nanomaterials directly. Table 11 lists additional reasons provided for decisions to train or not train their employees on the handling of nanomaterials.

Table 11: Reasons for offering health and safety training to employees handling nanomaterials

YES	Reasons Cited
8	Safety of employees (and 2 mentioned customers)
4	Protect against unknowns
3	Regular EHS training
2	Reduce exposure
2	Raise awareness
1	It is a new process
18	Did not indicate a reason
38	**Total**
NO	**Reasons Cited**
4	Have plans to implement a training
3	Employees do not handle nanomaterials directly
3	Have training but not nano-specific
2	Treat as hazardous materials
1	Materials are not dangerous
1	Do not have time
12	Did not indicate a reason
26	**Total**

Characteristics of Respondents with Training for Employees on the Handling of Nanomaterials

Of the thirty-eight respondents that offered health and safety training, the majority (28) also had a nano-specific EHS program. The characteristics of respondents who administered training were very similar to those who had a nano-specific EHS program.

Respondents from the US reported the highest percentage of training, followed by European, Asian, and Australian respondents, respectively (Table 12).

Table 12: Health and safety training by region

Region	Yes	No	% Yes
USA	21	4	84%
Europe	5	6	45%
Asia	11	14	44%
Australia	1	2	33%

There appears to be a relationship between company size and training, with larger organizations more likely to administer specific nanotech health and safety training (Table 13).

Table 13: Health and safety training according to organization size

Company Size	Yes	No	% Yes
1 to 49 employees	15	15	50%
50 to 999 employees	14	7	67%
1000 to 99,999 employees	5	3	63%
100,000+ employees	4	1	80%

Respondents with more employees handling nanomaterials are generally more likely to offer training (Table 14).

Table 14: Health and safety training according to nano-division size

# of Employees working with nanomaterials	Yes	No	% Yes
1 up to < 10 employees	13	13	50%
10 up to < 50 employees	17	11	61%
50 up to < 250 employees	5	1	83%
250 and more employees	3	1	75%

The relationship between company age and the likelihood of offering nano-specific EHS training was not clear, since a smaller percentage of medium-age companies (11 to 100 years old) had a nano-specific EHS program than young companies (10 years or younger). Refer to Table 15. At the same time, a larger percentage of old companies (over 100 years old) had a nano-specific EHS program than young companies (10 years or younger). If the two categories of bigger companies are combined, it would result in 55% of organizations over 10 years old and 60% of organizations 10 years or younger offering training. This shows that there isn't a strong correlation between age and the likelihood of offering nano-specific training.

Table 15: Health and safety training according to organization age

Age of Organization	Yes	No	% Yes
10 years or younger	21	14	60%
11 to 100 years old	9	11	45%
Over 100 years old	7	2	78%

Respondents that have been handling nanomaterials longer appeared to be more likely to administer a nano-specific EHS training (Table 16).

Table 16: Health and safety training according to nano-division age

Number of years working with nanomaterials	Yes	No	% Yes
1 year or less	2	3	40%
1 to 10 years	28	20	58%
Over 10 years	8	3	73%

Respondents who believed there were special risks associated with the nanomaterials handled in their organizations were more likely to administer nano-specific EHS training than those who did not know and those who believed there was no special risk (Table 17).

Table 17: Health and safety training according to risk beliefs

Is there risk associated with your nanomaterials	Yes	No	% Yes
There is risk	16	6	73%
Don't know	12	10	55%
There is NO risk	10	10	50%

Similar to the results for a nano-specific EHS program, the relationship between scale of production and the likelihood of administering nano-specific EHS training was not clear, since a smaller percentage of small scale and full scale producers had a nano-specific EHS program than pilot scale producers (Table 18).

Table 18: Health and safety training according to production scale

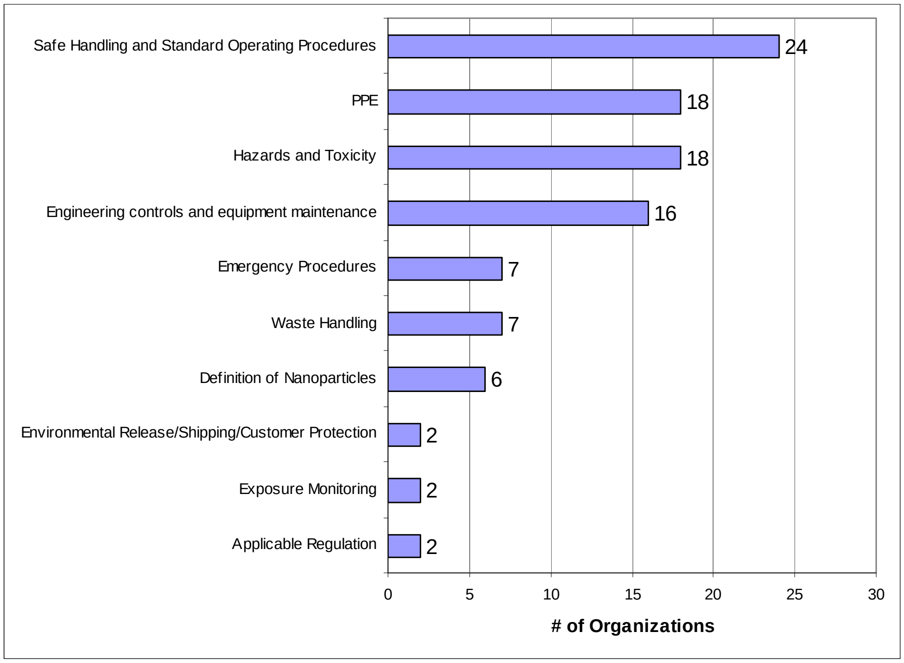
Scale of Production	Yes	No	% Yes
Small Scale	15	12	56%
Pilot scale	15	8	65%
Full or Commercial scale	7	5	58%
Non response	1	1	50%

Similarly, a weak relationship was found between quantity handled and the likelihood of administering a nano-specific EHS program. A slightly higher percentage (62%) of organizations whose employees work with over 1 kg of nanomaterials at a time administered training to employees on handling nanomaterials than those working with under 1 kg of nanomaterials at a time.

Training Description

The most commonly cited topics of training programs were: safe handling of nanomaterials and standard operating procedures (SOPs), hazards and toxicity, personal protective equipment, and engineering controls including equipment maintenance (Figure 14). Less often, respondents indicated their training included directions on how to act in case of emergency (fire, spills, etc), waste handling (including labeling and storage), and definitions of nanoparticles. Only a few respondents indicated their training included exposure monitoring, applicable regulation, environmental release, safe shipping, and customer protection.

Figure 14: Topics covered in health and safety training for employees on handling of nanomaterials



Respondents described various formats for their training and many of them used multiple formats. Of the 38 respondents that provide training, 27 described using verbal training in a classroom setting, sometimes in the form of a seminar. Sixteen used written communication, often in the form of hand-outs. Eight implemented online training or maintained a website with nano-specific EHS information; eight performed hands-on training in the lab, including a demonstration and a lab tour. Two used video training.

As shown in Figure 15, many respondents (21) resorted to governmental agencies as sources of information and guidelines for their training. Respondents listed the following agencies: NIOSH, OSHA, and EPA in the US, the UK Health and Safety Executive, and the Industrial Technology Research Institute in Taiwan. Fourteen respondents mentioned using scientific literature and toxicological studies as sources of information for their training. Thirteen respondents said they relied on internal expertise, and twelve mentioned using internet sources that included public databases such as ORC Worldwide,[19] the Micromedex Chemical Toxicology data base, and ICON EHS database.[20] Nine respondents mentioned they attended conferences, and eight respondents used external experts/consultants for sources of information. Six respondents mentioned referring to industry associations such as the American National Standards Institute (ANSI), the American Industrial Hygienist Association (AIHA), the American Chemistry Council (ACC), and the American Conference of Industrial Hygienists (ACGIH). Furthermore, six respondents mentioned using supplier Materials Safety and Data Sheets (MSDS) as sources of information for their training.

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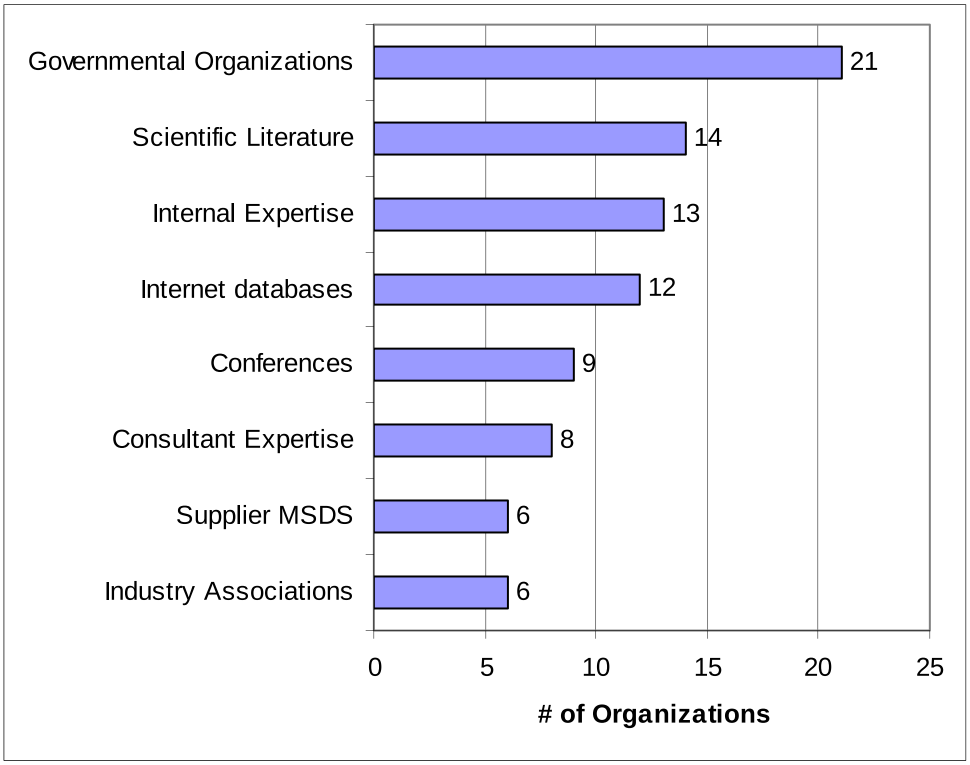
[19] ORC Worldwide. Nanotechnology Consensus Workplace Safety Guidelines. 2006. <http://www.orc-dc.com/Nano.Guidelines.Matrix.htm> October 2006.

[20] International Council on Nanotechnology. EHS Database. 2006. <http://icon.rice.edu/centersandinst/icon/resources.cfm?doc_id=8597> October 2006.

Figure 15: Sources of information for nano-specific health and safety training



While all 38 respondents who administered training indicated that all employees handling nanomaterials in their organization receive nano-specific training, the frequency of this training varied. Twenty eight respondents required nano-specific training upon start at the company. In addition to the initial training, 13 of the 28 respondents held annual or quarterly refreshers, six held refreshers upon introduction of a new nanomaterial, and three did both. Eight respondents did not require nano-specific training upon start at the company. Five of these respondents had training only when new material was introduced, two held training "periodically," and one provided nano-specific training only when standard EHS training was offered.

Thirty one respondents of those who administered nano-specific training (38) used only internal resources, two used external resources entirely, and five used a combination of both internal and external resources to provide training.

Summary of Nano-Specific Health and Safety Training

The organizational characteristics of organizations that more frequently reported nano-specific health and safety training were the same as for those who reported administering a nano-specific EHS program. Organization with larger numbers of employees handling nanomaterials, with older nano-divisions, higher beliefs of risk and those based in North America more frequently reported administering health and safety training for their employees on the handling of nanomaterials. On the other hand, production scale and amount of exposure did not appear to have an effect on training rates. Training most often included safe handling procedures and was held in a classroom setting. Organizations most often used governmental organizations and scientific literature as sources of health and safety information. Respondents mostly used internal resources to administer the training upon hire of new employees with periodic refresher sessions.

Planned Improvements to Nano-Specific Health and Safety Programs

Respondents were asked whether their organization was considering plans to improve its nano-specific health and safety practices, and if so, what those plans were. Thirty two of the respondents, or half of the survey sample, responded “yes”; 21 responded “no,” two were unsure, and nine did not respond. Fifteen of those organizations considering improvement plans stated their intention to continuously review and improve their practices with the most current information available. Four organizations were planning to improve their engineering controls. Three respondents simply stated their organization was headed in a “nano direction,” and six indicated there were no specific plans. Nine specific responses describing plans to improve their organization’s nano-specific EHS program were the following:

- Seek assistance from consulting firms
- Invest heavily in EHS improvements
- Collaborate with government agencies for research activities
- Improve training
- Design EHS according to the properties of the specific nanomaterials being used
- Continue to base their practices on the “precautionary principle”
- Benchmark, although did not state with whom
- Document ‘best practices’
- Create “better programs”

One respondent stated their organization created a nanotechnology workgroup under the European Commission to develop regulations and practices. Another respondent reported their organization will consider improvements to its health and safety practices when the R&D department suggests it do so.

Summary of Environmental Health and Safety Section

The data suggested that organizational characteristics play a significant role in determining whether an organization has an EHS program and training related to nanotechnology. While it could be expected that larger and older organizations have more resources, as well as a more developed EHS program in place, nanotechnology is a burgeoning field and so is the understanding of potential risks to human health and the environment. Therefore, it is difficult to presume “nano-specific” EHS programs are more developed amongst larger and older organizations because nanotechnology is new and developing rapidly. Instead, our data showed that nano-specific EHS practices were more prevalent in organizations that had been working with nanomaterials longer, had more employees handling nanomaterials and believed there were special risks associated with nanomaterials. On the other hand, our data did not show that higher production scales and greater amounts handled necessarily lead to the development of a nano-specific EHS program and training. The geographic location of organizations participating in the study had some implications for the EHS practices reported, whereas North American organizations most frequently reported administering nano-specific EHS program and training to their employees.

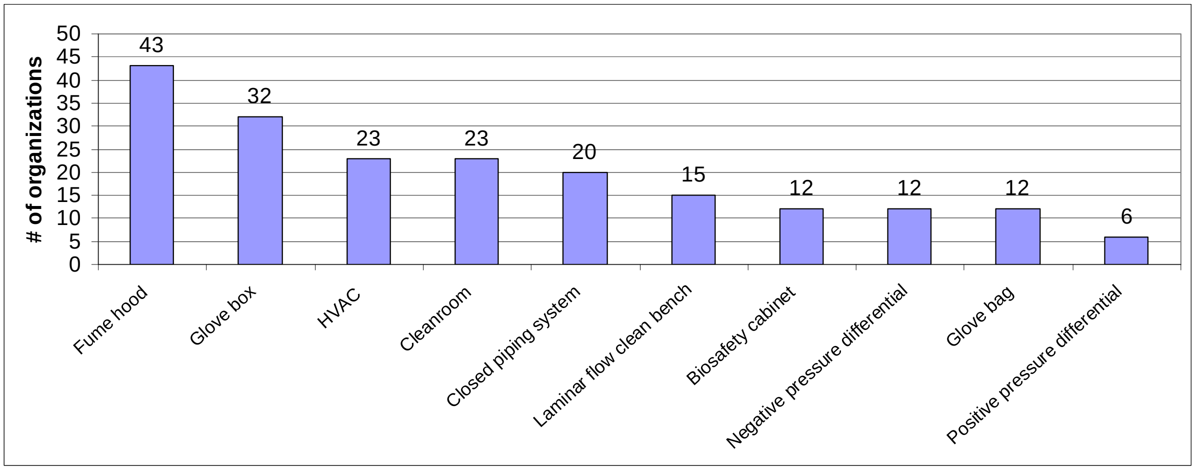
Respondents described their nano-specific EHS programs most often as guideline documents or risk assessments. A number of respondents treated nanoparticles either as fine particles or as hazardous materials and used EHS practices appropriate for handling those materials. Training most often included safe handling procedures and was held in a classroom setting. Organizations usually used governmental organizations and scientific literature as sources of health and safety information. Respondents mostly used internal resources to administer the training upon hire of new employees with periodic refresher sessions.

Finally, more than half of the respondents stated their intention to continuously review and improve their practices with the most current information available.

“Nano-specific” Engineering Controls

Respondents were asked whether “nano-specific” facility design and engineering controls were used to safely manage worker exposure. Furthermore, respondents were asked whether the organization utilized cleanrooms, fume hoods, biological safety cabinets, laminar flow clean benches, glove boxes, glove bags, a closed piping system, pressure differentials (negative or positive), isolated Heating, Ventilation, and Air Conditioning (HVAC) systems, or other controls specifically for handling nanomaterials. Overall reports of engineering controls are reported in Figure 16. The following section details the responses to this question in combination with respondent characteristics and characteristics of the nanomaterial that they work with.

Figure 16: Reports of “nano-specific” facility design and engineering controls



Fume hoods

Two thirds (43) of participating organizations reported using fume hoods in the handling of nanomaterials. Over half (32 of 51) of companies reported using fume hoods, while two thirds (4 of 6) of research labs and all university labs reported their use. Over half (23) of reports of fume hood use came from companies that were less than ten years old and over 60% from organizations that entered the nanotechnology field in the last five years. Organizations reporting that greater than 250 people directly handle nanomaterials all reported the use of fume hoods while only half (53%) of organizations with less than nine persons and 70% of organizations with between 10 and 49 persons handling nanomaterials did so (Table 19). Five out of six organizations with between 50 and 249 reported using fume hoods. Altogether, ten out of eleven (90%) organizations with fifty or more employees handling nanomaterials reported using fume hoods.

Table 19: Reported use of fume hoods by number of employees handling nanomaterials

	Number of organizations	Number using fume hoods	Percent
1-9 employees	26	14	53.8%
10-49 employees	27	19	70.4%
50-249 employees	6	5	83.3%
250 or more employees	5	5	100.0%

European organizations reported the highest percentage of fume hood use with nine out of eleven organizations indicating that they used fume hoods in the handling of nanomaterials (Table 20). Organizations from Asia reported the lowest use of fume hoods with thirteen out of twenty indicating their use. Nineteen of twenty five organizations from North America indicated the use of fume hoods.

Table 20: Reported use of fume hoods by region

Region	Number of organizations	Number using fume hood	Percent
Asia	25	13	52%
Europe	11	9	82%
North America	25	19	76%
Other	3	2	67%

There appears to be no large difference in the use of fume hoods resulting from the amount of nanomaterials used at a given time (Table 21). While 66% of organizations working with less than a kilogram reported using fume hoods in the handling of nanomaterials, a similar share (69%) of organizations working with amounts greater than one kilogram also reported using fume hoods. Similarly, six out of eleven organizations that handled only greater than one kilogram of nanomaterials and seven out of eleven organizations that only handled less than a gram of nanomaterials at a time reported using fume hoods.

Table 21: Reported use of fume hoods by amount of nanomaterial handled

	Number of organizations	Reports of Fume hoods	Percent
Less than kilogram	38	25	65.8%
Less than one gram	23	17	73.9%
Less than one milligram	10	8	80.0%
Greater than one kilogram	26	18	69.2%
Only less than one gram	11	7	63.6%
Only one Kilogram or Greater	11	6	54.5%

Fume hoods are used by organizations that handled a variety of different nanomaterial types. All organizations handling quantum dots, nanowires, and nanocrystals reported the use of fume hoods (Table 22). Twenty three of thirty four organizations handling nanopowders also reported the use of fume hoods as did twenty of twenty nine working with carbon nanotubes. Ten of twelve working with fullerenes also used fume hoods.

Table 22: Reported use of fume hoods by nanomaterial type

	Number	Fume hood	Percent
Nanopowders	34	23	67.6%
Carbon Nanotubes	29	20	69.0%
Dispersions	19	14	73.7%
Fullerenes	12	10	83.3%
Q dots	9	9	100.0%
Polymers	9	6	66.7%
Nanowires	8	8	100.0%
Nanocrystals	7	7	100.0%
Carbon Black	7	5	71.4%
Other	17	15	88.2%

The survey results indicated that while fume hoods were used with nanomaterials in a variety of combinations of phases, fume hoods were less likely to be used when the nanomaterial was in a dry powder form. While 17 of 23 organizations that reported handling nanomaterials in both dry powder form and also in solution reported using a fume hood, only seven of fifteen organizations that reported only working with dry powder indicated the use of a fume hood (Table 23). Fume hoods were more likely to be used when the nanomaterial was in a solution or was embedded in or bound to a matrix.

Table 23: Reported use of fume hoods by phases of nanomaterial during handling

Category	Phase of nanomaterial during handling	Use of fume hood	Percent
Dry powder and in solution	23	17	73.9%
Dry Powder only	15	7	46.7%
Solution only	6	3	50.0%
In solution and embedded/bound	6	5	83.3%
Dry powder, in solution, and embedded/bound to a surface	6	6	100.0%
Embedded/bound to a surface only	3	3	100.0%
Dry powder and in a matrix	2	0	0.0%
Missing	3	na	na

Of those reporting the use of fume hoods, 26 reported using some kind of exhaust filtration system with their ventilation system, though twelve respondents were unsure of what type. This may reflect the lack of knowledge by the organization representative who supplied the information. Nine of twelve responses that were unsure of the type of fume hood exhaust filtration were provided by persons in management positions. Of those that did provide information on the type of exhaust filtration, eight reported using HEPA filters, two reported using “standard”, non-HEPA filters, and two reported using wet scrubbers primarily for removing water soluble organic materials. One organization reported using sub-micron rated cartridge filters that blocks nanoparticles to less than 10 nanometers. Some respondents reported that when handling dry powders, fume hood exhaust systems would be shut off to prevent loss of the nanomaterial as well as to prevent inhalation. In this case, the glass shield would act as a physical barrier for protection, but the hood would provide no ventilation protection.

Just 23 of those that reported the use of a fume hood also reported its class, with class 2, or a minimum face velocity of 100 feet per minute, reported by five organizations. One organization reported using all classes. No other classes were reported. Most respondents to this question were unsure of fume hood class, again possibly reflecting the position of the person providing the information. One respondent described the inaccuracy of using face velocity as a measurement of efficacy. It was pointed out that different fume hood designs have different air turbulence patterns and are designed to be most efficient at a particular face velocity.

Fume hoods were the most widely reported engineering control. They tended to be used more by newer organizations and by organizations that were new to the nanotechnology field. While almost all large organizations reported using fume hoods, all but ten reports were from organizations with less than 50 employees handling nanomaterials. Fume hoods were used with a variety of materials and phases but the highest usage was among organizations that worked with solutions, which could be an indication that fume hoods were used more as a barrier of protection against harmful vapors than nanomaterials. Fume hoods were less likely to be used when the nanomaterial was in a dry powder form. As noted, this may have been due to the potential loss of dry powder form material and the risk of inhalation stemming from air turbulence generated by the fume hood exhaust system. Most reports of fume hood use were associated with the handling of nanopowders, carbon nanotubes, dispersions, and fullerenes.

Many respondents did not know the type of filtration system used with their fume hoods. Of those that did provide information on the type of exhaust filtration only a minority utilized HEPA filters. HEPA filtration is often described as being the best level of available filtration. Yet, only eight organizations reported using HEPA filters, two reported using “standard”, non-HEPA filters, and two reported using wet scrubbers primarily for removing water soluble organic materials.

Glove boxes and glove bags

Thirty two organizations reported utilizing glove boxes for handling nanomaterials and twelve reported using glove bags. Almost half of the reported uses of glove boxes came from organizations less than five years old and 21 of 32 came from organizations that have been in the nanotechnology field for five years or less. Half of research labs reported use of glove boxes and five of six university labs and nearly half of the companies did so as well (23 of 51). As with fume hoods, most organizations with large numbers of employees handling nanomaterials reported using glove boxes in their nanomaterial operations (Table 24). For organizations with greater than 50 employees involved in the handling of nanomaterials, nearly 73 % reported using glove boxes. Ten of twenty six organizations with nine or less employees handling nanomaterials reported using glove boxes and fourteen of twenty seven organizations with between ten and forty nine employees handling nanomaterials did so.

Glove bags were used less overall, with only 12 out of 64 organizations reporting their use. Of these, four of five university labs reported using glove bags, but only six of 51 companies did so.

Table 24: Reported use of glove boxes and glove bags by number of employees handling nanomaterials

	Number of organizations	Number using glove box	Percent	Number using glove bag	Percent
1-9 employees	26	10	38.5%	3	11.5%
10-49 employees	27	14	51.9%	4	14.8%
50-249 employees	6	4	66.7%	2	33.3%
250 or more employees	5	4	80.0%	3	60.0%

North American organizations had the highest frequency (64%) of reporting the use of glove boxes in their nanomaterial operations (Table 25). This result is in contrast to Asian countries, where only 36 % reported using glove boxes. Five out of eleven European organizations reported using glove boxes.

Glove bags were less frequently reported to be used in nanomaterials operations. Only one European organization reported using a glove bag. Similar numbers of organizations from both North America and Asia reported use of glove bags.

Table 25: Reported use of glove boxes and glove bags by region

Region	Number of organizations	Number using Glove Box	Percent	Number using Glove Bag	Percent
Asia	25	9	36%	6	24%
Europe	11	5	45%	1	9%
North America	25	16	64%	5	20%
Other	3	2	67%	0	0%

Glove boxes are used more frequently in operations that handled nanomaterials on a smaller scale (Table 26). Twenty of thirty-eight organizations working with nanomaterials in amounts less than one kilogram reported using glove boxes and six of ten organizations working with less than one milligram reported their use. Eleven of 26 (42 %) organizations working with greater than one kilogram reported their use. The contrast between large and small volume operations, however, was clearer in the categories that compared organizations working in only large amounts or only in small amounts. Of organizations working with nanomaterials in amounts greater than one kilogram only, one reported using a glove box. On the other hand, five of eleven organizations working only with nanomaterials in an amount less than one gram reported using glove boxes.

The difference between large and small operations appears to stay the same for glove bags, though the trend is less clear. The single highest reported use of glove bags was among organizations working with amounts of less than one milligram. Six of thirty-eight organizations working with less than one kilogram and five of twenty six organizations working with greater than one kilogram of nanomaterials at a given time reported using glove bags. Two of eleven organizations working only with amounts less than one gram reported using glove bags while only one of eleven organizations working only with amounts greater than one kilogram reported using glove bags.

Table 26: Reported use of glove boxes and glove bags by amount of nanomaterial handled

	Number of organizations	Reports of Glove Boxes	Percent	Reports of Glove Bags	Percent
Less than one kilogram	38	20	52.6%	6	15.8%
Less than one gram	23	11	47.8%	3	13.0%
Less than one milligram	10	6	60.0%	3	30.0%
Greater than one kilogram	26	11	42.3%	5	19.2%
Only less than one gram	11	5	45.5%	2	18.2%
Only one kilogram or greater	11	1	9.1%	1	9.1%

The highest number of reports of the use of glove boxes came from those organizations working with nanopowders (20 of 34) and carbon nanotubes (17 of 29, Table 27). This is, at least in part, a reflection of the large presence of these organizations in the overall sample. Those organizations working with colloidal dispersions were the least likely to report using a glove box. Nearly all organizations working with nanowires, nanocrystals and carbon black reported using glove boxes.

Reported use of glove bags appeared to follow a similar trend, with the highest number of reports of glove bag usage coming from organizations working with nanopowders and carbon nanotubes. Again, significant portions of those organizations working with nanocrystals and carbon black also reported the use of glove bags.

Table 27: Reported use of glove boxes and glove bags by nanomaterial type

	Number	Reports of Glove Boxes	Percent	Reports of Glove Bags	Percent
Nanopowders	34	20	58.8%	8	23.5%
Carbon Nanotubes	29	17	58.6%	7	24.1%
Colloidal Dispersions	19	9	47.4%	7	36.8%
Fullerenes	12	9	75.0%	4	33.3%
Quantum Dots	9	7	77.8%	3	33.3%
Polymers	9	5	55.6%	3	33.3%
Nanowires	8	7	87.5%	3	37.5%
Nanocrystals	7	6	85.7%	4	57.1%
Carbon Black	7	6	85.7%	4	57.1%
Other	17	9	52.9%	9	52.9%

Glove boxes were reported to be used with nanomaterials in a number of different phases (Table 28). Organizations working with nanomaterials in dry powder, in suspension and embedded or bound in a matrix had the highest percentage share of reported usage of glove boxes (83%). Organizations working only with solutions had the lowest reported usage of glove boxes (1 of 6). However, 22 of 32 reports of the use of glove boxes came from organizations working with dry powders and solutions.

Half of the organizations working with nanomaterials in dry powder, in suspension or embedded or bound in a matrix reported using glove bags. Organizations only working with dry powder reported lower usage of glove bags (1 of 15). No organizations working with solutions only reported using glove bags, although five of twenty three organizations working with solutions and dry powder did so – likely for their applications with powders.

Table 28: Reported use of glove boxes and glove bags by phases of nanomaterial during handling

Category	Phase of nanomaterial during handling	Reports of Glove Boxes	Percent	Reports of Glove Bags	Percent
Dry powder and in solution	23	13	56.5%	5	21.7%
Dry powder only	15	8	53.3%	1	6.7%
In suspension only	6	1	16.7%	0	0.0%
In solution and embedded/bound	6	3	50.0%	1	16.7%
Dry powder, in suspension, and embedded/bound to a surface	6	5	83.3%	3	50.0%
Embedded/bound to a surface only	3	1	33.3%	2	66.7%
Dry powder and embedded/bound	2	0	0.0%	0	0.0%

One organization noted that while they did utilize glove bags, this control could cause problems by outgassing, resulting in the release of its contents. Another respondent stated that glove bags can build up static electricity charges, which can be problematic for flammable or potentially explosive nanomaterials.

Glove boxes and bags are used by newer organizations and those newer to the nanotechnology field that at the same time work with smaller amounts of nanomaterials.

While most reports came from companies, the majority of university labs also utilized both glove boxes and bags. While used by organizations handling a variety of phases, a majority of reports came from organizations working in either the dry form or in suspension. At the same time, almost all organizations working with nanowires, nanocrystals and carbon black reported using glove boxes. Two of these organizations reported only doing research and development involving nanowires. However, the organizations that reported using glove boxes in conjunction with carbon black and nanocrystals did so in a manufacturing setting.

While some organizations indicated that the use of glove boxes and glove bags were intended to reduce worker exposure, a few indicated that these controls were used primarily to protect light and oxygen-sensitive materials from the ambient environment. Other responses indicated that the use of glove bags in particular carried the risk of unexpected release of the contents and also the potential to accumulate an electro-static charge. This would be of particular concern with handling nanopowders since one novel property of scaling down certain materials to the nanoscale is the lower energy barrier required for flammability and explosivity. *Science* magazine described a photo shoot in which a flash bulb caused the ignition of single walled carbon nanotubes.[21] One respondent described dealing with this issue through another engineering control altogether: the use of an explosion-proof enclosure around the reactor used to produce the nanopowder.

Cleanroom

Twenty three organizations reported using a cleanroom in their nanomaterial operations. The reported usage of cleanrooms suggests that it was nanomaterial operations working in multiple scales and with a variety of phases that were more inclined to use a cleanroom. This suggests that cleanrooms are used in nanomaterial operations that are larger and more diverse.

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[21] P. M. Ajayan, M. Terrones, A. de la Guardia, V. Huc, N. Grobert, B. Q. Wei, H. Lezec, G. Ramanath, and T. W. Ebbesen. 2002. "Nanotubes in a flash—ignition and reconstruction." *Science* 296 (April 26):705.

Companies reported the use of cleanrooms most frequently. Seventeen of 23 reports of using cleanrooms came from companies while the rest were from labs. Of these, three were reported by the six university labs. Cleanrooms were used in operations of various sizes but 16 of 22 came from organizations with less than 50 people handling nanomaterials (Table 29). Six out of eleven (72%) organizations with greater than 50 employees handling nanomaterials reported using a cleanroom as part of their nanomaterial operations. Sixteen out of fifty three organizations (30%) that employed 49 or fewer people to handle nanomaterials reported using a cleanroom.

Table 29: Reported use of cleanrooms by number of employees handling nanomaterials

	Number of organizations	Number using cleanroom	Percent
1-9 employees	26	6	23.1%
10-49 employees	27	10	37.0%
50-249 employees	6	2	33.3%
250 or more employees	5	4	80.0%

North American organizations were the most frequent users of cleanrooms (Table 30). Eight out of twenty five Asian organizations reported using a cleanroom and only one European organization did so.

Table 30: Reported use of cleanrooms by region

Region	Number of organizations	Number using cleanroom	Percent
Asia	25	8	32%
Europe	11	1	9%
North America	25	13	52%
Other	3	0	0%

Cleanrooms were used by operations working at multiple scales, although their use was reported most frequently by organizations working at both smaller and medium scales (Table 31). Seven out of ten organizations working with less than one milligram reported using a cleanroom compared to eighteen out of 38 organizations working with less than one kilogram. However, only one organization working with only less than one gram reported using a cleanroom, which was the same as organizations working with amounts only greater than one kilogram.

Table 31: Reported use of cleanrooms by amount of nanomaterial handled

	Number of organizations	Number using cleanroom	Percent
Less than one kilogram	38	18	47.4%
Less than one gram	23	9	39.1%
Less than one milligram	10	7	70.0%
Greater than one kilogram	26	5	19.2%
Only less than one gram	11	1	9.1%
Only one Kilogram or Greater	11	1	9.1%

Of six organizations working with nanomaterials as a dry powder, in suspension and embedded or bound to a surface, four reported using a cleanroom (Table 32). Nine of twenty three organizations working with solutions and with nanomaterials embedded or bound to a surface reported using a cleanroom. No organizations working only with dry powder or only with nanomaterials embedded on a surface reported using a cleanroom. Only one organization working only with solutions reported use of a cleanroom. These reports reinforce the more general impression that nanomaterial operations that work with a diverse set of phases are more inclined to use a cleanroom.

Table 32: Reported use of cleanrooms by phases of nanomaterial during handling

Category	Number of organizations	Number using cleanroom	Percent
Dry powder and in suspension	15	2	13.3%
Dry Powder only	6	0	0.0%
In suspension only	3	1	33.3%
In suspension and embedded/bound	23	9	39.1%
Dry powder, in suspension, and embedded/bound to a surface	6	4	66.7%
Embedded/bound to a surface only	2	0	0.0%
Dry powder and in a matrix	6	3	50.0%

Cleanrooms were used with a variety of different types of nanomaterials (Table 33). The highest reports of cleanroom use came from organizations working with nanocrystals (5 of 7), fullerenes (7 of 12) and nanowires (4 of 8). A significant minority of organizations working with quantum dots (4 of 9), nanopowders (12 of 34), carbon nanotubes (11 of 29), and polymers (3 of 9) also reported using a cleanroom as a part of their nanomaterial operations.

Table 33: Reported use of cleanrooms by nanomaterial type

	Number	Number using cleanroom	Percent
Nanopowders	34	12	35.3%
Carbon Nanotubes	29	11	37.9%
Colloidal Dispersions	19	6	31.6%
Fullerenes	12	7	58.3%
Quantum Dots	9	4	44.4%
Polymers	9	3	33.3%
Nanowires	8	4	50.0%
Nanocrystals	7	5	71.4%
Carbon Black	7	3	42.9%
Other	17	4	23.5%

Cleanrooms tended to be utilized by older organizations and organizations that have been in the nanotechnology field longer. Organizations that employed less than 50 persons in the handling of nanomaterials and worked with small to medium amounts of nanomaterials at any given time had higher reports of cleanroom use. Very few organizations that worked only with materials in a single phase reported doing so in a cleanroom. In general, cleanrooms were utilized by operations that were diverse in the nanomaterials used and the phases in which they were handled.

HVAC

Organizations were asked about separate and isolated Heating, Ventilation, and Air conditioning (HVAC) systems in the areas where nanomaterials were handled. Twenty three organizations reported using a separate HVAC system. Sixteen of 20 reports came from smaller operations with less than 50 employees handling nanomaterials although most large organizations in the sample also reported using this control (Table 34).

Table 34: Reported use of HVAC systems by number of employees handling nanomaterials

	Number of organizations	HVAC	Percent
1-9 employees	26	6	23.1%
10-49 employees	27	10	37.0%
50-249 employees	6	3	50.0%
250 or more employees	5	4	80.0%

Twelve of twenty five North American organizations reported using separate HVAC systems (Table 35). This was comparable to European organizations that also reported use of separate HVAC systems. Asian organizations reported the lowest use of separate HVAC systems (5 of 25).

Table 35: Reported use of HVAC systems by region

Region	Number of organizations	Number using HVAC	Percent
Asia	25	5	20%
Europe	11	5	45%
North America	25	12	48%
Other	3	1	33%

Separate HVAC systems were used by organizations working with a variety of different amounts of nanomaterials at any one time (Table 36). Only two of eleven organizations working with only with amounts greater than a kilogram or only with less than one gram reported using a separate HVAC system. Organizations that worked with a variety of amounts reported greater usage. For instance, half of the organizations working with less than one milligram of nanomaterials at a time reported using a separate HVAC system. Thirteen of thirty eight organizations working with less than one kilogram of nanomaterials reported usage of a separate HVAC system, although some also worked with amounts greater than one kilogram.

Table 36: Reported use of HVAC systems by amount of nanomaterial handled

	Number of organizations	Number using HVAC	Percent
Less than one kilogram	38	13	34.2%
Less than one gram	23	8	34.8%
Less than one milligram	10	5	50.0%
Greater than one kilogram	26	10	38.5%
Only less than one gram	11	2	18.2%
Only one kilogram or greater	11	2	18.2%

Separate HVAC systems were used by organizations that worked with nanomaterials in a variety of phases (Table 37). The lowest share of reports came from organizations working with nanomaterials in a single phase only. Organizations that worked with dry powder only or nanomaterials bound to a surface only reported no usage of a separate HVAC system and only one of three organizations that worked only with solutions reported also using an HVAC system. On the other hand, four of six organizations that worked with dry powder and with nanomaterials bound to a surface reported using a separate HVAC system, as did nine of twenty three organization that worked with solutions and embedded on a surface, five of fifteen organizations working with dry powder and in suspension, and three of six organizations working with nanomaterials in dry powder, in suspension and bound to a surface.

Table 37: Reported use of HVAC systems by phase of nanomaterial during handling

Category	Number or organizations	Number using HVAC	Percent
Dry powder and in suspension	15	5	33.3%
Dry powder only	6	0	0.0%
In suspension only	3	1	33.3%
In suspension and embedded/bound	23	9	39.1%
Dry powder, in suspension, and embedded/bound to a surface	6	3	50.0%
Embedded/bound to a surface only	2	0	0.0%
Dry powder and embedded/bound	6	4	66.7%

Many organizations working with nanocrystals (5 of 7) and nanowires (5 of 8) reported using a separate HVAC system in their nanomaterial operations (Table 38). Roughly half of the organizations working with fullerenes, quantum dots, and nanopowders reported using separate HVAC systems, compared to approximately a quarter of organizations working with carbon nanotubes.

Table 38: Reported use of HVAC system by type of nanomaterial

	Number	Number using HVAC	Percent
Nanopowders	34	16	47.1%
Carbon Nanotubes	29	8	27.6%
Colloidal Dispersions	19	8	42.1%
Fullerenes	12	6	50.0%
Quantum Dots	9	5	55.6%
Polymers	9	3	33.3%
Nanowires	8	5	62.5%
Nanocrystals	7	5	71.4%
Carbon Black	7	3	42.9%
Other	17	13	76.5%

HVAC systems were used by organizations with fewer numbers of employees working with a variety of amounts of nanomaterials at any given time. Few organizations that reported working only in very large or very small amounts reported using this control. HVAC systems reportedly were used with nanopowders and nanotubes in either the dry powder form or in dispersions.

Most reports of separate HVAC systems came from organizations that had been working with nanomaterials for five or less years. However, half also came from organizations that had been in existence for over eleven years suggesting that it is well established organizations that have recently moved into the nanotechnology field that are inclined to utilize this control. As with cleanrooms, separate HVAC systems were used by organizations with fewer employees handling nanomaterials and who worked with nanomaterials in a variety of phases. Again, like cleanrooms, few organizations that worked only with materials in a single phase reported using this control. The similarities with reports of cleanroom use were not surprising since cleanrooms require a separate HVAC system in order to maintain a sterile environment. Fourteen of 23 reports of the use of HVAC systems correlated with reports of clean room use.

Closed piping systems

Respondents were asked whether their nanomaterials operations utilized a separate plumbing system that would segregate any materials deposited down a drain into a separate collection system. Thirteen affirmative responses were collected through telephone interviews, which permitted clarification of the meaning of this engineering control. Some of these responses defined a closed piping system as an enclosed process, where no nanomaterial leaves the system. Of the other affirmative responses to this question, two of nine were ignored because the respondent indicated a meaning different than intended by the question. Twenty of 64 organizations reported using a closed piping system (separate drain) for their nanomaterial operations. Thirteen of twenty reports came from organizations that began working with nanomaterials less than five years ago and half came from organizations that began in that same time period. Half of the reports of use of this control came from smaller organizations employing less than 10 persons in the handling of nanomaterials (Table 39).

Table 39: Reported use of closed piping system by number of employees handling nanomaterials

	Number of organizations	Number using closed piping system	Percent
1-9 employees	26	10	38.5%
10-49 employees	27	6	22.2%
50-249 employees	6	1	16.7%
250 or more employees	5	3	60.0%

Nine of twenty five Asian organizations reported using a closed piping system (Table 40). This was similar to that reported by European organizations. North American organizations appeared to be the least likely to use this control (6 of 25).

Table 40: Reported use of closed piping system by region

Region	Number of organizations	Use of closed piping system	Percent
Asia	25	9	36%
Europe	11	4	36%
North America	25	6	24%
Other	3	1	33%

Closed piping systems were reported at greater frequency by organizations working with larger amounts of nanomaterials (Table 41). Eleven of twenty six organizations working with amounts greater than one kilogram reported using a closed piping system. Of the eleven organizations that worked only with amounts greater than one kilogram, six (55%) reported using a closed piping system. On the other hand, two of eleven organizations working with only less than one gram reported using this control compared to three of ten organizations working with amounts less than one milligram.

Table 41: Reported use of closed piping system by amount of nanomaterial handled

	Number of organizations	Use of closed piping system	Percent
Less than one kilogram	38	9	23.7%
Less than one gram	23	4	17.4%
Less than one milligram	10	3	30.0%
Greater than one kilogram	26	11	42.3%
Only less than one gram	11	2	18.2%
Only one kilogram or greater	11	6	54.5%

Organizations working with nanomaterials in a variety of phases reported using a closed piping system (Table 42). Half of the organizations working with nanomaterials in suspension only reported using a closed piping system versus a third of organizations working with dry powder. One of three organizations working only with nanomaterials bound to a surface reported using this control.

Table 42: Reported use of closed piping system by phase of nanomaterial during handling

Phase	Number of organizations	Use of closed piping system	Percent
Dry powder only	15	5	33.3%
In suspension only	6	3	50.0%
Embedded/bound to a surface only	3	1	33.3%
Dry powder and in suspension	23	6	26.1%
In suspension and embedded/bound	6	0	0.0%
Dry powder and embedded/bound	2	1	50.0%
Dry powder, in suspension, and embedded/bound	6	4	66.7%

Closed piping systems were utilized by many organizations that worked with different types of nanomaterials (Table 43). Four of seven organizations that worked with nanocrystals or with carbon black reported use of a closed piping system. Of the materials most frequently reported, fourteen of thirty four organizations that worked with nanopowders also reported use of a closed piping system compared to eight of twenty nine organizations working with carbon nanotubes.

Table 43: Reported use of closed piping system by nanomaterial type

	Number	Using closed piping system	Percent
Nanopowders	34	14	41.2%
Carbon Nanotubes	29	8	27.6%
Colloidal Dispersions	19	7	36.8%
Fullerenes	12	3	25.0%
Quantum Dots	9	3	33.3%
Polymers	9	4	44.4%
Nanowires	8	3	37.5%
Nanocrystals	7	4	57.1%
Carbon Black	7	4	57.1%
Other	17	9	52.9%

Closed piping systems were used by newer organizations with fewer employees handling nanomaterials but who worked with large amounts at any given time. North American organizations were the least likely to report using this control. Closed piping systems were used with a variety of nanomaterials and in a variety of phases, although reports are higher for organizations working with powders and suspensions.

Laminar flow clean benches

Fifteen of sixty four organizations reported the use of laminar flow clean benches, which was reported more by organizations employing fewer people in the handling of nanomaterials (Table 44). Eleven of fifty three organizations employing less than forty nine people reported using a laminar flow clean bench. These organizations accounted for over 73% of all reported uses of this control.

Table 44: Reported use of laminar flow clean benches by number of employees handling nanomaterials

	Number of organizations	Number using laminar flow clean bench	Percent
1-9 employees	26	4	15.4%
10-49 employees	27	7	25.9%
50-249 employees	6	1	16.7%
250 or more employees	5	3	60.0%

Use of laminar flow clean benches was reported in equal shares (five each) across regions (Table 45). This was equivalent to 45% of the sample originating in Europe but only twenty percent of organizations from Asia or North America.

Table 45: Reported use of laminar flow clean benches by region

Region	Number of organizations	Use of laminar flow clean bench	Percent
Asia	25	5	20%
Europe	11	5	45%
North America	25	5	20%
Other	3	0	0%

Organizations working with smaller amounts of nanomaterials had higher reports of laminar flow clean bench use (Table 46). No organization that handled only greater than a kilogram of nanomaterials at a given time reported using a laminar flow clean bench. However, four of ten organizations working with less than a milligram and three of eleven organizations working only with less than one gram reported utilizing this control.

Table 46: Reported use of laminar flow clean benches by amount of nanomaterial handled

	Number of organizations	Use of laminar flow clean bench	Percent
Less than one kilogram	38	9	23.7%
Less than one gram	23	6	26.1%
Less than one milligram	10	4	40.0%
Greater than one kilogram	26	6	23.1%
Only less than one gram	11	3	27.3%
Only one kilogram or greater	11	0	0.0%

Respondents indicated that laminar flow clean benches were used with nanomaterials in a variety of phases and combinations of phases (Table 47). The single highest number of reports of utilizing a laminar flow clean bench in nanomaterial operations came from organizations working with nanomaterials as a dry powder and in suspension (7 of 23).

Table 47: Reported use of laminar flow clean benches by phase of nanomaterial during handling

Phase	Number of organizations	Use of laminar flow clean bench	Percent
Dry powder only	15	1	6.7%
In suspension only	6	1	16.7%
Embedded/bound to a surface only	3	0	0.0%
Dry powder and in suspension	23	7	30.4%
In suspension and embedded/bound	6	2	33.3%
Dry powder and embedded/bound	2	0	0.0%
Dry powder, in suspension, and embedded/bound	6	4	66.7%

The use of laminar flow clean benches was reported with a variety of types of nanomaterials (Table 48). The single highest number of reports came from organizations working with nanopowders (11 of 34). Over half of the organizations working with carbon black also reported using this control compared to over forty percent of organizations working with dispersions, quantum dots, and nanocrystals.

Table 48: Reported use of laminar flow clean benches by nanomaterial type

	Number	Using laminar flow clean bench	Percent
Nanopowders	34	11	32.4%
Carbon Nanotubes	29	7	24.1%
Colloidal Dispersions	19	8	42.1%
Fullerenes	12	3	25.0%
Quantum Dots	9	4	44.4%
Polymers	9	3	33.3%
Nanowires	8	2	25.0%
Nanocrystals	7	3	42.9%
Carbon Black	7	4	57.1%
Other	17	5	29.4%

Laminar flow clean benches were used by smaller organizations and organizations that worked with smaller amounts of nanomaterials at any given time. They were used primarily by organizations working with powders in the dry form or in suspension. One organization noted that the primary purpose of laminar flow clean bench use was to keep the material clean. However, another respondent noted that this control was their primary engineering control and was selected due to its ability to prevent inhalation of powder form materials. There appeared to be no strong trend in the use of this control by region or by age of the organization.

Biological safety cabinets

Twelve of sixty four organizations reported using biological safety cabinets in their nanomaterial operations. This control was more frequently cited by organizations older than 25 years (6 of 12) and organizations that had been in the nanotechnology field longer – nine of twelve reports came from organizations that had been working with nanomaterials for five years or more. These reports were spread evenly across categories of organizations based on the number of employees working with nanomaterials (Table 49).

Table 49: Reported use of biological safety cabinets by number of employees handling nanomaterials

	Number of organizations	Number using biological safety cabinet	Percent
1-9 employees	26	3	11.5%
10-49 employees	27	4	14.8%
50-249 employees	6	2	33.3%
250 or more employees	5	3	60.0%

North American organizations reported half of the total reports of biological safety cabinet use (Table 50).

Table 50: Reported use of biological safety cabinets by region

Region	Number of organizations	Use of biological safety cabinet	Percent
Asia	25	3	12%
Europe	11	2	18%
North America	25	7	28%
Other	3	0	0%

Higher instances of reported use of biological safety cabinets came from organizations working with a range of smaller amounts of nanomaterials at any given time (Table 51). No organization that worked with amounts greater than one kilogram reported using a biological safety cabinet. Furthermore, only one organization that worked with less than one gram reported using this control. Eight of thirty organizations working with less than one kilogram reported use of this control as did four of eight organizations working with less than one gram (but greater amounts as well).

Table 51: Reported use of biological safety cabinets by amount of nanomaterial handled

	Number of organizations	Use of biological safety cabinet	Percent
Less than one kilogram	38	8	21.1%
Less than one gram	23	4	17.4%
Less than one milligram	10	2	20.0%
Greater than one kilogram	26	4	15.4%
Only less than one gram	11	1	9.1%
Only one kilogram or greater	11	0	0.0%

Biological safety cabinets were used with nanomaterials in a variety of phases (Table 52). The single highest number (4 of 23) of reported uses of this control came from organizations working with nanomaterials in dry powder form and in a suspension.

Table 52: Reported use of biological safety cabinets by phase of nanomaterial during handling

Phase handled	Number of organizations	Use of biological safety cabinets	Percent
Dry Powder only	15	2	13.3%
In suspension only	6	1	16.7%
Embedded/bound to a surface only	3	0	0.0%
Dry powder and in suspension	23	4	17.4%
In suspension and embedded/bound	6	2	33.3%
Dry powder and embedded/bound	2	0	0.0%
Dry powder, in suspension, and embedded/bound	6	3	50.0%

Biological safety cabinets were used with a variety of types of nanomaterials (Table 53). The single highest number of reports came from organizations working with nanopowders. Ten of thirty four of these organizations reported using biological safety cabinets in their nanomaterial operations.

Table 53: Reported use of biological safety cabinets by nanomaterial type

	Number	Using biological safety cabinet	Percent
Nanopowders	34	10	29.4%
Carbon Nanotubes	29	3	10.3%
Colloidal Dispersions	19	7	36.8%
Fullerenes	12	2	16.7%
Quantum Dots	9	4	44.4%
Polymers	9	4	44.4%
Nanowires	8	3	37.5%
Nanocrystals	7	3	42.9%
Carbon Black	7	3	42.9%
Other	17	10	58.8%

One organization indicated that their biological safety cabinet, type 2b2, did not re-circulate air like conventional biological safety cabinets. The air was HEPA-filtered before being exhausted, thus preventing the emission of nanomaterials into the environment. While this type of cabinet was available commercially, it did not appear to be widely utilized for nanomaterial applications.

Biological safety cabinets were used by older organizations that had been in the nanotechnology field for relatively longer. The cabinets were used by organizations working with a range of smaller amounts, particularly nanopowders in powder or suspended form or colloidal dispersions. North American organizations reported marginally higher use of this control compared to Asian or European organizations.

Pressure differentials

There were eighteen reports of the use of pressure differentials in nanomaterial operations facilities. Twelve of these indicated the use of a negative pressure differential and six reported the use of a positive pressure differential. Three quarters of the reports of negative pressure differentials came from organizations with less than fifty employees handling nanomaterials (Table 54). No organizations with nine or less employees handling nanomaterials reported the use of a positive pressure differential. However, half of the reports of a negative pressure differential came from these organizations. In addition, half of the reports of positive pressure differentials and a quarter of the reports of negative pressure differentials came from organizations with greater than ten but less than 50 employees working with nanomaterials. Two very large organizations reported the use of both types of pressure differentials.

Table 54: Reported use of pressure differentials by number of employees handling nanomaterials

	Number of organizations	Positive	Percent	Negative	Percent
1-9 employees	26	0	0.0%	6	23.1%
10-49 employees	27	3	11.1%	3	11.1%
50-249 employees	6	1	16.7%	1	16.7%
250 or more employees	5	2	40.0%	2	40.0%

Five out of six reports of the use of a positive pressure differential came from organizations originating in North America (Table 55). Half of the reports of negative pressure differential came from North America while two Asian organizations and three European organizations also reported using negative pressure differentials in their nanomaterials operations.

Table 55: Reported use of pressure differentials by region

Region	Number of organizations	Positive	Percent	Negative	Percent
Asia	25	1	4%	2	8%
Europe	11	0	0%	3	27%
North America	25	5	20%	6	24%
Other	3	0	0%	1	33%

Most reports of positive pressure differentials came from organizations handling a range of amounts but that included smaller amounts of nanomaterials at any given time (Table 56). No organization that worked only with amounts greater than one kilogram reported using a positive pressure differential and only one of eleven that worked only with a gram or less reported using a negative differential. On the other hand, six of twenty six organizations that work with amounts of nanomaterials greater than one kilogram reported utilizing a negative pressure differential. In addition, five of thirty eight organizations working with less than a kilogram indicated the use of a negative pressure differential.

Table 56: Reported use of pressure differentials by amount of nanomaterial handled

	Number of organizations	Positive	Percent	Negative	Percent
Less than one kilogram	38	4	10.5%	5	13.2%
Less than one gram	23	3	13.0%	3	13.0%
Less than one milligram	10	2	20.0%	3	30.0%
Greater than one kilogram	26	1	3.8%	6	23.1%
Only less than one gram	11	1	9.1%	1	9.1%
Only one kilogram or greater	11	0	0.0%	1	9.1%

Organizations reported using pressure differentials with nanomaterials in a variety of phases (Table 57). Organizations working with nanomaterials bound to a surface or embedded on a matrix and dry powder did not report the use of a positive pressure differential. Two thirds of reports of the use of a negative pressure differential came from organizations working with nanomaterials as dry powders and in suspension as well as from organizations working with nanomaterials as dry powders, in suspension, and bound to a surface.

Table 57: Reported use of pressure differentials by phase of nanomaterial during handling

Phase	Number of organizations	Positive	Percent	Negative	Percent
Dry Powder only	15	1	6.7%	1	6.7%
In suspension only	6	1	16.7%	1	16.7%
Embedded/bound to a surface only	3	0	0.0%	2	66.7%
Dry powder and in suspension	23	1	4.3%	4	17.4%
In suspension and embedded/bound	6	1	16.7%	0	0.0%
Dry powder and embedded/bound	2	0	0.0%	0	0.0%
Dry powder, in suspension, and embedded/bound	6	2	33.3%	4	66.7%

Pressure differentials were used by organizations working with a variety of types of nanoparticles (Table 58). The single highest numbers of reports of both types of pressure differentials came from organizations working with nanopowders.

Table 58: Reported use of pressure differentials by nanomaterial type

	Number	Positive	Percent	Negative	Percent
Nanopowders	34	5	14.7%	6	17.6%
Carbon Nanotubes	29	1	3.4%	4	13.8%
Colloidal Dispersions	19	2	10.5%	2	10.5%
Fullerenes	12	1	8.3%	1	8.3%
Quantum Dots	9	2	22.2%	1	11.1%
Polymers	9	1	11.1%	2	22.2%
Nanowires	8	1	12.5%	0	0.0%
Nanocrystals	7	1	14.3%	1	14.3%
Carbon Black	7	1	14.3%	1	14.3%
Other	17	4	23.5%	3	17.6%

Use of pressure differentials was not reported widely especially when compared to reports of cleanroom use, where use of pressure differentials was standard. While there were 22 organizations that reported use of a cleanroom, only six organizations reported using positive pressure differentials. Negative pressure differentials were reported twice as many times. In each case, most reports came from North American organizations. Pressure differentials were reported in higher numbers by organizations that worked with nanomaterials in a variety of small and medium amounts as well as a variety of types of nanomaterials and in multiple phases.

Specialized controls

A subset of total responses offered additional information about the engineering controls utilized in their nanomaterial operations. These specialized controls include:

- Sixteen organizations indicated that all or part of their nanomaterial operations was enclosed to prevent worker exposure. Fourteen of the responses were from companies versus academic or research labs. Ten of the organizations were located in North America. This is an important finding because several other organizations reported using certain engineering controls less to protect workers from exposure than to prevent the loss of the nanomaterial or to protect the material from the ambient environment. All of these reports were collected through telephone interviews, which could explain, in part, the under-representation of Asian organizations, most of which submitted written questionnaires, in these findings.

- One organization reported the use of an air lock and sealed containers for collecting nanomaterials from the reactor. The reactors operated in a vacuum and collection was done automatically in the air lock, into an environmentally-sealed container. The air lock allowed for any residual particulate matter to be removed by vacuum before removing the sealed container from the reactor. This process was built in- house.
- One organization synthesized its nanomaterials in an enclosed environment that was vented automatically before opening and also had a self-cleaning burn cycle to eliminate residual material. This device fit in the fume hood and was engineered in-house.
- One organization noted that their clean rooms had positive pressure differentials that could be exhausted with intermediate spaces of lower pressure between labs and offices.
- One organization described using portable peristaltic pumps to transfer liquid to waste containers in order to prevent potential spills and reduce aerosolization of the material. Peristaltic pumps, because they work on positive displacement, are less prone to producing aerosols as opposed to conventional high pressure pumps. The organization noted that they made this engineering control decision with the help of NIOSH. Their facility was designed to be flexible and upgradeable as new technologies and information become available.
- One organization reported using a distillation system for evaporating solvent from a colloidal dispersion within an explosion-proof enclosure. This enclosure was designed with concern for the potential for these particular nanomaterials to be explosive.
- One organization described using an in-line disperser device, which would open a bag of fine particulate feed stock and transfer the material to the chemical reactor in order to minimize handling of the dry powder form. The device would mechanically dispose of the used bag into a waste drum. Use of this device within a HEPA filtered enclosure would allow for an exposure and emission-free process. Devices such as these are available commercially, but based upon the frequency of appearances in our data, are not well known.
- One organization described a remote control set up for the nanomaterial production equipment. This allowed the equipment to be operated in an isolated environment within a ventilation enclosure. Only certain trained and respirator-equipped individuals would be allowed access to the room for cleaning or maintenance.
- One organization described the use of safety alarms for their nanomaterial production. Within the closed system were two sensors for changes in oxygen and pressure. If either sensor was activated, the equipment shuts down, which should prevent the potential release of nanomaterials due to a malfunction or accident.

Participants reported using a variety of engineering controls. Although some organizations detailed specialized or modified engineering controls for nanomaterials applications, most reported using commercially available, off-the-shelf technologies.

There were significant differences between continents in the use of these controls. For instance, of 11 European organizations, only one reported the use of a cleanroom, but most reported using fume hoods and about half reported using glove boxes and bags and separate HVAC systems. In addition, compared to North American organizations, Asian organizations used fewer “high–end” engineering controls with only eight reports of cleanrooms and 13 reports of fume hoods. At the same time, these organizations reported greater use of glove boxes and bags.

In general, larger organizations that handled a number of different nanomaterials in a variety of phases and engaged in a variety of nano-related operations reported the use of all engineering controls in higher numbers. This result likely is a product, at least in part, of the higher capital costs of using engineering controls for safety compared to lower cost controls such as PPE. The pattern holds true, particularly for reports of fume hoods, cleanrooms, HVAC systems and closed piping systems.

While the use of engineering controls has significant implications for environmental health and safety, it is not clear that all specific controls were chosen primarily out of concern for the particular EHS implications of working with materials at the nano-scale. As noted, while fume hoods were used less frequently with materials in the powder form, when employed, the ventilation system may be shut off to protect the sample. In addition, the use of fume hoods with dispersions suggested that the primary EHS concern was with the solvent being used rather than the nanomaterial itself. Similarly, respondents indicated that glove boxes and bags were at times used primarily to protect the integrity of the material sample rather than out of concern for worker exposure.

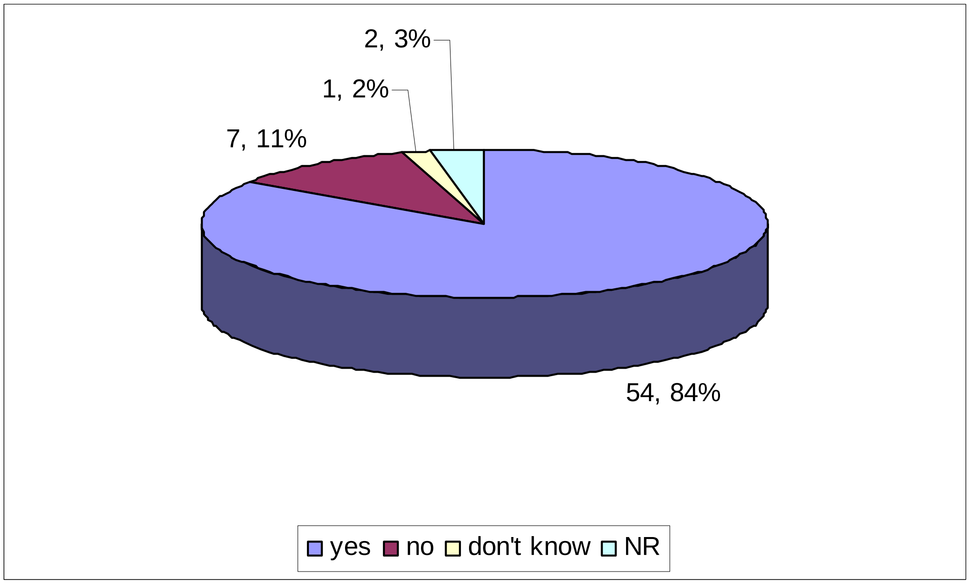
On the other hand, fourteen organizations reported utilizing enclosed systems designed to limit worker exposure. Furthermore, others reported engineering controls to limit other forms or risks associated with nanomaterials, such as the heightened flammability of nano-scale powders. Clearly, a significant portion of the sample population was concerned with utilizing engineering controls to limit worker exposure to nanomaterials.

Personal Protective Equipment and Clothing (PPE)

The respondents were asked if their organization has PPE recommendations for its employees when working with nanomaterials, and if so, what those recommendations were. The intent of these questions was both to gain an understanding of what types of PPE are currently being used in the nanotechnology workplace and to uncover unconventional PPE strategies. These questions were divided into categories to help respondents be as thorough as possible in describing their organization’s recommendations, which also helped compartmentalize discussions during telephone interviews.

Fifty-four of the respondents, or 84% of the survey sample, indicated their organization had recommendations for its employees regarding personal protective equipment and clothing that should or should not be worn in the lab while working with nanomaterials (Figure 17). Of the remaining ten responses, seven indicated his/her organization did not have PPE recommendations for its employees, one did not know, and two did not respond. Two reasons given for why organizations did not have PPE recommendations were: 1) the employees did not handle nanomaterials directly (e.g., it is contained in a reactor), and 2) the employees were expected to understand what they were individually working with and protect themselves accordingly – everyone works with different materials and therefore, it is too difficult to anticipate everyone's needs.

Figure 17: Numbers of organizations with PPE recommendations for its employees when working with nanomaterials



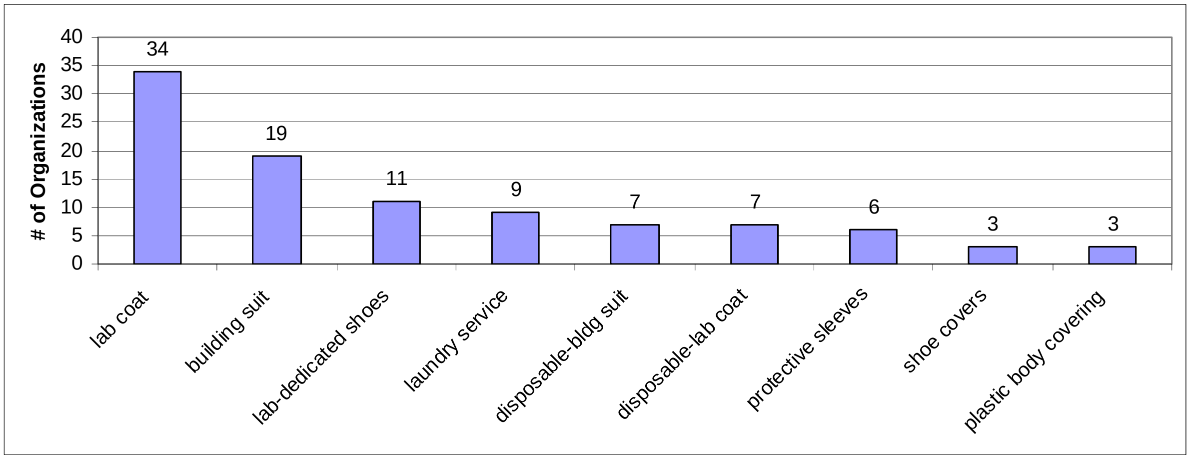
Cross-analyses also were performed on the PPE response data to investigate their relationship with industry, company size and age, geographical location, and material. Results indicated no apparent association between the business type and/or whether the organization manufactured, used, or performed research and development on nanomaterials, and the provision of PPE recommendations. Similarly, there was no apparent connection between nano-division age, nano-division size, overall size of company, and/or country of origin and reports that the organization had PPE recommendations. However, results were suggestive that older companies (regardless of how long the company has been working with nanomaterials) were more likely to have PPE recommendations for its employees. Taking into account the nanomaterials with which these organizations were working, there was no clear association between the material form, phase, amount handled, and/or generally the elemental composition with reports of PPE recommendations. However, the "carbonaceous" elemental category contained all the "no PPE recommendations" mentioned by respondents, with the exception of two non-responses from organizations that only worked with non-carbonaceous dispersions.

Clothing

Forty-seven of the respondents (73%) indicated their organization had recommendations specifically for clothing that should or should not be worn while working with nanomaterials. Sixteen respondents did not answer this question. See Figure 18.

Thirty-four respondents recommended lab coats, and nine of these respondents identified the material as cotton (note: one response stating that a "standard" lab coat is recommended was not assumed to be cotton), one as nylon, and three as disposable material (e.g., Tyvek, plastic). In one case, the employees were encouraged to wear a disposable lab coat over their cotton lab coat. Nineteen of the respondents indicated a building suit (e.g., “bunny suit,” overalls, “working suit”) was recommended, and eleven of these specified disposable building suits, usually made of Tyvek. Ten of the organizations recommended either a lab coat or a building suit, depending on the amount of exposure to nanomaterials (a building suit would be used for higher exposure). When working at high exposure activities, four organizations recommend that employees wear a disposable, typically plastic, body covering over their standard work clothes. Other recommendations included lab-dedicated shoes (7), protective sleeves (3), and shoe covers/booties (3). Eleven respondents indicated they specifically told their employees not to wear their work clothes home, and seven specified work clothing should be laundered. Laundry periods varied greatly among the responses: weekly, monthly, “frequency not known,” and “regular” cleaning. Generally, few respondents explained the reasons for their recommended clothing choices, although some indicated the choices were made based on “non-nano” reasons. For example, one respondent indicated that the use of building suits was meant to protect the product and not the employee.

Figure 18: Recommended clothing when working with nanomaterials



Gloves

Fifty of the 64 respondents (78%) indicated that recommendations on gloves were provided to employees. One responded “unknown” and thirteen were non-responses.

Respondents indicated a number of glove materials were utilized, most often nitrile (12), latex (7), and rubber (6). Five respondents indicated the use of other materials, including PVC, polyethylene, neoprene, and leather. Two responses obtained via third party and written means could not be deciphered; they were called “skin gloves” and “special gloves.” Long gloves that cover the wrists were mentioned by seven respondents. One respondent indicated that double gloves were recommended, another that wrist barriers were used, and a third that gloves with cuffs were standard lab wear.

The reasons for glove recommendation choices were not explained by every respondent. However, ten respondents did indicate their choices were based specifically on chemical compatibility; seven indicated that the use of specific glove types was application specific, and two stated a cost concern. One respondent stated nitrile gloves were recommended by their organization because nitrile has a lower number of perforations.

Another stated that their organization does not believe gloves are impervious, but rather a barrier of protection.

Eye Protection

When asked if their organization had recommendations for eye protection, 48 of the respondents (75%) indicated that such recommendations existed. One responded “no”, one did not know, and fourteen did not respond.

Safety glasses were mentioned by 33 respondents, and twelve of these responses specified side shields. Twenty-four respondents listed goggles as recommended eye protection when working with nanomaterials. Ten respondents listed both safety glasses and goggles, usually stating that goggles were required in specific areas; however, it was not made clear if the choice between safety glasses and goggles was dependent on whether nanomaterials were being handled. Eight respondents indicated that a full-face shield was recommended, but not always for nano-specific reasons (e.g., when there is increased exposure to solvents or hot material); however, one respondent said a full-face shield was recommended specifically when powders were being handled. Three respondents said that contact lenses were allowed in the lab; one respondent said they were not.

Miscellaneous

In this category, recommendations pertaining to disposable dust masks, hair bonnets, and other PPE not previously mentioned were extracted from the respondents. In particular, unconventional PPE strategies were being sought. Twenty-six of the respondents indicated their organization did have such recommendations, where three indicated they did not and 35 (or 55%) were non-responses. However, one of the “no” responses indicated previously that nanomaterials were enclosed in their process, and that the employees did not handle it directly.

Twenty respondents indicated disposable dust masks are recommended for employee use when working with nanomaterials, and 6 mentioned hair bonnets. One response indicated that “special equipment” is required when working with nanomaterials, although no details were provided. One respondent indicated the use of a helmet, although it is unlikely this recommendation was made for protection from nanomaterials. Two respondents specifically indicated their recommendations were not made for nano-related reasons.

One respondent described advising employees who inhaled nanoparticles or fine powders to consume milk and high sugar content syrup, namely jaggery (unrefined sugar from sugar cane or the date palm). Drinking milk was recommended based upon anecdotal evidence of workers in flour mills exposed to fine particulates. Drinking milk the evening before work seemed to provide symptomatic relief. Advice to consume high sugar content syrup is supported by peer-reviewed research using rats[22].

One respondent described using anti-static shoes in areas where nanomaterials are handled. These were chosen due to the concern of the explosive properties of the nanomaterials. The shoes reduced the build-up of static charge, which could potentially ignite the materials.

Although not necessarily personal protective equipment, another respondent described the placement of sticky mats at lab entrances. These are sheets of sticky paper

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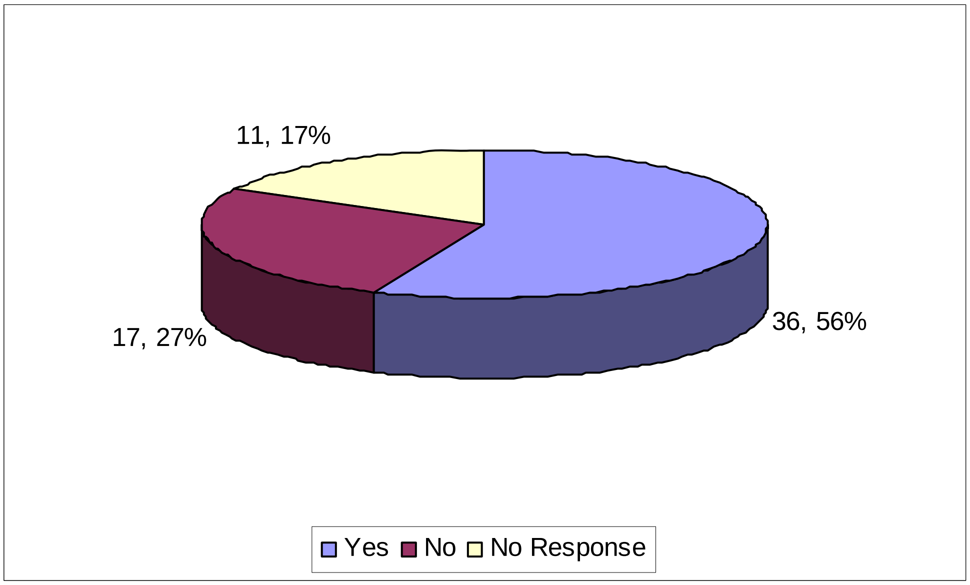
[22] Enhanced Translocation of Particles from Lungs by Jaggery. Environmental Health Perspectives. 1994: 102 (supplement 5): 211-214.

adhered to the floor that must be crossed when leaving the lab. It is intended that nanomaterials attached to the shoes of employees will stick to the mats and not be transferred to the rest of the building.

Respiratory Protection

This category investigated recommendations pertaining to respirators, and did not include recommendations for disposable dust masks. Thirty-six of the respondents, or just a little over half, indicated that employees used respiratory protection when working with nanomaterials (Figure 19). Seventeen did not. However, it should be noted that in two cases where respondents indicated respirators were not used, their responses implied that respirators in fact were used by employees when working with nanomaterials; taking this discrepancy into account would bring the number of "yes" responses to 38, or 59%. Eleven respondents did not answer the question.

Figure 19: Number of organizations that use respirators when working with nanomaterials



Reasons provided for not using respiratory protection varied. Three respondents stated their organization's engineering controls were sufficient to minimize worker exposure to nanomaterials. Three respondents stated that nanomaterials were not in a free form (i.e., they were bound), one stated that the quantities handled were very small, and another noted that nano-scale matter was contained in an enclosed process; therefore, the potential for worker exposure was minimal in all three scenarios and respiratory protection was not believed to be necessary. Three respondents indicated that dust masks were deemed sufficient protection when working with nanomaterials.

All respondents who indicated that their workers used respiratory protection while working with nanomaterials provided information on their chosen respirator, with two exceptions (both from the third party category). However, information provided by responders generally was not descriptive. The filter specifications mentioned were as follows:

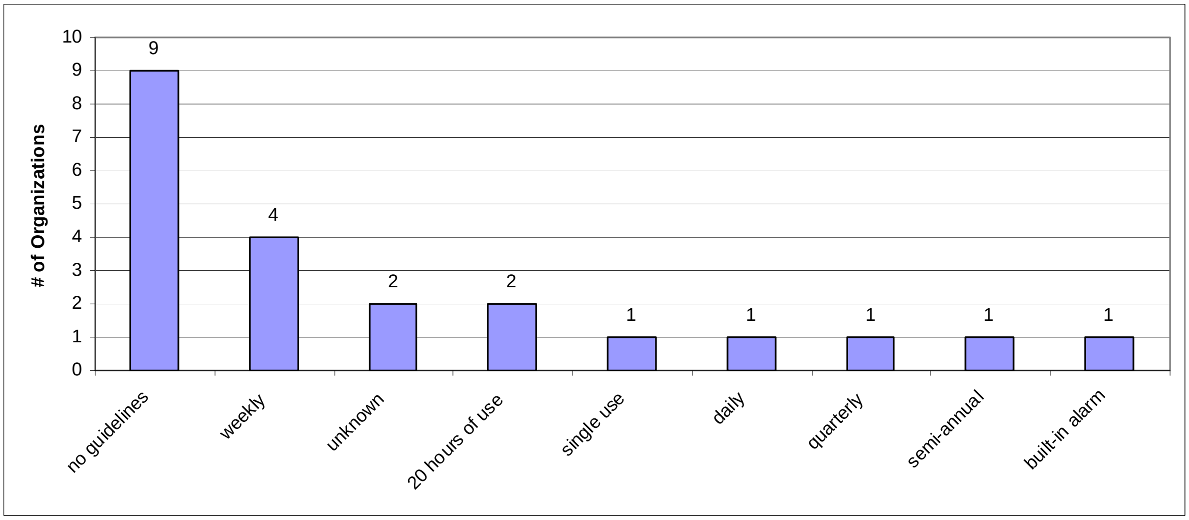
- United States: N/P100 (11) and N/P95 (4)

- Japan: RL3 (1), RL2 (1), DS3 (1)
- Europe: FFP3 (1), P3 (1)
- Australia: P2 (2), P1 (1)

One respondent stated the use of a 1-micron filter, and another the use of three-layer cotton filtration. Five respondents did not know their filter specifications. Nine of the respondents indicated they recommended a full face mask, 25 recommended a half mask, and one recommended a quarter mask that seals from the bridge of the nose to below the lips. One respondent indicated that a hood was used because it was easier to fit securely. Further, twenty-three of the respondents stated they used a cartridge respirator, and 14 stated their respirators were fully disposable. Two respondents indicated the use of a positive airflow pack that did not filter the air, but instead blew air away from the worker's face.

Respondents whose organization recommended cartridge and/or disposable respirators were asked about their change-out/disposable schedule (Figure 20). Fourteen respondents with respirator recommendations did not provide a response. Most of the respondents (9) indicated their organization had no guidelines; change-outs and disposal occurred when the filter was clogged, and in a couple cases, the respondents indicated this was made apparent only when the worker actually had difficulty breathing and/or smelled chemical vapors. Otherwise the responses varied greatly, ranging from single use (1), daily (1), after 20 hours of contact use (2), weekly (4), quarterly (1), and semi-annually (1). One respondent indicated their respirators employed a built-in alarm that sounded when the filter needed changing. One respondent indicated their respirators were changed-out at an "appropriate frequency" that was based on routine confirmation of pressure-differentials and respirability, and another respondent simply stated their change-out/disposal schedules varied by site. Two respondents stated they were uncertain of the changing/disposal schedules.

Figure 20: Respirator change-out and/or disposal schedules for # of Organizations



There were apparent trends for the choices made with respect to respiratory protection. Most choices were made based on recommendations made by government agencies (5), vendors/suppliers (3), other companies (2), literature (2), and by a consultant (1). Four respondents indicated their choice was made independently based on the filter specifications in comparison with the size of the nanomaterials begin handled. Two respondents referred to results of human exposure assessments, and one company relied on the results of its own related testing. Four respondents stated convenience as the sole reason for its choice of respirator, and two stated cost considerations. Two respondents indicated they chose their respirator based on solvent compatibility. One respondent did not know the reasoning behind his/her organization's selection of their recommended respirator. Interestingly, one respondent stated his organization's choice of respirator was inadequate for working with nanomaterial based on the filter specifications.

Multivariable Analyses of PPE Recommendations

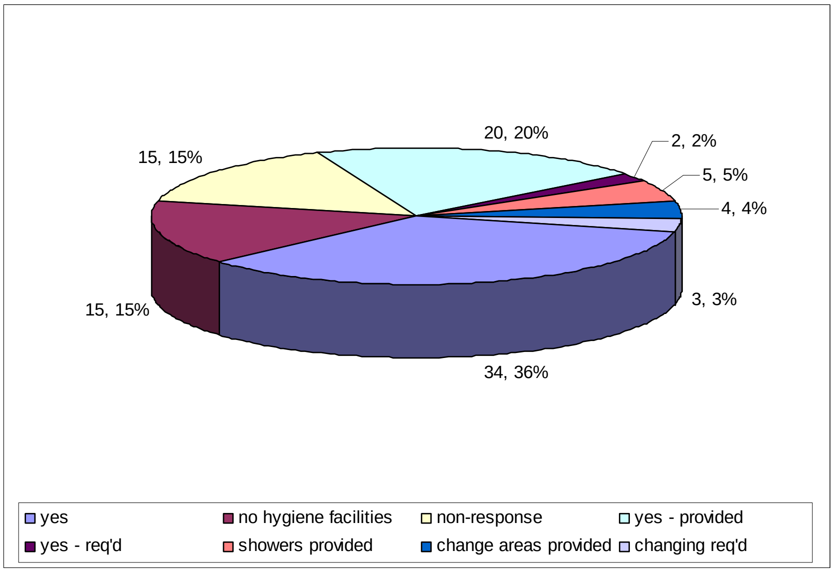
Cross-analyses were performed on the PPE response data to investigate their relationship with industry, company size and age, geographical location, and material. The results indicated that smaller companies generally have been more resourceful in their PPE recommendations. The smaller companies tended to provide more detail in their responses and were more likely to indicate "nano reasons" for their PPE recommendations. The smaller companies appeared to use more disposable PPE, and they focused more on minimizing skin exposure and waste disposal of contaminated items than larger organizations. In looking at the countries of origin, there were no strong patterns other than the Asian respondents reporting most often the use of glove materials other than nitrile and latex, e.g., rubber, PVC, PE, leather, and "skin gloves." Organizations in the U.S. tended to use full-face shields more often than other countries. Forty eight percent of organizations working with powder recommended dust masks to their employees, whereas 19% of the organizations that did not work with powder required dust masks when working with nanomaterials. Finally, 70% of companies whose employees typically worked with nanomaterials at a scale of micrograms to milligrams recommended lab coats, whereas only 45% of companies working at larger scales recommended lab coats.

Cross-analyses of respirator recommendations revealed trends in the data. Respirators were not used at organizations that worked only with nanomaterials both in solution and fixed/embedded on a surface, and only about half of the organizations working with nanomaterials either in solution or fixed/embedded used respirators; respirators were commonly used at all other organizations. The use of respirators tends to vary with the amount of nanomaterial being handled. Respirators were used at 35% of organizations working at the microgram to milligram scale, as opposed to 66% working at larger scales. Similarly, 71% of the organizations working at pilot and/or full/commercial production used respirators, and 52% working at small scales used respirators. Respirators were used at 100% of organizations that stated they worked in the Chemicals sector and 93% of those in Nanomaterials Manufacturing; respirators were used by only 50% of the other business categories. Respirators were used by 72% of organizations that manufactured nanomaterials, but at only 36% of organizations that were non-manufacturers of nanomaterials (e.g., users and research and/or development). Interestingly, 34 out of the 36 manufacturers in the survey sample also conducted R&D, and 23 also were users of nanomaterials. Respirators tended to be used more often at smaller organizations – 75% at organizations four years and younger, as opposed to 48% at organizations older than four years. Seventy three percent of the organizations in Japan used respirators when working with nanomaterials, as opposed to only 44% of organizations in the U.S. In terms of specific respirators being used, the only apparent trends were that change-out/disposal schedules were more frequent at higher scales of production and among organizations that worked with nanomaterials in the dry powder form.

Hygiene Facilities

Respondents were asked whether changing rooms and/or showers were available for employee use, and if their use was required by employees that worked with nanomaterials. Thirty-four of the respondents indicated that one or both were available, 15 stated they were not available, and 15 were non-responses (Figure 21). Of those who indicated that hygiene facilities were available, 20 stated generally that these facilities were provided, two stated these facilities were provided and their use was required, five stated that only showers were available (but not necessarily required), three provided only changing areas (but did not necessarily require use), and three provided and required the use of changing rooms.

Figure 21: Hygiene facilities



Organization Policy on Use of PPE Recommendations

Of the fifty-four organizations that provided PPE recommendations to their employees for working with nanomaterials, 10 indicated the use of this PPE was not mandatory. Only one respondent explained why PPE was not mandatory – the organization had implemented a voluntary approach to PPE, and each employee could decide for himself/herself what PPE was needed for adequate protection.

Summary of PPE Recommendations

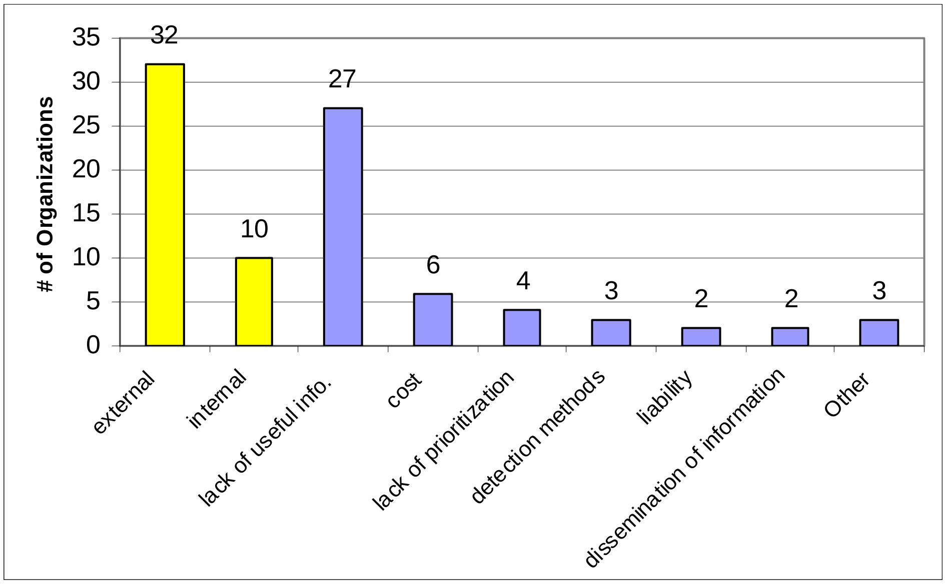
Overall, most organizations reported having PPE recommendations for their employees while working with nanomaterials, although conventional lab wear was most often reported as the recommended means of protection. For instance, lab coats and/or building suits, latex and/or nitrile gloves, safety glasses and dust masks were the most common form of equipment recommended to employees when handling nanomaterials. Most respirators were chosen based on recommendations from a governmental agency, the vendor/supplier, and/or based on compatibility with nanomaterial dimensions. When examined in conjunction with geographic location, industry, company age and/or size, and material being handled, there were few strong patterns apparent in the data. Respirators were used frequently when working with nanomaterials or performing high exposure activities, especially in the Chemicals and Nanomaterial Manufacturing sectors. A majority of employees in Japan used respirators, whereas fewer than half of the US respondents reported the use of respirators. In addition, younger companies were more likely to use respirators. Dust masks were used most commonly by employees working with dry powder, and Asian respondents more often reported the use of glove materials other than latex and nitrile.

Some respondents indicated their organizations did not recommend PPE for employees when handling nanomaterials because they did not believe a risk existed or their engineering controls were deemed sufficient to minimize working exposure. Further, cost and convenience were mentioned as factors when choosing PPE in some cases. In essence, most respondents stated there was a lack of information and consistent guidelines on effective PPE for handling nanomaterials.

Beliefs about Impediments to Health and Safety Management

Respondents were asked if there were impediments to their organizations' 'health and safety' management with respect to nanomaterials. This question elicited 53 responses, of which 39 believed there was an impediment to the management of the organization's health and safety (Figure 22).

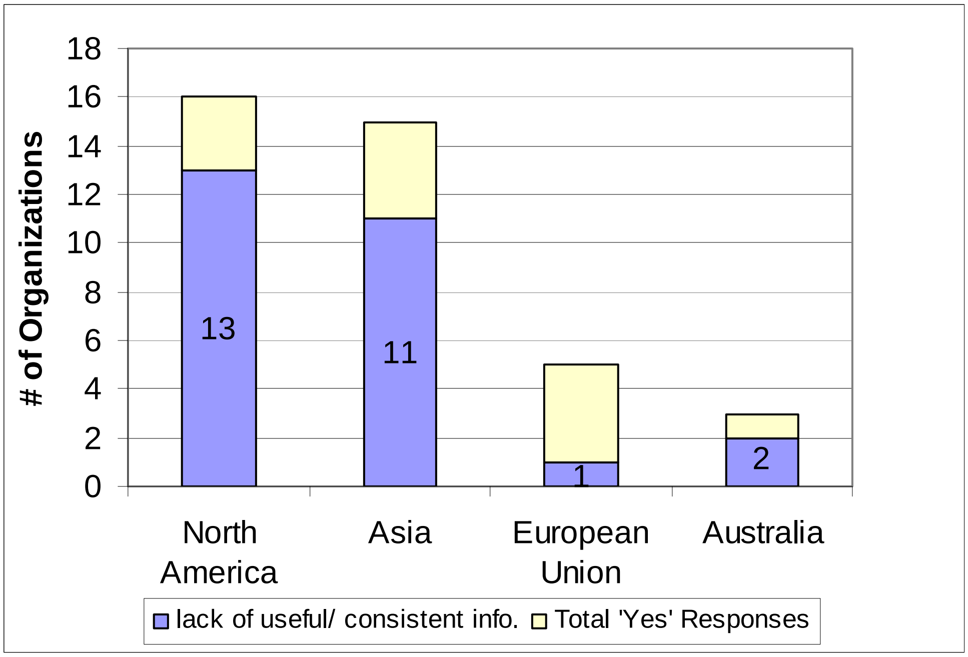
Figure 22: Reported impediments to management of 'health and safety' programs



Respondents then were prompted to describe these impediments. Thirty two organizations described impediments that were external to the organization and ten described internal impediments. These categories were not mutually exclusive and a respondent could describe more than one impediment. Of the external impediments, the most frequently mentioned was the lack of useful information and consistent guidelines (23). Other external barriers to EHS management included: ineffective detection and measurement techniques for nanoparticles (3), concerns of liability and the potential for litigation (2), and the dissemination of information (1).

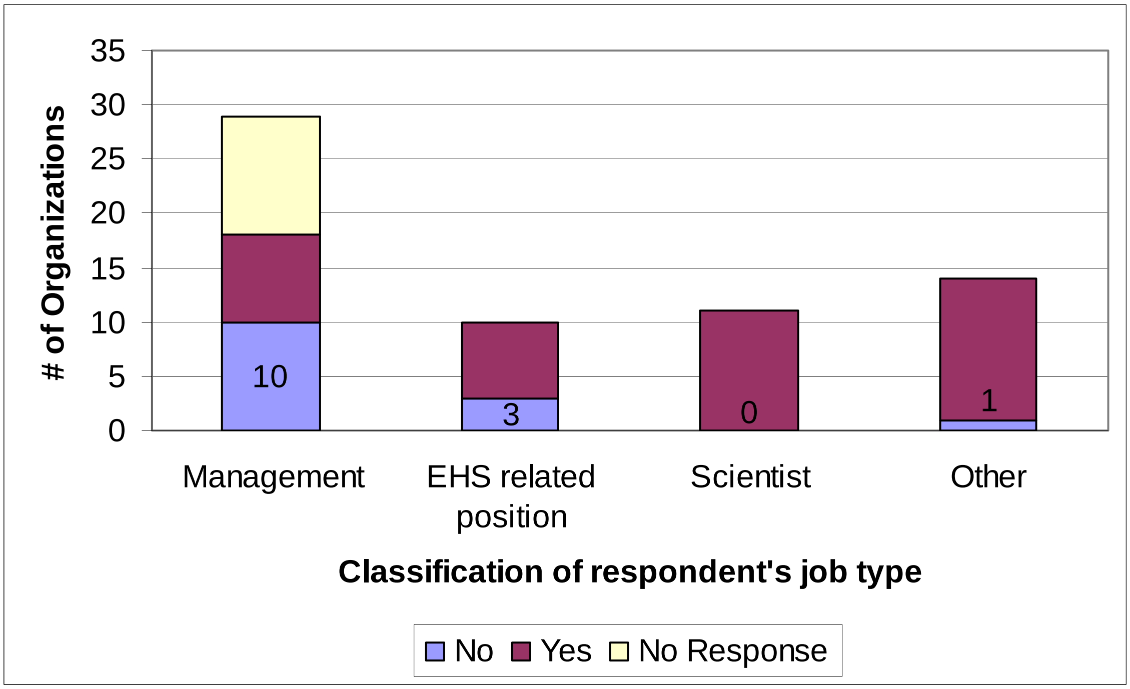
Of the ten organizations that described internal impediments, the most frequently mentioned was the cost (six responses) associated with implementing improved EHS practices. Four organizations described the internal barrier as a lack of prioritization of EHS management. Respondents stated that in the work environment there were many competing interests and EHS concerns did not receive priority. One respondent described the lack of prioritization as involving two attitudes. He described the first attitude as the “naïve approach” where workers believed it required too much effort to adopt safe practices and did not acknowledge the importance of safety precautions. He described the second attitude, as the “cavalier approach” where workers lacked faith in safety controls and believed there was little risk in handling nanomaterials. The respondent described the lack of information as leading to both of these attitudes. Another respondent described the dissemination of information as an internal impediment. In this case, the large size of the organization and geographically distant departments made the sharing of EHS knowledge difficult.

Figure 23: Responses indicating lack of useful and consistent information was an impediment to organizations health and safety management



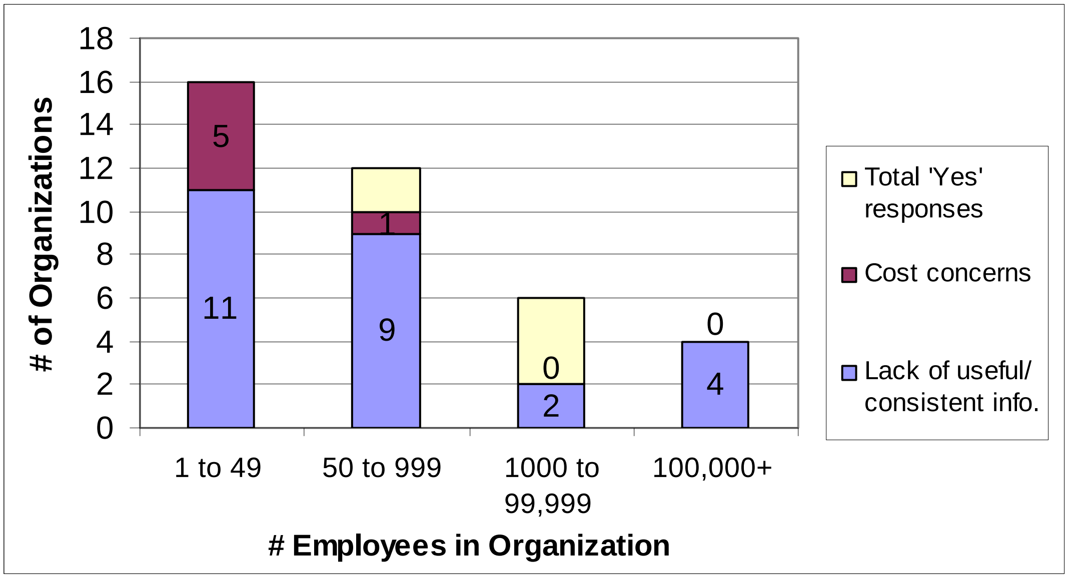
Respondents from North America, Asia, and Australia were more likely than respondents in Europe to describe the lack of useful and consistent information as an impediment to the health and safety management (Figure 23).

Figure 24: Impediments described by different respondents classified by job title



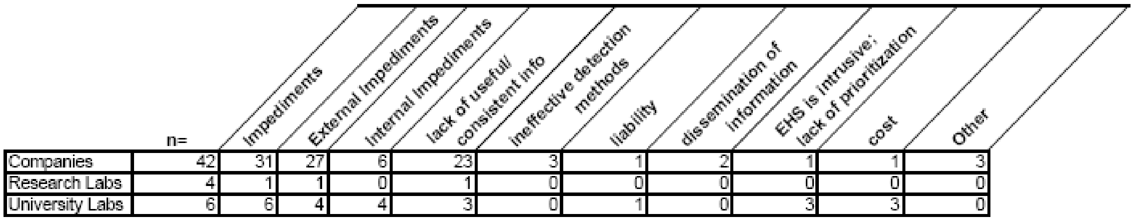
Respondents to this question whose job title and responsibilities could be categorized by management or executive administration were the only type who did not respond and a majority of those who did respond stated that there were no impediments (Figure 24). Respondents whose job title could be classified as being EHS- related or scientist were more likely to state that there were impediments with respect to health and safety management.

Figure 25: Impediments described by different respondents classified organization size



Smaller companies were more likely than larger organizations to describe cost concerns as an impediment to health and safety management (Figure 25). Organizations larger than 1,000 employees did not mention cost as a concern. The largest companies (100,000+ employees) emphasized the lack of useful and consistent information as an impediment.

Table 59: Impediments described by organizations classified by organization type



	n=	Impediments	External Impediments	Internal Impediments	lack of useful/ consistent info	ineffective detection methods	liability	dissemination of information	EHS is intrusive; lack of prioritization	cost	Other
Companies	42	31	27	6	23	3	1	2	1	1	3
Research Labs	4	1	1	0	1	0	0	0	0	0	0
University Labs	6	6	4	4	3	0	1	0	3	3	0

University labs were more likely to state there that there were internal impediments (Table 59). All six university labs described internal impediments, including cost concerns (3), lack of prioritization on EHS (3), and concerns for liability (1). Three university labs described the lack of information as an external impediment. This was in contrast to responses provided by research labs and companies. Of the four research labs that answered this question, only one described an impediment, the lack of information. Companies primarily described external impediments. Of the 42 companies, 31 acknowledged impediments. Twenty seven of these were external impediments and only six were internal. Only one company described cost as a concern and one company described the lack of EHS prioritization as a concern. The most frequently cited impediment by companies was the lack of information.

Summary of Beliefs of Impediments towards Health and Safety Management

Most of the responding organizations described an impediment to the management of health and safety. Half of all organizations described an external impediment, of which the lack of useful information and consistent guidelines were overwhelmingly the most described impediments. Fewer organizations described an internal impediment. The most common internal impediment was cost concerns, followed by a lack of prioritization of EHS concerns.

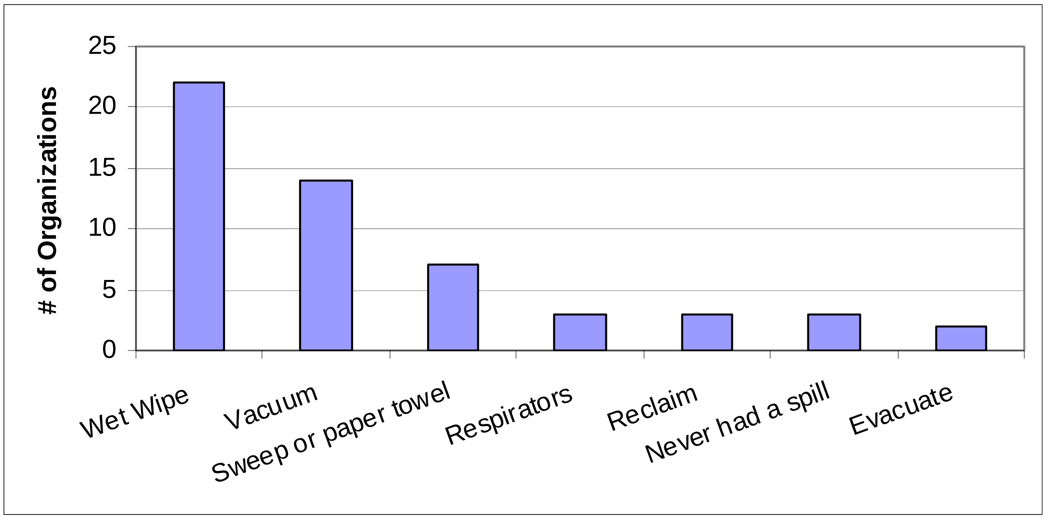
Waste Management of Nanomaterials

Clean-Up of Spills Containing Nanomaterials

Overall, fifty-five respondents shared specific practices for cleaning up spills involving nanomaterials. Thirty-four indicated that they handled spills involving nanomaterials the same as other spills, five indicated there were differences, and six described only the procedures without stating if they were handled differently. From those who handled nano-spills differently than regular spills, four indicated they stored the spilled nanomaterials in separate, sealed waste containers.

Specific practices of how to clean up nanomaterial spills are described in Figure 26. Three respondents required employees to wear respirators while containing and cleaning a spill, and two recommend evacuating the area after a spill. Twenty-two respondents mentioned using wet wipes with a solvent or adsorbent, while four swept with a broom or used a dry paper towel to contain a spill. Fourteen respondents vacuumed nano-spills, of which six used vacuum cleaners equipped with HEPA filtration where two respondents specifically mentioned that HEPA filters were not effective for nanoparticles. In one case, it was stated that a vacuum hose was used because the electric motor of a vacuum cleaner has the potential to ignite flammable nanomaterials. Three respondents indicated their employees tried to retrieve and reuse the nanomaterial after a spill in an effort to reduce waste. Three respondents mentioned they have never had a spill. Cross-analyses indicated no correlation with spill treatment methods between manufacturing versus non-manufacturing organizations or between R&D and non-R&D facilities.

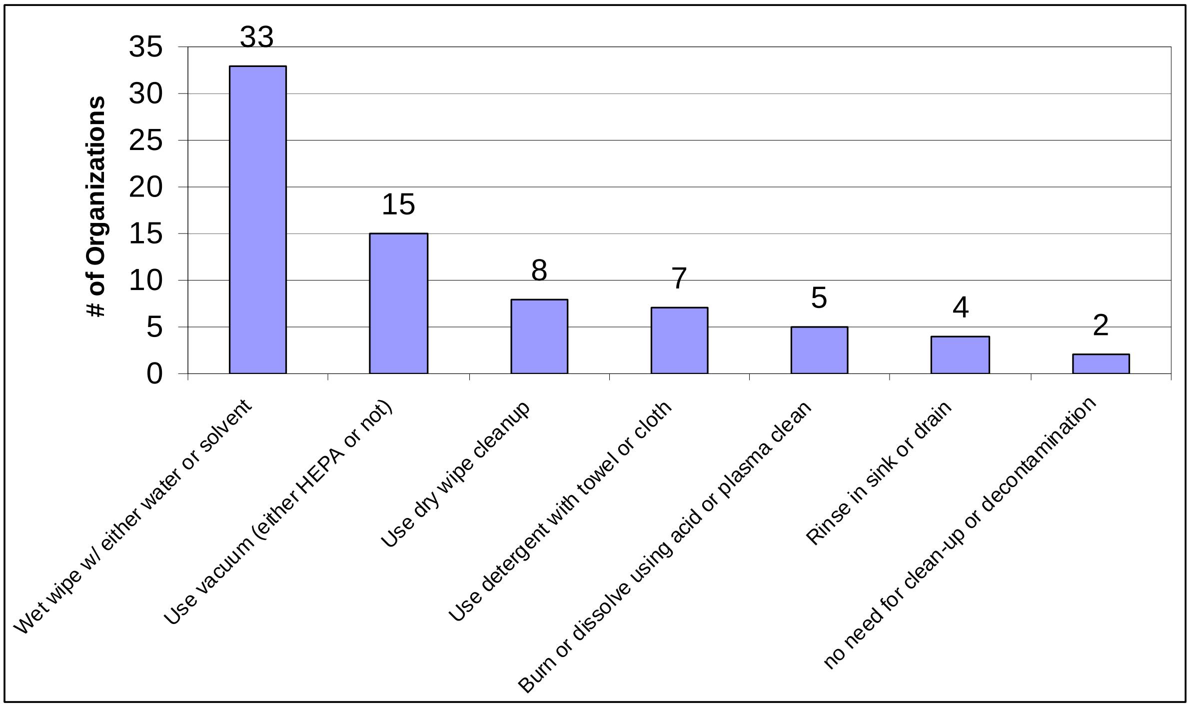
Figure 26: Respondent practices for cleaning up spills



Equipment Decontamination

Respondents were asked to describe the methods employed for routine cleaning or decontamination of equipment used for nanomaterial applications. Figure 27 shows the multiple reported methods for cleaning. Organizations frequently reported using more than one depending on the nanomaterial and its phase during handling. Eleven organizations did not respond to this question. Of the responding organizations, seven were represented by management personnel alone. Only management personnel reported that there was never any need for equipment cleaning. Similar to reported practices for cleaning up of spills, the most widely used method for cleaning equipment is the use of a wet wipe with either water or a solvent. Frequently, this cleaning method was accompanied by the use of a vacuum.

Figure 27: Reported methods for cleaning equipment used for nanomaterial applications



The wet wipe method and use of a vacuum appears to be the preferred method for cleaning equipment used with nanopowders and nanomaterials in powder or solution phases (Tables 60 and 61). Four organizations specifically described the use of a vacuum equipped with High Efficiency Particulate Air (HEPA) filtration. Over half of those that reported working with nanopowders and carbon nanotubes reported cleaning their equipment with the wet wipe method and 20 of 33 reports of using the wet wipe method came from organizations working with nanomaterials in either or both dry powder form and in a solution. At the same time, seven of eight reports of using dry wipe methods come from organizations working with nanomaterials in dry powder form and in solutions.

Table 60: Reported equipment cleaning methods by type of nanomaterial

	Number	Dry wipe	Wet wipe	Vacuum	Rinse in sink or drain	Burn or dissolve
Nanopowders	34	5	16	5	2	3
Carbon nanotubes	29	3	14	9	3	1
Colloidal dispersions	19	2	9	2	2	2
Fullerenes	12	1	3	2	2	1
Quantum Dots	9	0	6	1	1	0
Polymers	9	0	4	0	2	2
Nanowires	8	1	3	1	1	0
Nanocrystals	7	2	2	2	1	0
Carbon Black	7	0	2	1	0	1
Other	17	1	6	0	1	0

Table 61: Reported methods for equipment cleaning by phase of nanomaterial during handling

Phase	Number of organizations	Dry wipe	Wet wipe	Vacuum
Dry Powder only	15	0	6	5
Solution only	6	1	3	1
Embedded/bound to a surface only	3	0	1	0
Dry powder and in solution	23	7	11	6
In solution and embedded/bound	6	0	5	1
Dry powder and in a matrix	2	0	2	1
Dry powder, in solution, and embedded/bound to a surface	6	0	3	1

North American and European organizations had higher reported use of wet wipe methods than Asian organizations, but Asian organization reported slightly higher use of vacuums to clean equipment (Table 62). There were no strong trends in cleaning methods by other company characteristics, including age, number of employees handling nanomaterials, duration of time in the nanotechnology field or whether they manufacture, use or do research and development with nanomaterials.

Table 62: Reported methods for equipment cleaning by region

Region	# of Organizations	Dry wipe	Wet wipe	Vacuum	Rinse in sink or drain	Burn or dissolve
Asia	25	2	8	7	1	0
Europe	11	2	8	2	1	1
North America	25	3	16	5	1	4
Other	3	1	1	1	1	0

Five organizations reported that their organizations had developed established guidelines for cleaning equipment while six explicitly stated that there were no such established protocols. All but three of these responses, however, were elicited through telephone interviews suggesting that the existence of decontamination guidelines may be understated in these findings. One organization that worked with fullerenes and quantum dots primarily in dispersions described using a specialized and custom-built “pretreatment system" for equipment cleaning that involved a series of solvent washes. The solvents were then disposed of as hazardous waste.

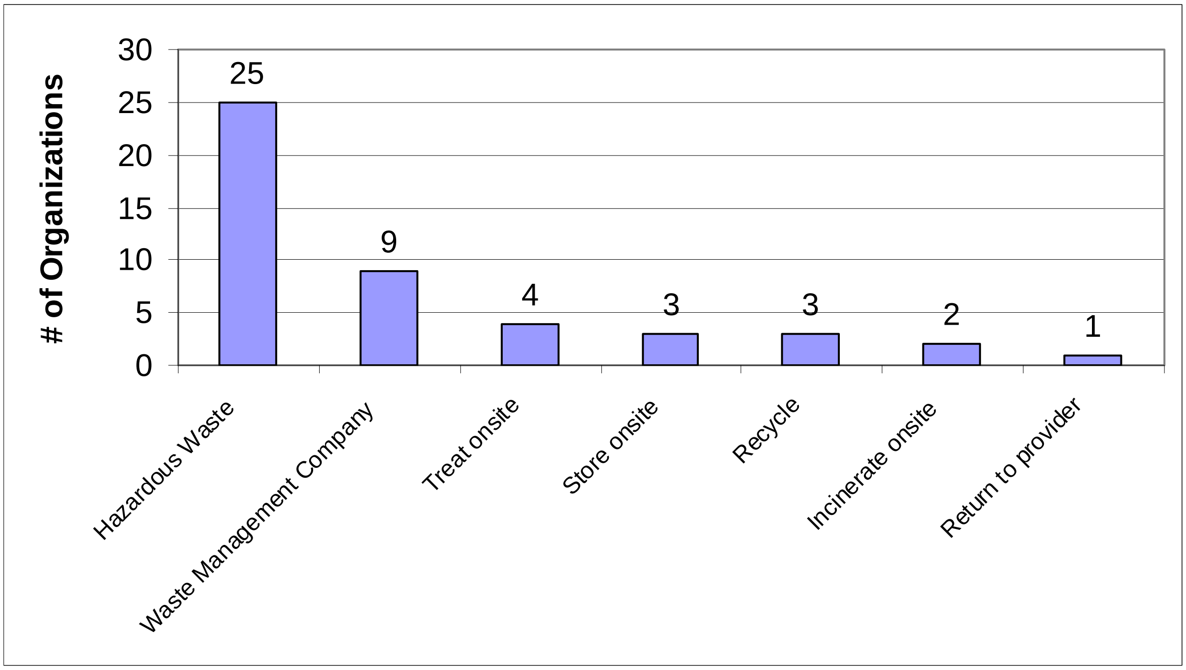
Waste Disposal

The majority of respondents (34 out of 47 who responded to this question) disposed of waste containing nanomaterials (including spills) through a waste management company (Figure 28). Twenty-four respondents specifically mentioned they disposed of nanomaterials as hazardous waste, while four respondents reported that the chemical nature of the material dictated the method of disposal. For example, two respondents indicated they disposed of silica and aluminum oxide nanoparticles in the sink. Whereas a majority of US, European and Australian firms disposed of their nano-waste as hazardous, only one organization in Asia reported doing this. Further, 68% of respondents working with non-metals (i.e., traditionally non-hazardous in the bulk from) disposed of their nano-waste as hazardous material, whereas 52% working with metals and 35% working with carbonaceous material disposed of their waste as hazardous waste. While most nanomaterials were disposed of as hazardous waste, two U.S., respondents mentioned they believe nanomaterials generally were not regulated as hazardous waste under Subtitle C of the U.S. Resource Conservation and Recovery Act, and therefore was not required to go to a licensed Treatment, Storage and Disposal facility. For this reason, some of their waste went to a landfill regulated under Subtitle D (municipal and solid wastes). Internally, some organizations had stricter waste disposal rules than others. One respondent indicated that even contaminated gloves wee disposed of as hazardous waste, while another respondent said it was a challenge to enforce any hazardous waste disposal rules in the lab.

The 13 respondents that did not dispose of their nanomaterial waste through an external company used various internal waste management methods. Four respondents treated nanomaterials in-house before disposal. These respondents focused on removing the "nano properties" by aggregating the materials in solution. Three respondents stored all nanomaterials on-site because the quantities were small or they are waiting for government regulations to address the issue. Three respondents recycled all their nanomaterials – two of them used an enclosed production system and one via a third-party recycler; these respondents worked with all elemental categories of nanomaterials except carbonaceous material. Two respondents incinerated their nano-waste on-site (all carbonaceous material); another used a method approved by the US EPA for incineration of nanomaterials, which were fixed in resin or plastic. One respondent returned all the nanomaterials to its suppliers and customers.

Five respondents specifically indicated they tried to generate very little waste because the material was expensive and also because they were trying to implement "green" nano-science.

Figure 28: Methods respondents use for disposal of nanomaterials



Respondents were asked if they disposed of their nanomaterials in separate disposal containers. Thirty-five respondents indicated they did not use separate containers, whereas 21 indicated they did use separate containers. Twenty-five percent of nanomaterial manufacturers and 43% of non-manufacturers reported using separate waste containers. There was no strong relationship between geographical location and separation of waste, nor was there a strong relationship between material phase and separation of waste.

Similarly, 34 respondents labeled the containers by elemental make-up of the bulk material, while only 17 labeled it specifically as nanomaterial. One respondent stated they labeled their waste as nanomaterial because the International Aviation and Transportation Agency requires such labeling in order to distribute their product. Similarly, another respondent labeled waste as nanomaterial waste to comply with US Department of Transportation regulations. One respondent added that their labeling listed the physical properties of the nanomaterials. On the other hand, one respondent shared that they initially labeled the waste containers as “nanomaterial,” but the waste disposal company was not interested in that information, so now they label their waste as bulk material. A cross-analysis suggested no strong relationship between type of organization (manufacturing or R&D), material element and phase or geographical location, and labeling practices. For storage, respondents mentioned using glass containers, metal containers, and sealed metal drums.

Respondents shared some concerns with regards to waste. One respondent said their organization was concerned with effluent from fume hoods, which discharged to the atmosphere; they were not sure how to resolve this issue. This same respondent did not believe that filtration units were sufficient for particles smaller than 50 nm. Another respondent believed there was a need for equipment to collect nanomaterial waste safely. A third respondent believed that regulations needed to take into account the unique properties of nano-scale matter when developing regulatory thresholds for effluent from fume hoods.

Summary of Waste Practices

Respondents reported most frequent use of wet wipes and vacuuming for clean-up of nano-spills. This practice most likely would reduce the inhalation exposure of employees performing the clean-up, although only two respondents reported the use of respirators while cleaning.

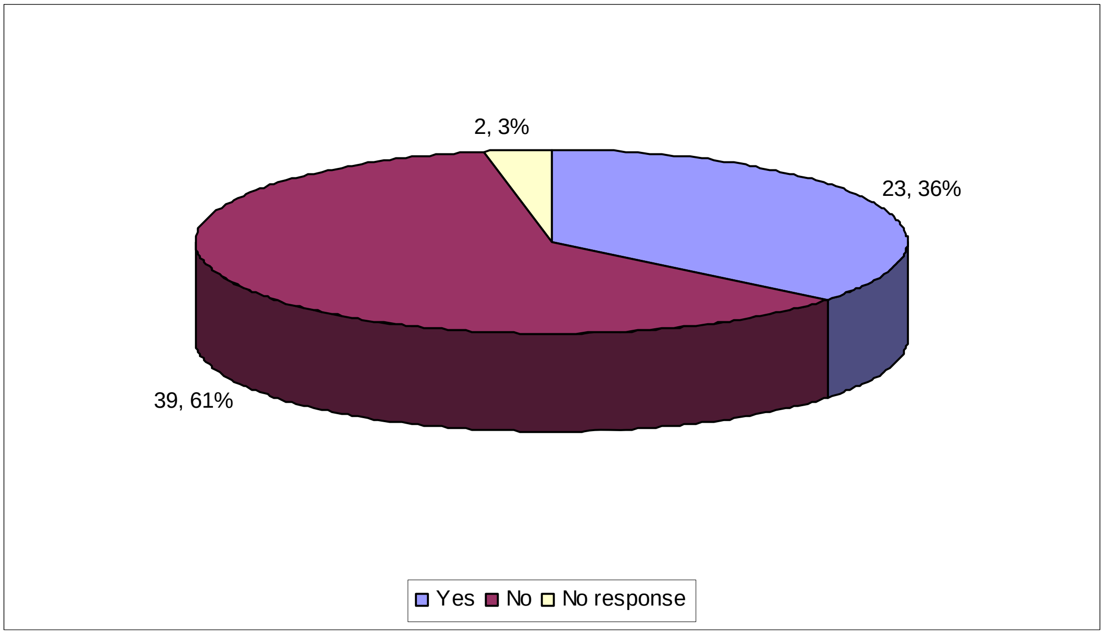
The most frequently reported method for cleaning equipment used in nanomaterial applications is a wet wipe with either water or solvent. Vacuuming is also frequently used. This trend is particularly strong for organizations working with nanopowders and nanomaterials in dry powder form and in solutions. At the same time most reports of dry wipe cleaning methods came from organizations working with nanomaterials as either a dry powder or in solution

Most respondents reported discarding of nanomaterials as hazardous waste through a waste management company. A few other respondents reported they incinerated, agglomerated, stored or recycled nanomaterials instead. A larger share of respondents did not separate nano-waste in separate containers and did not label it as "nanomaterial," but rather classified it by the bulk material. Reasons to label nanomaterials included transportation regulations. Some respondents shared concerns about waste discharge in the environment.

Monitoring the Work Environment for Nanoparticles

Respondents were asked if their organization monitored the work environment for nanoparticles. Twenty three respondents stated they performed monitoring, while 39 stated they did not (Figure 29).

Figure 29: Respondents were asked: Do you monitor the work environment for nanoparticles?

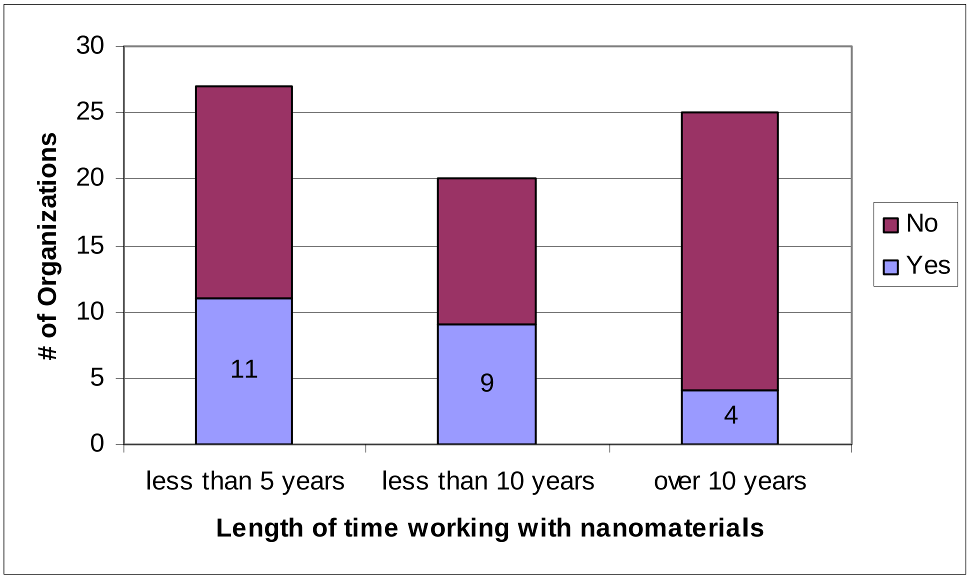


Of the 39 respondents who did not monitor the workplace, only 13 provided reasons for not monitoring. Five stated that they did not believe it was necessary due to the nature of the material handled. Two respondents described a lack of information about the parameters to measure and the available equipment. Two respondents planned to begin monitoring in the future. One respondent expressed a concern for the cost of monitoring.

Organizations that handled or produced quantities greater than one kilogram of nanomaterials at a time were more likely (11 of 26 respondents) to monitor the work place than organizations that handled less than one kilogram (12 of 36, data not shown).

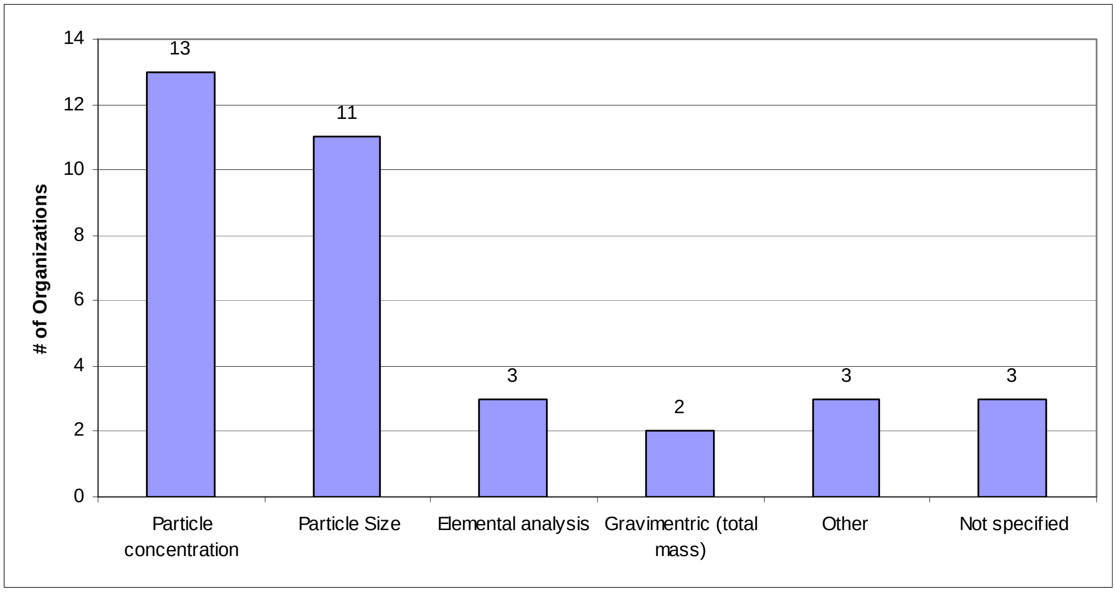
Organizations that have worked with nanomaterials for over ten years were less likely to monitor the work environment for nanoparticles than organizations that worked with nanomaterials less than ten years (Figure 30).

Figure 30: Length of time respondents have worked with nanomaterials and whether they monitor the work environment for nanoparticles



Respondents described a number of parameters that were measured (Figure 31). Some respondents measured more than one of these parameters. Particle concentration was the most frequently measured parameter (12 out of 23 organizations). Particle size was measured by eleven organizations.

Figure 31: Respondents described the parameters monitored



The most commonly used equipment for monitoring were particle counters (Figure 32). These devices are capable of measuring particle concentration within a specified range of sizes. The models described below are all hand held devices and are relatively inexpensive. The most commonly described device (7 responses) was the TSI P-TRAK portable condensation particle counter (CPC). This particular device is capable of measuring particulates between 20 -1000nm. One respondent described using the TSI CPC 3007. This model is a handheld device and is similar to the P-TRAK, with an extended range of detection down to 10nm.[23] Five other condensation particle counters were described as being used for monitoring with no specific information describing the model.

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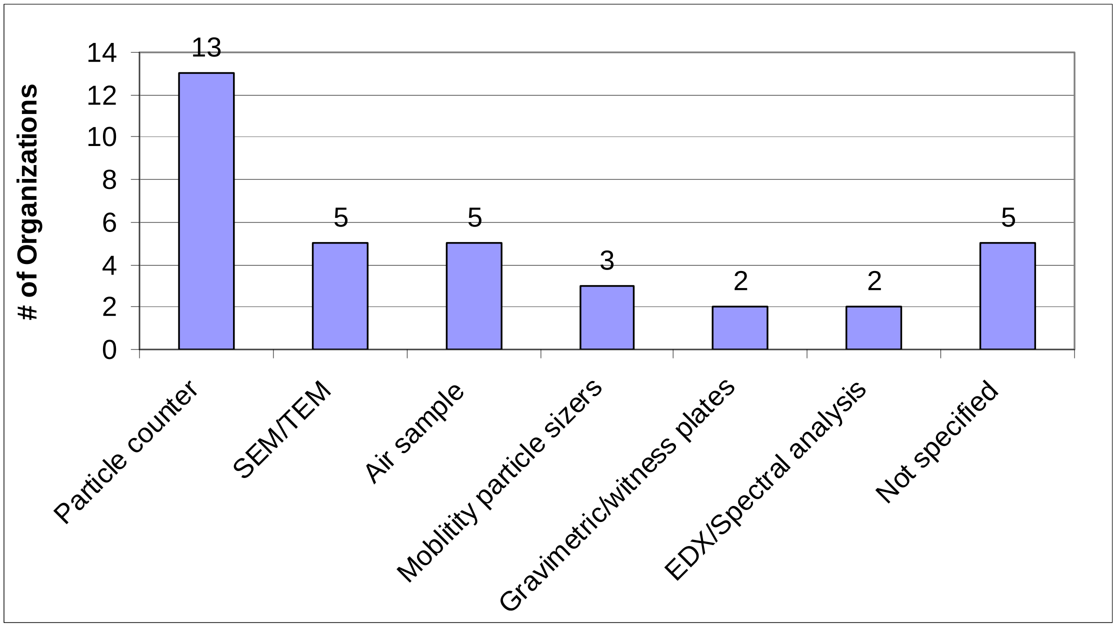
[23] TSI Incorporated. Exposure Monitoring, Nanparticle Aerosol Monitoring. <http://www.tsi.com/JoinCategories.aspx?Cid1=153&Cid2=197> September 2006.

Figure 32: Equipment used by respondents for monitoring



Four respondents described using devices that measured outside of the nanoscale (1-100 nm) range. The Rion KR-12a optical particle counter is a handheld device capable of measuring six size ranges simultaneously, the lowest of which is 300 nm.[24] Two respondents mentioned using the TSI DustTrak, which measures particle sizes with a lower limit at 100 nm. One respondent described using the Met One Gt-331. This is a portable device that simultaneously provides concentrations for PM (Particulate Matter) standards of 1, 2.5, 7, and 10 micrometers.[25]

Respondents were asked why particular measurements devices were purchased. In general, condensation particle counters were selected based upon:

- recommendations by experts (8 respondents), including NIOSH (3)
- as being relatively inexpensive (3)
- handheld (2)
- easy to use (2)
- readily available (2)
- capable of real time measurements (1)

Three respondents described the use of Scanning Mobility Particle Sizers (SMPS). These devices are capable of generating a size distribution of particulate concentrations over a specified range. One respondent described using the TSI 3034 SMPS. This is a benchtop model, capable of generating a size distribution of particle concentrations between 10-497 nm every three minutes. The device displays particle concentrations for 54 size ranges. Another respondent affirmed the use of the TSI Fast Mobility Particle Sizer. This device also is a benchtop model, capable of generating a size distribution of particle concentrations every second, between 5.6 and 560 nm for 32 size ranges.

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[24] Rion Co. Handheld Particle Counter KR-12A. < http://www.rion.co.jp/dbcon/pdf/KR-12A-E.PDF> September 2006.

[25] Product information sheet provided by Met One. September 21, 2006.

Five respondents described collecting air samples with a canister and filter. The filter then could be analyzed with electron microscopy to observe the sizes of particles. Two respondents described the use of portable respirometers that simulate human respiration and collect air in a special filter for several days. This design collects air samples in the workers breathing zone. Three respondents also described performing elemental analysis of air samples with either an EDX (energy dispersive x-ray analysis) or an X-ray spectrometer. Similar to air canisters, wipes can be used to collect particles from a surface and examined under microscopy.

Gravimetric or “witness” plates can be used in a similar manner to air filter canisters. A collection dish is placed in the lab and particles adsorb to the surface. The plate can be weighed to estimate the total mass of the deposited particles and can be examined with either electron microscopy or EDX. The use of gravimetric analysis was described by two respondents.

Two organizations described the outsourcing of work place monitoring to private companies. This may be an efficient choice for small companies who lack the expertise or do not wish to invest in measurement devices. In both cases, little information was available regarding the method of measurement due to the detachment from the procedures.

Respondents were asked how often monitoring of the work place was performed. Responses to this question varied greatly. Respondents may have described more than one category. Respondents stated performing monitoring:

- on an irregular basis (10)
- at initiation of work (4)
- when a change in work occurs (4)
- continuous monitoring (4)
- less than once per week, more than once per month (4)
- at least once per year (1)
- based on results of risk assessment (1)

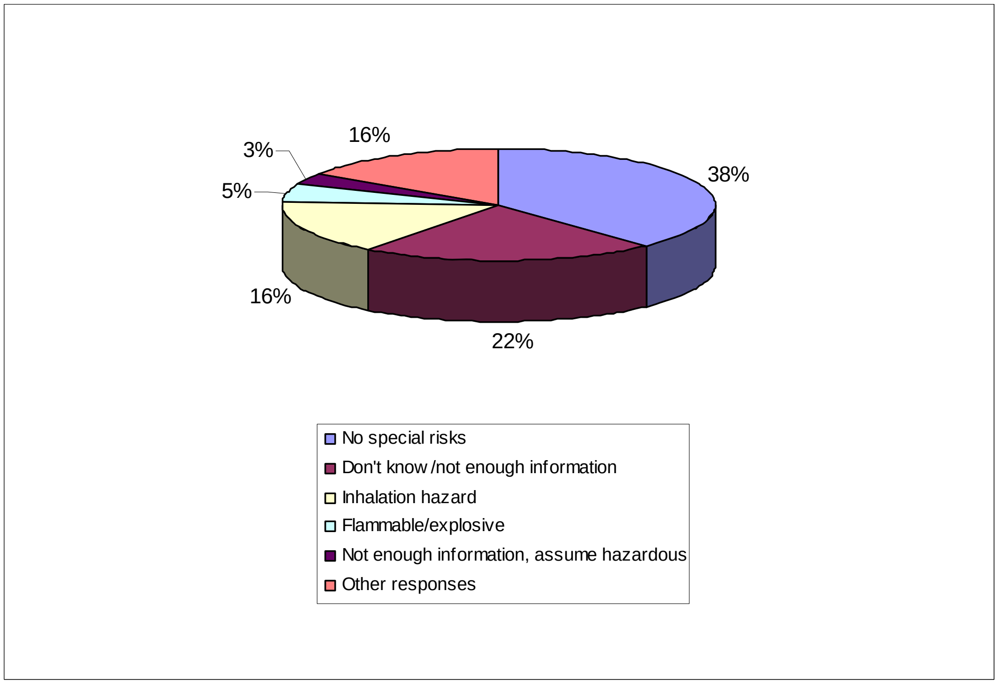
Summary of Monitoring for Nanoparticles

The majority of respondents did not perform monitoring of the workplace for nanoparticles. Those that did monitor the workplace, most frequently measured particle concentrations and size. The most common device used for monitoring was a particle counter, which estimates particle concentration. Unexpectedly, four of the respondents who described using these devices used equipment that measures outside of the nanoscale.

Attitudes towards Risk of Nanomaterials Handled

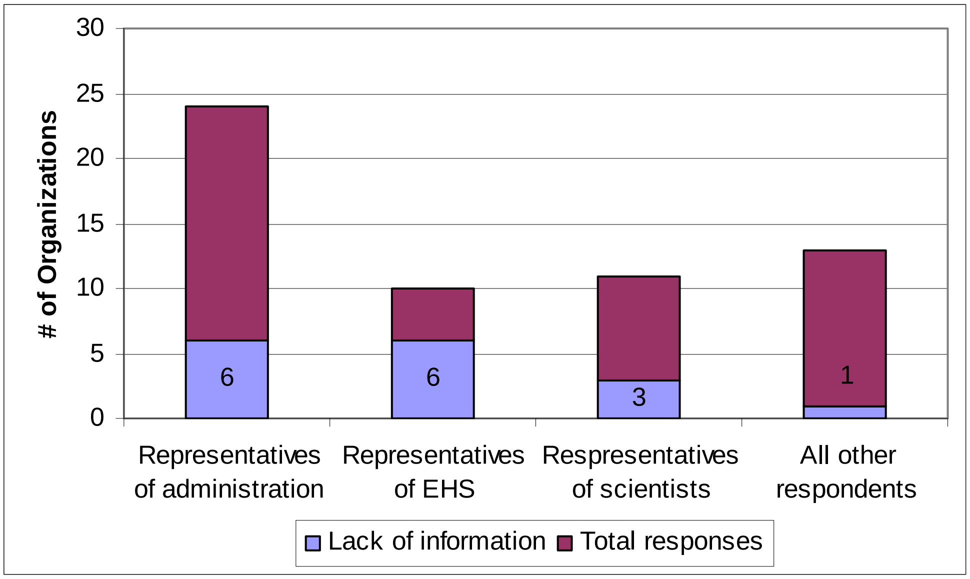
Respondents were asked if they thought there were any special risks associated with the nanomaterials handled or produced at their organization. Thirty-eight percent of respondents believed there were no special risks (Figure 33). Twenty-two percent stated that they did not know or lacked enough information to answer the question. Forty percent described risks. Sixteen percent stated that they believed their nanomaterials may pose an inhalation hazard. Additional responses describing risk included: flammability or explosive nature of materials (3), assume material is hazardous (2), concern for possible affect to the environment (1), possible toxicity for organisms (1), heavy metal nature of elemental constituents (1), and possible hazard due to the high energy requirements of nanomaterial production equipment (1). The category of "other responses" may include any of the above or a combination of statements. Six organizations did not respond to this question.

Figure 33: Described risks of nanomaterials handled at participating organizations



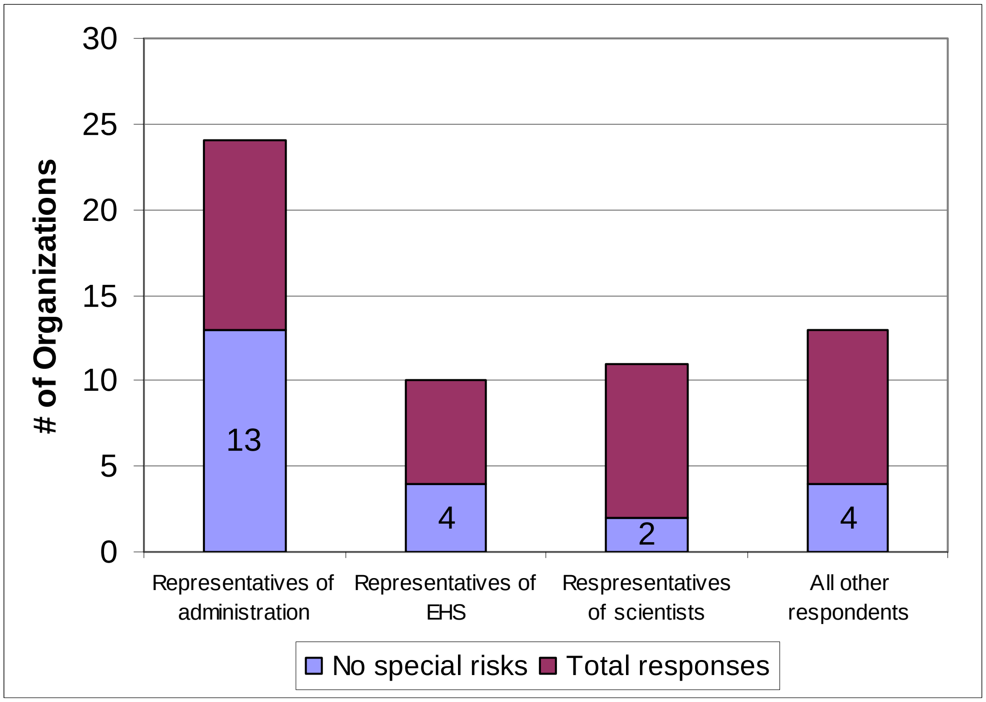
The population of respondents can be characterized as representing three types of workers based upon job titles and responsibilities. Interviews involving multiple participants representing multiple categories or jobs that do not fit into the three categories are described as other. Representative of EHS employees were more likely to describe a lack of information when asked if there were special risks associated with the nanomaterials handled (Figure 34). Representatives of administration and scientists were less likely in our study to describe the lack of information as a response.

Figure 34: Described risk of nanomaterials classified by respondent's job title and responsibilities



In the survey, employees involved with management (13/24) were more likely to indicate that there are no special risks associated with the nanomaterials handled than scientists (2/11) and EHS-related personnel (4/10) (Figure 35).

Figure 35: Responses of "no special risks" of nanomaterials handled, classified by respondent's job title and responsibilities



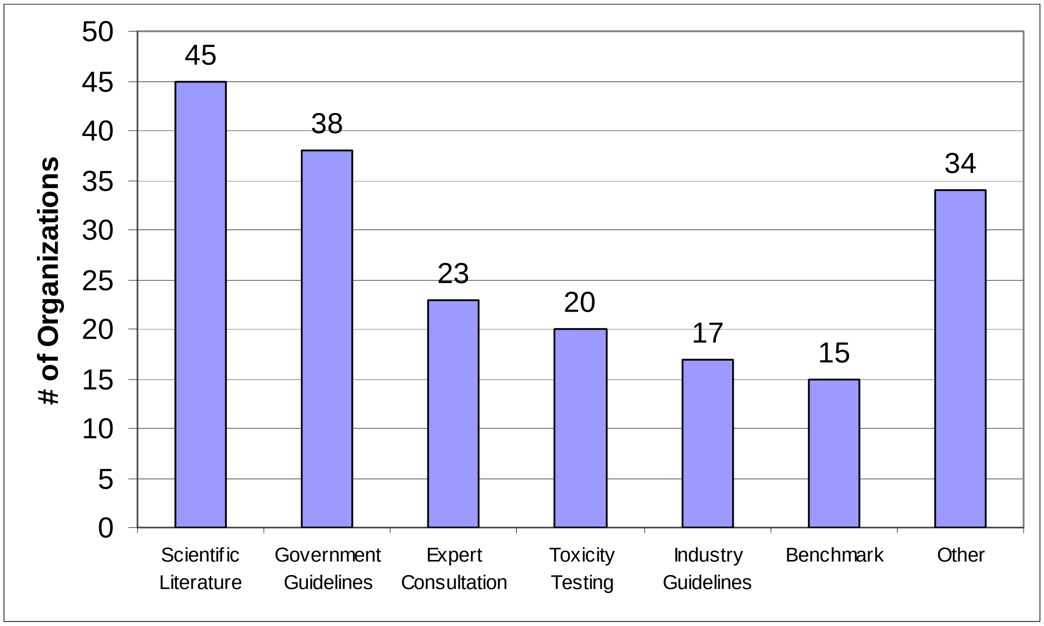
Summary of Attitudes towards Risk of Nanomaterials Handled

The most frequent response to the question of any special risks that handled nanomaterials may pose was the description of a general or specific risk. This included concerns such as inhalation exposure and potential for flammability of materials or general concern for hazard. A similar number of respondents believed there were no special risks associated with the nanomaterials handled. This response was most frequently described by respondents whose job title could be characterized as administrative or management. Approximately one-fifth of respondents stated that they did not know or needed more information to assess the risks of their nanomaterials. EHS-related employees were more likely to state the there was not enough available information.

Methods for Determining Risk of Nanomaterials

Respondents were asked, “How do you determine if there are risks associated with the nanomaterials handled or produced in your organization?” The questionnaire provided a series of prompts (described in graph) as methods that could be used to determine risk. The use of scientific literature (45) was the most popular method for determining risk, followed by government guidelines (38, Figure 36).

Figure 36: Methods used by respondents for determining risk of nanomaterials handled at their organization



Included within the other category are: MSDS or manufacturer information (6), risk assessments (5), other information sources such as internet or news articles (5), internal expertise (4), collaboration with other labs and colleagues (3), and characterization of materials (1).

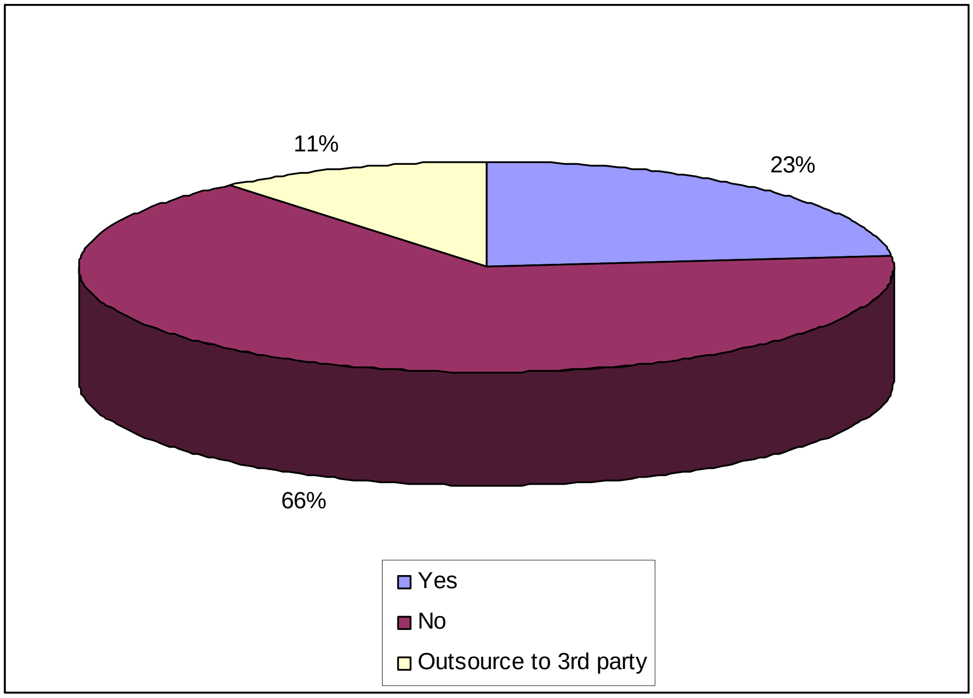
Summary of Methods for Determining Risk of Nanomaterials

The most frequently used methods for determining the risks of nanomaterials were described as consultation of scientific literature, government guidelines, and the use of expert consultation.

Toxicity Testing

Respondents were asked "Does your organization perform its own toxicological testing?" Thirteen organizations stated they performed their own toxicological testing (Figure 37). Fifty respondents stated they did not perform toxicity testing, but a subset of these (13) added that they outsourced some of their materials for toxicity testing. This was not asked explicitly and was only revealed through phone interviews. Therefore, the actual number of organizations that outsource toxicity testing may indeed be higher.

Figure 37: Organizations which perform or outsource toxicological testing on nanomaterials



Organizations that manufacture nanomaterials were examined to determine if there was a difference in frequency of toxicity testing with organizations not involved with manufacturing. Sixty three organizations answered both questions. Of the 35 manufacturers of nanomaterials, 14 performed or outsourced toxicological testing. Of the 28 organizations not involved with manufacturing, six performed or outsourced toxicological testing.

Manufacturers of nanomaterials were more likely to perform toxicological research or to have it outsourced to a third party (14 of 35 respondents) than organizations that were not involved in manufacturing (6 of 28).

Respondents from Europe were the most likely to describe performing (2/11) or outsourcing (5/11) toxicological testing (Table 63). Respondents in North America were the least likely to describe either of these activities.

Table 63: Number of organizations involved with toxicity testing in different regions

	Yes	No	3rd party
Asia	7	18	0
Europe	2	4	5
North America	4	18	2
Australia	0	3	0

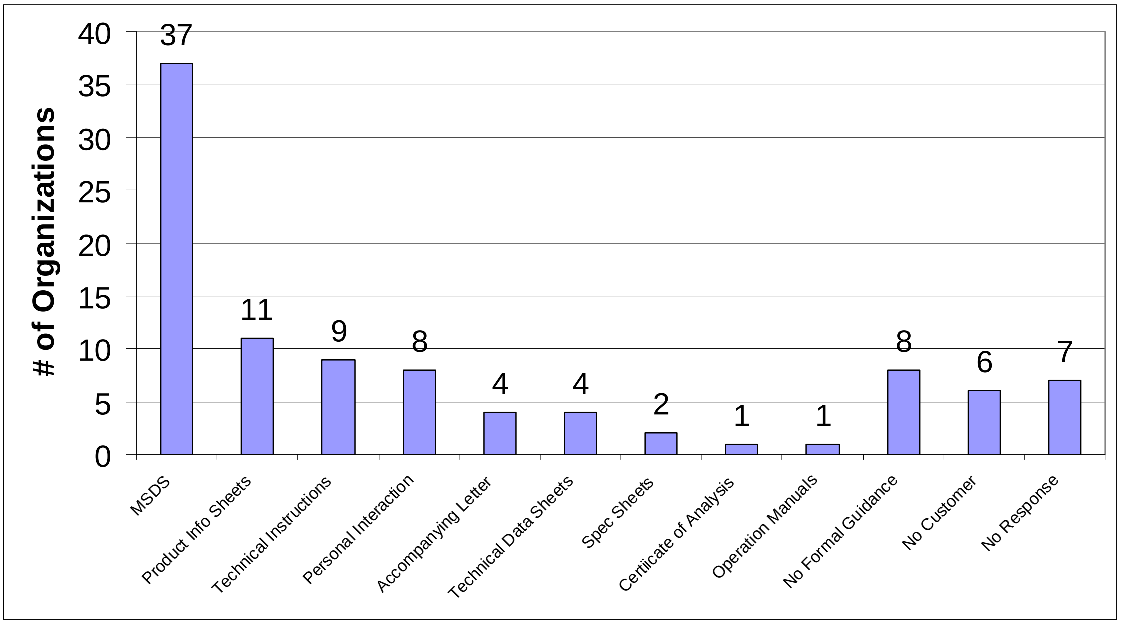
Summary of Toxicological Testing

Most of the organizations that participated in this survey did not perform toxicological testing of their nanomaterials. Manufacturers of nanomaterials were more likely to be involved with toxicological testing than non-manufacturers. Organizations in Europe were the most likely to perform or outsource toxicity testing to a 3rd party.

Product Stewardship

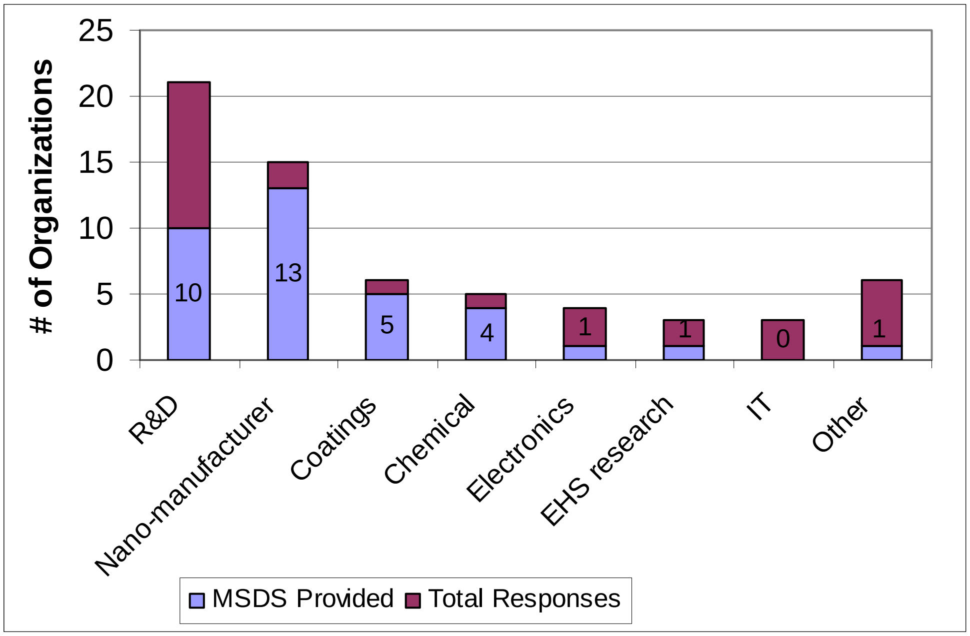
Respondents were asked "What form of guidance information about the safe use of your nano-products do you provide to customers?" Nano-products were not specifically defined, but would include any product made of or including nanomaterials. In the event that the organization did not have customers in the traditional sense, the definition of customers (in telephone interviews only) was broadened to include the exchange of nanomaterials between labs or departments. The most common form of guidance was the MSDS (Figure 38, followed by product information sheets. Eight organizations provided no formal guidance and seven organizations did not respond to this question.

Figure 38: Guidance provided for safe use of nano-products



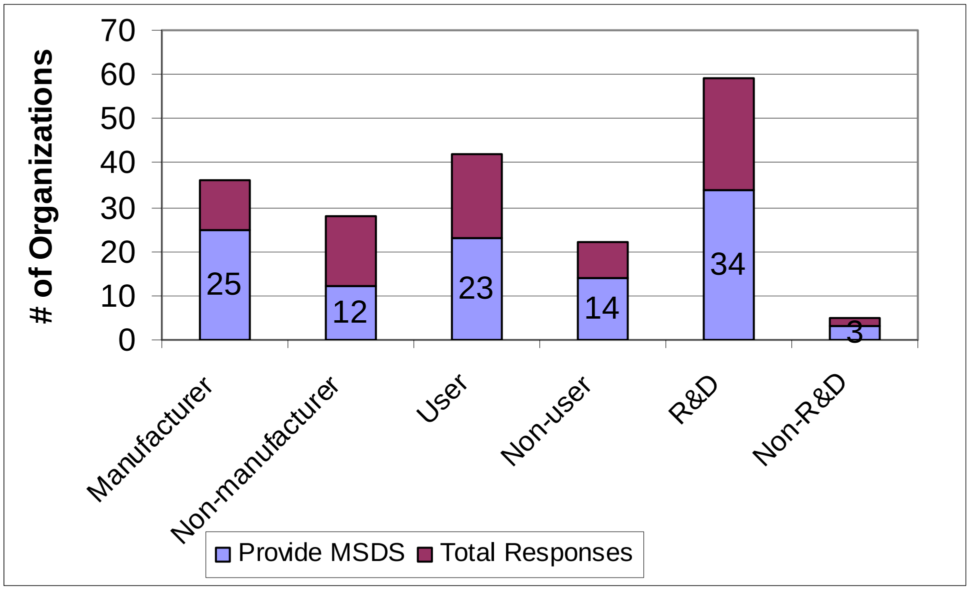
Based upon classification of business type, nano-manufacturers, coatings and chemical companies were more likely than other business types to provide MSDS as the guidance for the safe use of nano-products (Figure 39)

Figure 39: MSDS provided for safe use of nano-products, responses classified by business type



Although most organizations performed more than one of the described activities, it was shown that manufacturers were most likely to provide MSDS as the guidance for the safe use of their products (Figure 40). There were very few differences between users and non-users and R&D and non-R&D organizations in this regard.

Figure 40: MSDS provided for safe use of nano-products based on nanomaterial activities



Respondents also were asked if the guidance information was available to the public. Only 19 organizations responded to this question, of which 10 stated this information was available to the public (non-customers). For those organizations that did not make this information available to the public, five did not have “formal” customers. Their customers included colleagues within the company and other companies or labs.

Organizations in Europe were more likely to provide MSDS than organizations in Asia and North America (Table 64). The three participant organizations in Australia all provided MSDS with their nano-products. Only one company in Asia reported providing this information to the public (1/25). Three out of eleven in Europe, five out of twenty-five in North America, and one out of three in Australia provided this information to the public.

Table 64: MSDS provided, based upon geographical region

	Total	MSDS Provided	Rate	Available to public	Rate
Asia	25	13	52%	1	4%
Europe	11	9	81%	3	27%
North America	25	12	48%	5	20%
Australia	3	3	100%	1	33%

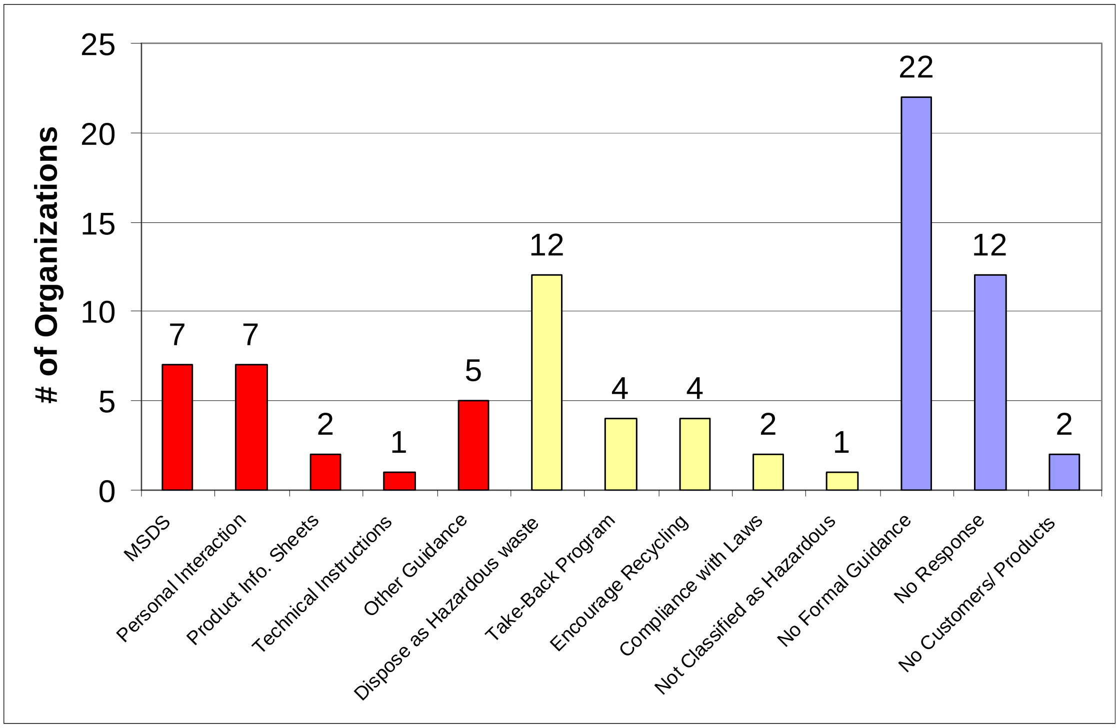
Smaller companies were more likely to provide guidance information for safe use and offer the information to the public (Table 65). Nearly half of the sample (30/64) were small, with less than 50 employees. Twenty of these small organizations provided MSDS and six made this information available to the public.

Table 65: MSDS provided, based upon company size

Organization Size (# of Employees)	Total	MSDS Provided	Rate	Available to Public	Rate
1-49	30	20	67%	6	20%
50-999	21	13	62%	3	14%
1,000-99,999	8	3	38%	1	13%
100,000+	5	1	20%	0	0%

Respondents were asked “What form of guidance do you provide to customers for the safe disposal of your nano-products?” (Figure 41) Responses included two types: one category was the method of guidance transmission (red) and the other was the method of disposal (yellow). Response types were not exclusive and neither category was requested specifically. The largest group of respondents stated that no formal guidance was offered.

Figure 41: Guidance for safe disposal of nano-products



The most frequently described methods of transmitting guidance for safe disposal were through personal interactions and MSDS. Of the seven organizations that shared this information through personal interactions, four did not have 'formal' customers and would share this information internally with colleagues within the organization. Two of the seven organizations that provided MSDS specifically stated that guidance for disposal of the material was not provided in the document. Other forms of guidance included non-disclosure agreements, emails, and accompanying letters.

Regarding method of disposal, twelve organizations suggested disposal of nanomaterials as a hazardous waste. Four organizations had a take-back program for unused materials. Four organizations encouraged the recycling of their nano-products. Two organizations described a process in which the nanomaterials were coagulated prior to disposal. One organization that prepared coatings containing nanoparticles provided guidance regarding the sanding of the finished product. Once coated, the guidance stressed wet sanding of the surface, that the sanding equipment should have an attached vacuum, and that the individual should wear a dust mask.

Of the 29 organizations that provided some form of guidance regarding disposal, no respondent stated that the information was available to the public and five organizations specifically stated the information was not available.

Summary of Product Stewardship

MSDS and personal interactions were the most commonly described methods for transmitting information of product stewardship. For safe use, manufacturers tended to provide MSDS as guidance. Respondents in Europe more frequently described providing MSDS for safe use than respondents from other regions. From the perspective of company size, small companies were more likely to provide MSDS for safe use and to provide the information to the public. However, many customers are lacking information regarding safe disposal of nano-products. The most recommended method for safe disposal of nano-products was as hazardous waste. None of the surveyed organizations stated their guidance for safe disposal was available to the public.

V. Discussion

In this study, a questionnaire was developed to elucidate current practices in nanomaterial workplace health, safety and product stewardship. Surveys were administered primarily using telephone interviews, although some written and web-based surveys were received as well. The surveys were conducted globally over a 2.5 month time frame with sponsorship by the International Council on Nanotechnology (ICON). While the overall objective was to discover current practices, the comprehensiveness of the questionnaire coupled with the number of surveys allowed us to reach some general conclusions regarding practices and potential explanations for reported data. These conclusions should be of great value to study participants, as well as non-participants, towards the continuing development of “best practices” in nanomaterial safety, disposal and product stewardship.

The survey results revealed that, generally, organizations working with nanomaterials are using conventional chemical safety methods, with some instances of organizations taking measures beyond those of conventional chemical hygiene. Conventional methods typically are employed through the life-cycle of nanomaterials. Respondents generally dispose of nanomaterials through a waste management company without specifically labeling waste containers as containing nanomaterials. The majority of respondents inform customers about the properties of the materials through an MSDS. The primary reason for treating nanomaterials similarly to other chemicals is the lack of information on nanomaterial characteristics and hazards. A number of respondents indicated they take precautions by treating nanomaterials as hazardous materials and employ the use of engineering controls and PPE to protect against all possible hazards. Some organizations employ the use of cleanrooms and bunny suits when handling nanomaterials, but not always with the intent to reduce worker exposure. Others use engineering controls such as glove boxes and glove bags or design their own enclosed system thus minimizing exposure.

Some respondents indicated the use of generic guidelines for working with fine particulates and dusts. Since inhalation is a known exposure route, respondents using nanopowders reported widespread use of dust masks and respirators. Less frequent use of fume hoods was described due to the turbulent airflow that can suspend the material in the air, resulting in the loss of material. Many of the safety measures were based on the toxicity of other materials handled in the lab. For example, most respondents indicated their choice of gloves was based on which solvents were being used. While these general trends were true for the entire sample, which was heavily weighted towards small companies and organizations working with nanopowders or nanopowders and materials in suspension, certain trends exist based on organizational, industry and nanomaterial characteristics.

Geography

The geographic location of participating organizations had implications for respondents’ beliefs of risk and the EHS practices they reported. A higher percentage of North American (sample included only US respondents) organizations administer nano-specific EHS programs and training than European, Asian and Australian organizations. In North America and Asia, a lack of information is seen as the primary impediment, while in Europe and Australia, fewer respondents believe this as an impediment. Including both in-house and outsourced toxicological testing, Europe clearly performs the most toxicological testing of nanomaterials. Asia performs the most (28%) in-house toxicological research. Compared to North American organizations, Asian organizations use less high capital cost engineering controls such as cleanrooms, closed piping systems and separate HVAC systems, but had more widespread use lower capital cost equipment such as glove boxes, glove bags and respirators. More respondents in Europe and Australia believe there are no special risks related to the nanomaterials handled. Respondents in North America (56%) and Europe (45%) are more likely to monitor than in Asia (17%) or Australia (0%).

Size and Age

The size and age of respondents and the size and age of their nanomaterial division seems to have an influence on the EHS controls employed and the impediments to improving their EHS program. Older companies more frequently stated having internal impediments than younger organizations. External impediments were reported similarly by all organizations of all ages, which primarily were seen as a lack of useful and consistent information. Our data showed that nano-specific EHS programs and training are more prevalent in organizations that have been working with nanomaterials longer and have more employees handling nanomaterials.

Organizations that handled greater than one kilogram were more likely to report monitoring the work place for nanoparticles than organizations that handled less than one kilogram. This could be explained by the increased likelihood of exposure to nanoparticles at such facilities.

In general, the larger organizations that handle a number of different nanomaterials in a variety of phases and engage in a variety of nano-related operations reported the use of more diverse engineering controls. This is likely a product, at least in part, of the higher capital costs of using engineering controls for safety compared to the lower cost of PPE controls. Most reports of cleanrooms came from older organizations. On the other hand, glove boxes and bags, in particular, appeared to be more readily utilized by operations with fewer employees handling nanomaterials on a smaller scale, particularly university research settings. This may be due to the low capital costs and because these controls are designed for handling materials on a small scale. Laminar flow clean benches also tended to be used by smaller nanomaterial operations. Fume hoods were used frequently by organizations new to the nanotechnology field in the last five years – more than 60% of those reporting use of fume hoods are such organizations.

There is some indication that older organizations are more likely to have PPE recommendations. On the other hand, smaller organizations tended to provide more detailed responses, and were more likely to indicate that PPE recommendations are based on nano reasons, possibly because they are only in the nano-business. Employees are more likely to use respirators in smaller companies. More disposable PPE is generally being used by smaller organizations, and slightly more detail to skin exposure and waste disposal of contaminated items was described by smaller companies.

Organizations working with nanomaterials longer than 10 years less frequently provide guidance to their customers for the safe use of their nano-products. The rate of providing guidance in small organizations is higher than larger organizations.

Material

Most companies reported that they worked primarily with powder or with both powders and suspensions of nanomaterials, which suggests that an emphasis in nanomaterials safe handling practices should be made towards minimizing inhalation exposure, use of appropriate ventilation and other air handling approaches. On the other hand, the type of material handled, its phase and elemental make-up do not appear to have a significant influence on EHS controls, although a few trends exist. Fume hoods were more likely to be used when the nanomaterial is in a solution or is embedded in a matrix or bound to a surface, though some organizations did report using fume hoods with dry powders (7 of 43). Several organizations described fume hoods as poor choices for handling dry powders due to the turbulent air and potential for material to be blown away. Closed piping systems were most frequently reported to be used with dry powders and nanomaterials in suspension. Glove boxes and bags were used by organizations that handle materials in a variety of phases, but nearly 70% of reported use of glove boxes came from those organizations working with powders and solutions. Forty-eight percent of organizations working with powder recommended dust masks to their employees, whereas 19% of organizations that did not work with powder require dust masks when working with nanomaterials. This result was not surprising because dust masks are well-known to be an inexpensive and convenient form of protection from airborne particles, although respirators provide a higher degree of protection from the inhalation of nanoparticles. All organizations that described not having PPE recommendations were working with carbonaceous compounds, with the exception of two organizations working only with colloidal dispersions. Organizations that work with only the dry powder form of nanomaterials were not any more likely to monitor the work place than organizations that do not handle the dry form. This result is difficult to explain because handling the dry powder form is more likely to result in exposure. The lack of clear trends could be due partly to the fact that two thirds of the respondents use materials in more than one phase, or this result might point to the need for nanomaterial handling guidelines.

Type of organization

The type of activities an organization is involved in such as manufacturing and R&D, the type of industry and setting (e.g. company or university) had some influence on the choice of EHS policy and practice. Most engineering controls were reported by organizations that were involved with both manufacturing and R&D. The data showed that respirators were used by employees while working with nanomaterials at the majority of organizations that manufacture nanomaterials, but much less frequently at organizations that were not involved with manufacturing. The higher use rate of respirators among the nanomaterial manufacturers could be due to the fact that they also handling larger quantities. In addition, manufacturers of nanomaterials were slightly more likely to perform toxicological research and monitoring.

One hundred percent of organizations classified as involved in the chemical industry and ninety-three percent of nanomaterial manufacturers used respiratory protection.

It was difficult to draw conclusions based on the type of organization (company, research lab, university, or consultant) because companies were largely overrepresented in the sample, but a few trends did exist. Companies more often reported administering a nano-specific EHS program and training than universities and research labs. Results suggested that university labs relied more often on individuals to determine the necessary PPE precautions. One respondent at a university lab stated it was "too difficult to anticipate everyone's needs". Glove bags were used more by university labs (4 of 12) than research labs (1 of 12). University labs described more internal impediments, such as the cost of improving EHS practices and a lack of EHS priority, than research labs or companies.

Sample Representation

The 337 organizations contacted in this study represent only a fraction of the nanotechnology organizations worldwide. One hundred and fifty five nanotechnology companies were contacted in North America (Table 66). This represents ~16% of the 950[26] nanotechnology companies on the continent. Twelve research labs and eleven university labs in the US were contacted, however, there were no reliable sources of information for the total number of these organizations. However, it is likely that only a small number of the university labs handling nanomaterials were contacted.

Estimates for the total number of organizations handling nanomaterials in Asia varied greatly. There were at least 300 nanotechnology companies, of which 67 companies were contacted. This represents a contact rate of less than 23% of the companies in Asia. Estimates of the total number of research and university labs working with nanomaterials in Asia could not be found.

In Europe, there are at least 375 companies, of which 61 were contacted, representing a contact rate of 18%. Estimates of the number of research and university labs in Europe handling nanomaterials could not be identified. However, it is likely only a small fraction of these labs were contacted.

Table 66: Contact rate by organization type and region

Region	Organization Type	Estimated Population	# Contacted	Estimated % Contacted
Asia	Company	>300	67	<23%
	Research Lab	not available	9	
	University Lab	not available	5	
Europe	Company	375	61	18%
	Research Lab	not available	4	
	University Lab	not available	3	
North America	Company	~900	155	17%
	Research Lab	not available	12	
	University Lab	not available	11	

Sixty-four respondents out of 337 organizations participated in the survey, which constituted an overall response rate of 19.0%. The phone interview response rate was 12.5% and the web-based response rate was 2.8%. It should be noted that the web-based responses were from a skewed population because those participants who were quick to respond participated primarily through telephone interviews.

The response rate of the study was similar to those of comparable studies. A study by Delmas and Toffel that assessed environmental management practices[27] reported a 17.2%

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[26] NanoVIP. "Nanotechnology International: companies, profiles and links". <http://www.nanovip.com/directory/International/index.php.> September 2006.

[27] Delmas, M.A., M.W. Toffel, "Survey Questionnaire on Environmental Management Practices," July 2006.

response rate. Another study, administered by the Australian Government's National Nanotechnology Strategy Taskforce, assessed the issues important to the country's nanoscience community. Twenty-nine out of 70 research groups, or 41.4%, participated in the study.[28] However, this study only targeted Australian nanoscience research groups using the Australian Research Council's network. A Japanese study[29] entitled "Current Practices of Risk Management for Nanomaterials by Companies in Japan" stated that "the number of participants was not great," but no response rate was provided. The study group circulated notices to a number of organizations and received only ten responses. The make-up of responses was reportedly biased towards the cosmetics industry, although participants included both users and manufacturers of carbon- and metal-containing nanomaterials.

The response rate of the Japanese organizations (50%) in the UCSB study was greater than was expected initially due to the help of a third party administering the survey. Consequently, Japan was overrepresented in the survey. Without the help of a third party, a lower response rate was expected due to issues such as a potentially greater concern with confidentiality, language barrier, and the time difference.

The North American response rate of 14% was expected to be the highest due to convenience (e.g., language, similar time zones and culture) and the fact that there are more nanotechnology firms in the US relative to the rest of the world. A lower response rate was expected from Europe due to vacation schedules, which occurred during the peak interview time in August. However, this did not prove to be a problem, and resulted in a 15% response rate. In addition, an 18% response rate resulted for "other" countries, where all three respondents were from Australia.

The web-survey was created to generate higher response rates. It was anticipated that the option to fill out a written questionnaire also would facilitate responses. However, these means of data collection created bias in the dataset due to higher non-response rates and incomplete answers than those resulting from telephone interviews. In particular, questionnaires distributed via a third party resulted in a large number of vague and/or incomplete responses. Although web-based/written questionnaires potentially are more convenient for the interviewer and interviewee and could generate a greater overall response rate, the trade-off was a lack of completeness since there was no opportunity for the interviewer to clarify questions and responses. Furthermore, there is a greater risk of compromising confidentiality when using a third party to gather data.

Influence of organizational representatives on survey responses

The density of responses was related to "who" within the organization responded to the questionnaire. In particular, EHS personnel or employees with EHS-related duties were frequently able to provide more EHS details in comparison with other employees, e.g.,

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[28] Australian Government, Department of Industry, Tourism, and Resources. 2005. "Survey of Nanoscience Research Groups: Issues Affecting Nanoscience in Australia." *Australian National Nanotechnology Strategic Taskforce*. <http://www.industry.gov.au/assets/documents/itrinternet/survey_analysis_report20060308115528.pdf>. May 25, 2006.

[29] National Institute of Advanced Industrial Science and Technology. "Current Practices of Risk Management for Nanomaterials by Companies in Japan" <http://staff.aist.go.jp/kishimoto-atsuo/nano/nanomanagement.htm> September 2006.

executive-level and managerial respondents, lawyers, and scientists. Although non-EHS personnel generally could respond to the questions, they often could not comment on details such as respiratory filter specifications, or whether fume hood exhaust filtration systems were being used at their facility. On the other hand, some EHS personnel did not know the specific description and characteristics of the nanomaterials, while research scientists did. In particular, there was a very strong correlation with job title and PPE-related responses. About 5% of the questions about recommended clothing, gloves and eye protection resulted in a non-response when EHS personnel participated in the survey versus 30% non-response otherwise. When specifically asked about respirator filter specifications, the non-response rate was 29% when EHS personnel participated and greater than 50% otherwise. EHS personnel also had a lower non-response rate on spill procedures and waste disposal. In addition, EHS personnel were able to respond to non-technical questions (e.g., company size and age, facility locations) as effectively as non-EHS personnel.

The role of the respondent had some influence on risk beliefs and impediments. According to our survey data, managers were less likely to believe there was an impediment to the management of the EHS program than EHS employees or scientists. Scientists and management perceived less risk in the handling and disposal of nanomaterials. On the other hand, EHS representatives were more concerned with the lack of information for safe handling.

Providing the questionnaire to respondents in advance of telephone interviews likely increased the completeness of answers provided. It also helped ease concerns organizations may have had in terms of sensitive and/or threatening questions; in fact, respondents typically agreed to participate soon after receiving the questionnaire, all without requesting a non-disclosure agreement. However, it is likely that not all respondents took advantage of obtaining the questions in advance, since many responses to questions requesting details pertaining to PPE, engineering controls and nanomaterials were either vague, unknown, or left unanswered. For this reason, it is better to secure EHS personnel for the interview. The dataset would have been more complete if EHS personnel participated in all surveys.

There was no limit pertaining to the number of respondents allowed to partake in a telephone interview. For this reason, it was possible for multiple personnel with varying job titles to attend the interview, including EHS personnel. However, these interviews typically took much longer than the allotted 60 minutes. Increasing the time necessary to complete the telephone interview was anticipated to decrease the response rate. Therefore, the questionnaire was developed with the intention of balancing depth and maintaining a reasonable interview length.

Nomenclature issues

Throughout the process of survey development and administration, there were several issues regarding nomenclature. Developing the initial list of nanomaterial forms was problematic due to the evolving nature of nanotechnology. It was decided to provide a more comprehensive, rather than restrictive list of nanomaterial forms in the questionnaire. However, there were instances of confusion due to some materials that may be described by multiple names. For example, some respondents used the terms nanocrystals and quantum dots interchangeably; or, a colloidal dispersion may be the same material as a nanopowder, but within a solvent carrier. These instances of confusion are evidence of a need within in the community to develop a standardized nomenclature. Respondents were encouraged to use their best judgment in selecting terms to describe their materials. The effect on the quality of data may not be strongly affected due to collection of other material identifying information such as elemental constituents and phase of material during handling.

In addition to issues of material nomenclature, respondents were not always clear with the terminology used to describe the engineering controls. The term "closed piping system" often was interpreted to describe an enclosed process. In phone interviews, this was clarified to use the team's internal definition of a closed/contained drainage system, which did not release nanomaterial effluent to the municipal sewage system. Although this was clarified in phone interviews, respondents may have interpreted this phrase differently in written and web-based surveys.

Based upon the responses, classified by respondent's job title and responsibilities, to questions regarding engineering controls and personal protective equipment, it became clear that in general, EHS-related employees were more familiar with terminology and the EHS program and would provide more comprehensive responses than management or administrative respondents. The same comparison of job type with the description of nanomaterials revealed that EHS-related personnel were not as knowledgeable in the types of materials handled as respondents who were scientists or in management positions. Therefore, it is suggested that future research should attempt to elicit participant(s) with technical knowledge of the materials handled and the EHS program and facilities.

Confidentiality concerns

Prior to the interviewing process, a concern about confidentiality was expressed by ICON members. It was expected that companies would not want to share trade secrets of the engineering and elemental make-up of their nanomaterials. In addition, organizations might be concerned over liability issues and did not want to be identified as using or not using certain practices and held liable for it. The confidentiality concerns were circumvented by establishing and publishing a confidentiality protocol, by addressing confidentiality openly in all pre-contact documents, and by expressing a commitment to maintaining confidentiality during the oral interview. The confidentiality protocol ensured that all information would be kept confidential, on a secure server and only aggregate results will be published in the final report. Only one respondent requested a non-disclosure agreement but after reading the confidentiality protocol it was deemed unnecessary. In addition, the questions were designed strategically to avoid sensitive information and respondents were asked to skip questions that they felt uncomfortable answering. Consequently, respondents seldom skipped questions because of confidentiality concerns but more often because they lacked information or knowledge. Only one organization did not want to record the interview due to company policy. Further, none of the organizations that declined to participate cited confidentiality as a reason. Granted, of the organizations that did not respond to the original solicitation, we could not know who was not responding on the basis of potential confidentiality concerns. However, while it was expected that some organizations would not participate based on confidentiality concerns, this did not appear to be the case and that could be attributed to the efforts to thwart such concerns.

VI. Limitations of this Study and Recommendations for Future Research

Limitations of this Study

There were several limitations to this research project. First, the sample size was too small to be representative of the global nanotechnology community and provide statistically significant results. However, due to the scope of this project and its exploratory nature, the UCSB research team was not aiming to survey the entire population; therefore, the results should be interpreted as indicative rather than definitive. Second, all information provided by respondents was self-reported and therefore was not verified by a third party. The means of interviewing respondents in this study relied on the knowledge and honesty of respondents. Finally, the participant pool was non-random and was based on voluntary participation. Respondents of this survey either wished to share their knowledge or advance the issue of developing “best practices” for handling nanomaterials.

Questions to Address

There are important questions raised by this study that still need to be answered. Respondents overwhelmingly described the lack of information as an impediment to their organization’s health and safety management. Respondents were interested in providing a safe work environment for their employees, but did not have the necessary information or believed that the available information was contradictory and/or confusing. This problem was exemplified by toxicology studies that provided contradictory results, or by the lack of data regarding the chemical and physical properties of nanomaterials. These responses emphasize the importance and necessity of research to understand these properties. Voluntary programs such as those being organized under US EPA, UK DEFRA and the German BAuA seek to bridge this gap through the compilation of pertinent information provided by companies.

Recommendations for Future Research

There are ways in which future research can build on and improve knowledge gained from this study. For one, it is recommended that any future research seeking definitive results attempt to survey a larger sample of nanotechnology organizations. Extending the survey period would help increase the response rate since time is required to build momentum for participation; while conducting surveys for this study, a majority of respondents scheduled interviews for later in the survey period and some were excluded due to time restrictions.

It is recommended that this form of research be conducted either in person or over the telephone. Written and internet surveys, and in this case those administered by a third party (which were written), proved ineffective for some questions in which interviewers needed to probe for answers or seek clarification, such as questions requesting information about PPE and engineering controls. Furthermore, the written and internet questionnaire formats did not allow the opportunity for the interviewee to request clarification of a question. For example, some respondents with English as a second language had a difficult time understanding the word “impediment.”

Although they would be more costly and time-consuming, interviews conducted at the organization’s site would provide the most accurate data in terms of verifying responses.

The opportunity to observe the activities in the work environment, in particular, would allow the opportunity to confirm responses. Future research could perform field evaluations of organizations to confirm reported practices, in the spirit of the work currently performed by NIOSH. For instance, although a respondent may indicate that all employees use respirators when handling nanomaterials, this may not be the case in reality.

Similarly, this survey's dataset was skewed because the survey was voluntary, so presumably only those with "good" controls would respond. In addition, the survey was not performed with actual workers "on the floor," but rather managers and EHS personnel (amongst others) who presumably know what "good" practices are and may not be relaying the reality of their workplace. For this reason, it is recommended that future researchers explore the possibility of including workers in the interviews to gain an understanding of the real picture, e.g., whether the employees *always* wear required PPE.

Future research should interview a larger sample size to obtain a more representative sample. In particular, it should be investigated whether more universities and R&D labs should be interviewed; the value of including more respondents in these categories is uncertain.

Research has been conducted to gather information on the number and locations of organizations working with nanomaterials around the globe. However, such information is available but at a high cost. For instance, The World Nanotechnology Market report, which includes this information, can be purchased for $1,400 USD[30]. It would be beneficial to this study, as well as future related studies, for this information to be readily available and affordable. An international inventory and/or directory of companies working on nanotechnologies would be an invaluable resource for better understanding how representative a survey sample is, as well as locating potential participants. It also would be useful to know what material forms these companies work with.

Choosing categories for data analysis proved a difficult task in this study, since nomenclature still is being developed for various aspects of the nanotechnology industry. Terms for nanomaterial structures (e.g., nanotubes, quantum dots, nano-onions), in particular, are very subjective, as are categorizing nanomaterials based on elemental constituents, distinguishing target industries/customers for nanomaterials, and classifying businesses that work with nanomaterials. Various organizations are working on establishing related nomenclature/classification systems. In the meantime, however, the use of SIC numbers to distinguish between industries may prove useful.

Finally, this research investigated only a portion of the life-cycle of nanomaterials. There is a lot more ground to cover, and therefore, it is recommended that future research investigate different periods of the product life-cycle in the nanotechnology industry. In this study, for example, there were no interviews with waste management companies or customers of nano-containing products. End-of-life was not fully investigated by this research, although it is of utmost importance.

VII. Conclusions

The aim of this study was to reveal current practices within nanomaterials industries regarding environmental, health and safety, product stewardship and environmental

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[30] RNCOS. The World Nanotechnology Market (2006). August 1, 2006. Available for purchase through MarketResearch.com <http://www.marketresearch.com/product/display.asp?productid=1324644&g=1>

protection. Sixty-four organizations were interviewed on four continents, the majority of which were in the private sector although some university and research labs were included. While most of the participating organizations were less than ten years old, some older organizations participated as well. Overall, the study included organizations of all sizes, ages, industries and using a variety of nanomaterials.

The survey results generally revealed that organizations working with nanomaterials use conventional chemical safety methods through the life-cycle of nanomaterials. In a few instances, organizations were taking measures beyond those of conventional chemical hygiene, such as designing enclosed processes for working with nanomaterials. Some respondents indicated the use of guidelines for working with hazardous materials or fine particulates and dusts.

Differences in EHS practices existed based on organizational characteristics such as geographical location, size, material handled and type of organization. Compared to North American organizations, Asian organizations used fewer high capital cost engineering controls such as cleanrooms, closed piping systems and separate HVAC systems, but had more widespread use of lower capital cost equipment such as glove boxes, glove bags and respirators. In North America and Asia, lack of information was seen as the primary impediment, while in Europe where the most toxicological testing was performed, fewer respondents perceived this as an impediment. Our data showed that nano-specific EHS programs and training were more prevalent in organizations that had been working with nanomaterials longer and had more employees handling nanomaterials. In general, larger organizations that handle a number of different nanomaterials in a variety of phases and engage in a variety of nano-related operations reported the use of more diverse engineering controls. More disposable PPE is used by smaller organizations, and slightly more detail to skin exposure and waste disposal of contaminated items was described by smaller companies. A large number of organizations working with powder recommended dust masks to their employees, and some recommended respirators. On the other hand, fume hoods were more likely to be used when the nanomaterial was in a solution or embedded in a matrix or bound to a surface. University labs described more internal impediments, such as cost concerns or lack of EHS priority for improving EHS practices, than research labs or companies.

Due to the limited time and resources of this project, our sample size was a small representation of the nanomaterial industry. Therefore, it is recommended that any future research strive to survey a larger sample of nanotechnology organizations. In addition, all information provided by respondents was self-reported and therefore not verified by a third party. Further research could perform field evaluations of organizations, in the spirit of the work currently performed by NIOSH. Finally, the participant pool was non-random and based on voluntary participation. Respondents either wished to share their knowledge or advance the issue of current practices for handling nanomaterials. These findings about “current practices” could be useful to the eventual development and implementation of “best practices” whether through regulation or voluntary programs. However, further research needs to be done to complete the understanding of current practices and how they address human health and environmental concerns related to nanomaterials.

VIII. Acknowledgements

This research was funded and supported by ICON and the Best Practices subcommittee of ICON. Environmental Defense's Tracy Godfrey contributed significantly to the development of the contact list. Keith Swain of the DuPont Company and Matthew Hull of Luna Innovations provided information about their respective organizations' risk assessment frameworks; they also pre-tested and provided valuable feedback on our questionnaire. Chuck Geraci of NIOSH provided information about important areas of interest for our research as well as valuable feedback on our questionnaire. We greatly appreciate the efforts of ICON member Hideo Shindo of NBCI who promoted this research in Japan, identified Japanese participants, and administered the survey including translating the questionnaire into Japanese and translating Japanese responses into English. We appreciate the efforts of Dianhong Shen at the Chinese Academy of Sciences, for collecting answers from respondents in China. We also express gratitude to Tsung-Tsan Su, Ting-Kuo Lee and Tsing-Tang Song at the Office of National Nanoscience and Nanotechnology Program in Taiwan for providing contact information and to David Vandenberg at UCSB for providing the team with EHS information in the form of documents and invaluable conversation. Finally, we would like offer our gratitude to all the survey participants who took the time to speak with us and share their practices, insights, and concerns. Without their interest and help, this report would not have been possible.

IX. Appendices

Appendix A: UCSB Survey Instrument

UNIVERSITY OF CALIFORNIA, SANTA BARBARA

BERKELEY • DAVIS • IRVINE • LOS ANGELES • MERCED • RIVERSIDE • SAN DIEGO • SAN FRANCISCO SANTA BARBARA • SANTA CRUZ

Survey of Current Health and Safety Practices in the Nanomaterial Industry

Thank you for agreeing to take part in this benchmarking exercise in nanotechnology industrial current practices in workplace and environmental health, safety and product stewardship.

All individual responses will be kept strictly confidential.

The survey will be administered through a telephone interview with one of the following Graduate Research Assistants who will be contacting you:

Joe Conti
Gina Gerritzen
Leia Huang
Keith Killpack
Maria Mircheva

If you have any questions, please contact the project team through the confidential email account: nanotech@bren.ucsb.edu .

Project Principle Investigators:

Patricia Holden, PI
Magali Delmas, Co-PI
Barbara Herr-Harthorn, Co-PI
Rich Applebaum, Co-PI

Section 1: Interview Subject Information

This first part of the survey is to learn about you, the respondent.

1a. What is your title?

1b. What are your responsibilities?
(Please also comment on how far your responsibilities extend, i.e. throughout the organization or mainly within your immediate facility.)

1c. How long have you been in this current position?

Section 2: Organization Information

This next section is to learn more about your organization and its involvement with the production or application of nanomaterials.

2a. What business are you in?
(For example, is your company a coatings manufacturer, a medical diagnostics company, an R&D organization in nanoparticles, a university research lab? Please be as complete as possible, including all classifications of your business.)

2b. Which of the following best describes your business as it relates to nanomaterials (check all that apply)?

- Your company *manufactures* nanomaterials
- Your company *uses* nanomaterials
- Your organization performs nanomaterials *research and development*
- Other *(please describe)*

3. In what industries are your nanomaterials' customers (or your customers for products *made from* nanomaterials)? Mark all that currently apply and/or are planned.

o Electronics
o Defense
o Sensing
o Cosmetics or other personal care products
o Coatings
o Medical
o Energy
o Automotive
o Plastics
o Construction
o Agriculture
o Nanomaterial manufacturer
o Research & development
o Retail
o Other:

4a. Approximately what year was your organization formed?

4b. How long has your organization been working with nanomaterials?

4c. Where is your organization's home location? Please indicate the Country, State (or Province), and City.

4d. In what countries does your company produce nanomaterials?

5a. How many employees are in your organization overall?

5b. How many employees work directly with (i.e. handle, produce, or research) nanomaterials in your organization? Please check the appropriate box below.

o 1 up to < 10 employees

- o 10 up to < 50 employees
- o 50 up to < 250 employees
- o 250 and more employees

Section 3: Nanomaterial-Specific Product Information

This next section is to get a general sense of the nanomaterials your organization works with. We would like you to describe the nanomaterials produced and/or handled in your organization in lay terms. No proprietary information is requested.

6a. What are all the different types of nanomaterials that your organization works with?

(Categories may include:)

- *Nanopowders*
- *Nanocrystals*
- *Quantum Dots*
- *Colloidal dispersions*
- *Fullerenes (Buckyballs)*
- *Nanotubes*
- *Nanowires*
- *Nanohorns*
- *Dendrimers*
- *Flakes*
- *Platelets*
- *Rods*
- *Polymers*
- *Carbon black*
- *Other – what?*

6b. What are the constituent materials of all these nanomaterials?

(For example, cadmium selenide, titania, silica, carbon, etc. This information is necessary for each nanomaterial.)

6c. What are the sizes of these nanomaterials?

(*This information is necessary for each nanomaterial. Please provide length and width measurements for nanotubes, nanowires, etc.)*

- *< 20 nm*
- *20 nm up to < 50 nm*
- *50 nm up to 100 nm*
- *> 100 nm*

6d. Are the nanomaterials you described mostly in solid form or are they in suspension? If in solid form, are they freely mobile or bound, for instance embedded in a coating or some other product? If in suspension, are they in water, or some other liquid?

(This information is necessary for each nanomaterial.)

6e. At what scale of production are these nanomaterials?

(This information is necessary for each nanomaterial.)

- *At a small scale, i.e. in a start-up company*
- *At the pilot scale within a larger industry*
- *At the full or commercial scale*

Section 4: General OEHS and Nano-OEHS

This section regards your organization's (or lab's) occupational and environmental health and safety programs, including monitoring and training. Specific practices are addressed later in the survey.

7a. Does your organization (or lab) implement a general 'health and safety' program?

- o Yes *(Continue to question 7b)*
- o No *(Skip to question 9a)*

7b. How many full-time equivalent 'health and safety' employees are in your organization?

8a. Does your organization (or lab) implement a "nano-specific" 'health and safety' program?

- o Yes *(Continue to question 8b)*
- o No - why not? *(Skip to question 9a)*

8b. How many full-time equivalent employees work in the "nano-specific" 'health and safety' program?

8c. Please describe your "nano-specific" 'health and safety' program and the reasons for the "nano-specific" program.

8d. Does your "nano-specific" 'health and safety' program vary by different locations within the organization? If yes, why?

8e. Does your "nano-specific" 'health and safety' program vary depending on the specific nanomaterial being handled? If so, how and why?

8f. Are any of your "nano-specific" or other 'health and safety' programs administered by outside contractors? If so, which programs and why?

9a. Does your organization (or lab) offer 'health and safety' training for your employees on the handling of nanomaterials? Why or why not?

- o Yes *(Continue to question 9b)*
- o No *(Skip to question 10)*

9b. What topics are covered in this training? and what formats do you use? *(For example, are there detailed written material, verbal communication, videos, website guides, regular training meetings, or other?)*

9c. Where do you obtain information and guidelines for your "nano-specific" 'health and safety' training?

9d. Do all employees who handle nanomaterials receive this training? If no, why would someone *not* receive this training?

- o Yes
- o No

9e. How often do employees receive “nano-specific” ‘health and safety’ training?
(Select all that apply, and please explain.)

- Annually
- Upon start at company
- When standard EHS training offered
- When new material is introduced
- Other:

9f. Who provides the training?

- Internal resource *(Proceed to 10)*
- External resource *(Proceed to 9g)*
- Both internal and external resources *(Proceed to 9g)*

9g. While they won’t be contacted through this study, can you provide the name of the external company?

Section 5: Containment & Exposure Controls

This section regards your organization’s containment and exposure controls.

10. To better understand the potential for nanomaterial exposure in your facility(ies), what amounts of nanomaterials do your employees typically work with at a time? Is it on the scale of:
(Note: If the answer is in “volume” units, please provide concentration information so that your answer can be converted to mass units.)

- Micrograms to less than one milligram
- Milligrams to less than one gram
- One gram to less than one kilogram
- Greater than one kilogram

11a. Are “nano-specific” facility design and engineering controls used to safely manage worker exposure to nanomaterials? If so, which of the following types are used?

- o Cleanroom
- o Fume hood – if so, which class (0-4)? *(If fume hoods are used, please proceed to 11b after this question; if not proceed to 12)*
- o Biological safety cabinet
- o Laminar flow clean bench
- o Glove box
- o Glove bag
- o HVAC system *(Please indicate if a separate HVAC system is used in the area(s) where nanomaterials are produced/handled.)*
- o Pressure differentials *(Please indicated whether positive or negative, and where implemented.)*
- o Closed piping system
- o Other – what?

11b. If you use fume hoods, are exhaust filtration systems being used in your fume hoods? If “yes”, then what is the particular type?

12. How do you clean (or decontaminate) equipment used for nanomaterial applications?
(For example, how are equipment cleaned prior to maintenance or other routine operations?)

13. This next section regards what your employees do to minimize their exposure to nanomaterials in the workplace and why specific choices are made, beginning with Personal Protective Equipment & Clothing.

13a. Do you have recommendations for your employees regarding protective equipment and/or clothing that should or *should not* be worn in the lab while working with nanomaterials?

- o Yes
- o No. Why not? *(Interviewer: skip to 16)*

13b. Please describe the following protective equipment choices and the reasons for making them.

❖ Clothing *(e.g., material or length of lab coats, building suits, special shoes, laundry service, etc.)* – Are work clothes taken home?

❖ Gloves *(e.g., material or length of gloves, etc.)*

❖ Eye protection (*e.g., safety glasses: full face coverage, side shields, special material; goggles, use of contact lenses, etc.)*

❖ Other *(e.g., disposable face masks, hair bonnets, etc.)*

13c. Are hygiene facilities (showers/change areas) provided and is their use required when employees leave the work area?

13d. Do your employees use respiratory protection while handling nanomaterials?

- o Yes *(Continue to question 13e)*
- o No. Why not? *(Skip to question 14)*

13e. What type of respiratory protection is used?

- o Filter specification? *(e.g., N100, P95)*
- o Full-face or half-mask?
- o Cartridge or disposable?
- o Other info:

13f. Why was this particular respiratory protection chosen?

13g. For cartridge or disposable respirators, how often are they changed out or disposed of?

14. Is use of protective equipment and clothing required of employees while working with nanomaterials? *Please describe how such requirements are enforced, if they are, or if use is voluntary.*

15. Is there anything else you'd like to mention regarding your organization's strategies to reduce employee exposure to nanomaterials?

16. Are you considering plans to improve your organization's (or lab's) "nano-specific" 'health and safety' practices? If so, what are your plans?

17. Are there impediments to your organization's 'health and safety' management with respect to nanomaterials? and are there plans to address these concerns? *[For example, either internal / organizational barriers such as cost concerns, or external barriers such as lack of information, are of interest.]*

Section 6: Waste Management

This next section includes a few questions regarding your organization's waste management practices.

18a. How do you handle spills involving nanomaterials? and are these practices different from "non-nano" spills?

18b. How do you dispose of waste containing nanomaterials?

18c. Are separate disposal containers for nanomaterials used either in the lab or in waste storage areas?

o Yes
o No

18d. On your waste Manifests (or inventory/stock sheets), are nanomaterials listed as “bulk material” or as “nanomaterial”?

18e. Is there anything else that you would like to mention regarding nanomaterial waste disposal in your organization (or lab)?

Section 7: Employee and Area Exposure Monitoring

19a. Does your organization monitor the work environment for nanoparticles?

o Yes *(Continue to question 19b)*
o No *(Skip to question 20a)*

19b. What is monitored? and how? Please elaborate. *[For example, if nanomaterial is freely mobile, is the air monitored, and how? or if in suspension, is dermal contact monitored, and how?]*

19c. What measurement equipment is used?

19d. Why was this equipment chosen?

19e. How frequently do you perform this monitoring of nanoparticles?

o At initiation of the work
o When a change occurs in the work

- Continuous monitoring
- More than once per week
- Less than once per week, more than once per month
- Less than once per month, more than once per year
- Never

Section 8: Risk Characterization

This section regards your organization’s risk characterization measures.

20a. Do you think there are any special risks associated with the nanomaterials handled or produced in your organization? If so, what do you think those risks are?

20b. How do you determine if there are risks associated with the nanomaterials handled or produced in your organization (or lab)? *For example:*

- *Have you conducted reviews of the scientific literature?*
- *Do you do toxicity or ecotoxicty testing?*
  - *What organisms and type of test apply, e.g. inhalation studies in rats, e-fate test methodology?*
- *Do you consult government regulations and guidelines?*
  - *For example, reports, guidelines or other from: EPA, EPA-TSCA, NIOSH, UK-HSE, or other?*
- *Do you consult industry guidelines?*
  - *What are the sources?*
- *Do you seek expert consultation?*
- *Do you benchmark with other organizations?*
- *Are there other ways that you determine risks?*

20c. Does your organization perform its own toxicological research?

- Yes

o No

(Note, if multiple nanomaterials, for which ones?)

Section 9: Product Stewardship

This section regards product stewardship.

21. What form of guidance information about the safe use of your nano-products do you provide to customers? and is it available to the public?

(For example, answers could include:)

- *Material Safety Data Sheets*
- *Indications on technical instructions*
- *Product info sheet*
- *Accompanying letter*
- *Other – what?*

22. What form of guidance do you provide to customers for the safe disposal of your nano-products? and is it available to the public?

For example:

- *Does your company have a take-back program?*
- *Do you encourage recycling?*
- *Do you encourage disposal as hazardous waste?*
- *Other – what?*

Section 10: Closing questions

In closing,

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

24. Is there anything that we haven't covered in this interview that you think is relevant and we need to understand and include in this survey?

Once again, thank you for your participation. As a reminder, all survey results will be aggregated into a final report for ICON, and ICON will disseminate the final report on its website, http://icon.rice.edu/. The tentative timeframe for the final report is late 2006.

Appendix B: Supplemental Data from Chinese Nanotechnology Organizations

After completion of the data collection period, seventeen additional written surveys and one additional web-based survey were submitted from nanotechnology organizations in China. Because the responses were received after the analysis of the primary data set was complete, these findings have been appended to the primary report. The web response was a late-responder from the original invitation to participate in the study. The seventeen written surveys were collected by a third party in China. This individual is a researcher at the Chinese Academy of Sciences and was referred to the research team by a member of ICON. The questionnaire was translated by a research team member, who is a native Chinese speaker, and provided to the third party to solicit Chinese participants. Instead of providing only contact information, the third party sent completed questionnaires to the research team. Although the organizations' names are indicated on the completed questionnaires, the methods used for selecting respondents are not known. Responses were returned to the team in Chinese and translated into English by the native speaking Chinese member of the research team. This data set was analyzed separately from, but compared to, the data in the primary report.

Overall, the supplemental Chinese data set has more non-responses per question and less detailed information than the data in the primary report. This is likely a result of the reliance on a third party to administer written surveys which precluded the opportunity for the research team to probe and clarify answers. In addition, the sample size is small and should not be considered representative of the nanomaterial industry in China. Future research in this area should seek to expand the sample size and administer interviews either in person or over the telephone to increase the density of information collected.

Respondent Characteristics

The supplemental data set differs significantly from the primary data by the type of participating organizations. Forty-four percent of responding organizations were university labs, 39% were private sector companies, and 17% were research labs. This contrasts strongly with the organizations represented in the primary report, which was represented by 80% private companies, 9% university labs, 9% research labs, and one consulting firm (2%).

This data set also differs with the representation of different job duties, based upon classification of job titles and responsibilities of responding individuals. Eight scientists (including one engineer), six representatives of executive administration or management, and three individuals represented by both scientific and administrative responsibilities participated in this survey. In the primary report, 46% of respondents held positions classified as executive administration or management, 17% were represented by scientists, 16% were represented by EHS personnel, and 21% were classified as other or some combination of the above.

Similar proportions of respondents were involved in manufacture, use or R&D of nanomaterials (27%, 20%, 47%, respectively and 6% other) as in the primary data survey (26%, 30%, 41%, and 3% other). There were a few more respondents that were involved in research and a few less that indicated they used nanomaterials. Also a much bigger proportion of the respondents in the supplementary dataset (50%) indicated they are involved in one activity only as opposed to 19% of respondents in the primary dataset.

On average, this supplementary dataset consists of younger organizations with an average age of 12 years versus an average age of 45 in the primary dataset. Of the 15 respondents, who answered this question, 12 organizations were less than 10 years old and three were 11 years or older. On the other hand, there is not much difference between the datasets in the amount of time respondents reported working with nanomaterials; it averaged six years for the supplementary dataset and seven years for the primary dataset. Only one organization in the supplementary dataset had worked with nanomaterials for more than 10 years. This organization had been working with nanomaterials for 15 years.

All organizations in the supplementary dataset were based in one major city in China. Respondents indicated they handle nanomaterials only in China, although one mentioned that some materials were imported from Russia.

The size distribution of participating organizations in this dataset is similar to the size distribution of the primary dataset (Table B 1), although it is slightly weighted toward organizations of medium size (50-999 employees) rather than small organizations (1-49 employees).

Table B 1: Size distribution of participating organizations

Total Number of Employees	# Organizations in the Supplemental Data		# Organizations in the Primary Data	
1-49 employees	6	35%	**30**	47%
50-999 employees	8	47%	**21**	33%
1000-99,999 employees	2	12%	**8**	13%
100,000+ employees	1	6%	**5**	8%
Total respondents	17	100%	64	100%

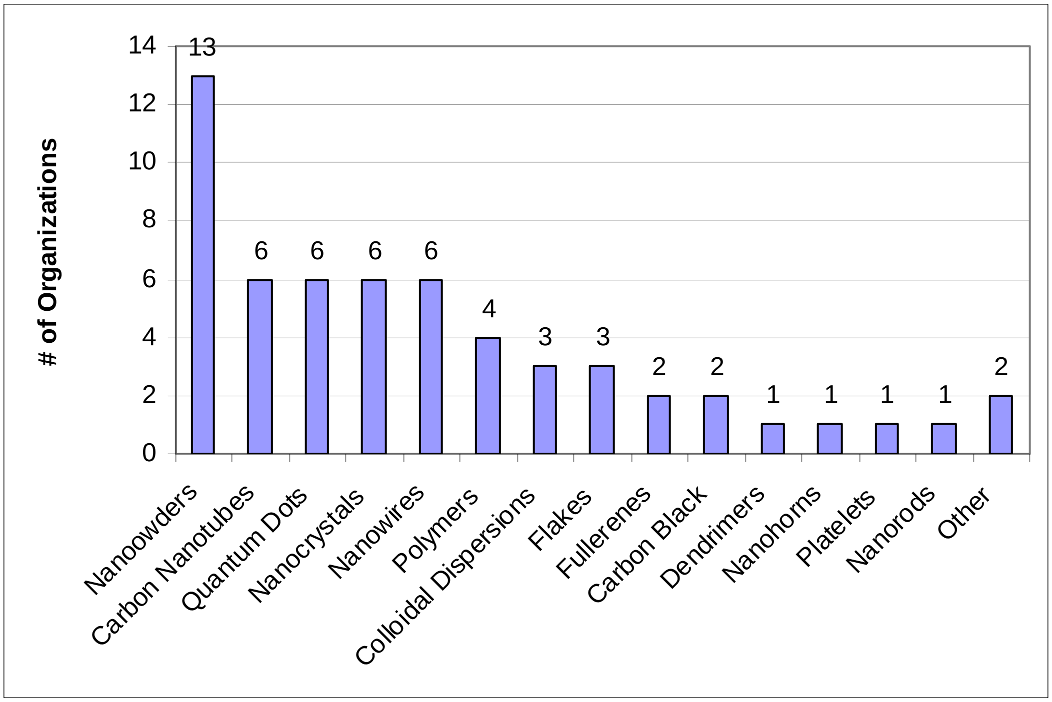
There is a similar trend in the size of nanomaterial divisions in participating organizations (Table B 2). The supplementary data is also weighted toward medium size nanomaterial divisions (10-49 employees) rather than small nanomaterial divisions (1-9 employees).

Table B 2: Size distribution of nanomaterial divisions of participating organizations

Number of Employees working with nanomaterials	Organizations in the Supplemental Data (#, %)		Organizations in the Primary Data (#, %)	
1-9 employees	5	29%	26	41%
10-49 employees	10	59%	27	42%
50-249 employees	2	12%	6	9%
250 or more employees	0	0%	5	8%
Total respondents	17	100%	64	100%

Respondents were asked to describe the characteristics of the nanomaterials handled or produced at their organization, including type of nanomaterial, range of sizes, elemental constituents, phases of material handled, and scale of production or use. Figure B 1 details the reported forms of nanomaterials handled by the responding organizations. Nanopowders were the most frequently reported form of nanomaterial handled (13), followed by carbon nanotubes (6), quantum dots (6), nanocrystals (6), and nanowires (6). This result is similar to the findings of the primary report, in which the most frequently handled forms are nanopowders (34), followed by carbon nanotubes (29), colloidal dispersions (19), and fullerenes (12).

Figure B 1: Number of respondents handling various types of nanomaterials



Respondents were also asked to describe the elemental constituents of the nanomaterials handled (Table B 3). These responses have been categorized as metals (pure metals or metal containing molecules, but not including metal oxides), metal oxides, carbonaceous (nanotubes, fullerenes, and carbon black), organic, and non-metals (both pure non-metals and non-metal containing compounds). These results are similar to the findings of the primary report.

Table B 3: Elemental characterization of nanomaterials handled

	Metal oxides	Non-metals	Carbonaceous	Metals	Organic
# of Organizations	10	9	6	5	3

Respondents were asked to describe the phases of the materials during handling, including in the case of solid, whether the nanomaterial is bound or freely mobile (Table B 4). Four organizations described only handling nanomaterials in suspension, followed by two organizations which only handle nanomaterials bound to a surface or embedded within a matrix and two organizations described handling nanomaterials in suspension and embedded or bound. Four respondents described handling nanomaterials as a “solid form.” This unclear statement could refer to either a freely mobile powder or nanomaterials embedded within a matrix or bound to a surface. These responses are presented in their own category.

These findings differ significantly from the information reported in the primary report. In the primary report 37% of organizations described handling nanomaterials as both a dry powder and in suspension. No organizations in the supplemental data described handling nanomaterials in these two phases.

Table B 4: Phases of nanomaterials handled by participants

	# of Organizations
In suspension only	4
Bound to a surface only	2
In suspension and bound to a surface	2
Dry powder only	1
Dry powder and in a matrix	1
Dry powder, in suspension, and bound to a surface	1
Response unclear- “Solid form”	4

Respondents described the scale of production or use of nanomaterials handled at their organization. Definitions for small, pilot, and full or commercial scale were not provided and the interpretation was left to the respondent. Fourteen organizations responded to this question (Table B 5).

Table B 5: Scale of production or use of nanomaterials described by respondents

Scale of Production	small scale	pilot scale	full or commercial scale	both small and pilot scale
# of Organizations	6	4	3	1

EHS Programs and Training- in progress

As compared to the primary dataset, a larger percentage of organizations in the supplementary dataset indicated not having an EHS program (8 vs. 22%). In addition, the average number of employees in EHS is lower: six employees in the supplementary dataset compared with 55 employees in the primary dataset. This result is consistent with the profile of the Chinese organizations in the supplementary dataset which have fewer employees on average (6,439) than the organizations in the primary dataset (20,887).

A lower percentage of organizations in the supplementary dataset indicated that they have a nano-specific EHS (33%) compared to the primary dataset (58%). Of the six organizations with a nano-specific EHS program, five provided the number of employees working to administer that program. The average nano-specific EHS Full Time Equivalents (FTEs) in the supplementary dataset is 3.6 FTEs which is higher than the average of 1.6 FTEs in the primary dataset. Only three respondents described their program. All three indicated that the program was established to ensure safety of employees; one respondent added that there are unknown risks and another added that the program ensures the safety of the nanomaterials as well as the employees.

Respondents were asked if their nano-specific EHS program varied by type of nanomaterial handled. All four respondents to this question indicated that their program varied by type of material, because different nanomaterials have different characteristics and hazards depending on the constituent materials and the phase (e.g. dry powder or in solution). Respondents were also asked if their nano-specific program varied at different locations within the company. Two out of three respondents indicated that their program does vary because different materials are handled in each lab.

Organizations in the supplementary dataset reported a lower rate of training employees on the handling of nanomaterials. Thirty-nine percent of the organizations in the supplementary dataset reported doing so compared to 59% in the primary dataset. Three respondents indicated they provide written material and verbal training, while one administered training in the lab. Four out of five respondents indicated they used books and internet sources for developing the training program and one used an outside company. In the primary dataset the most popular source of training information were government organizations followed by scientific literature and internal expertise.

Engineering Controls and PPE

Responses to questions about engineering controls and PPE were generally vague. Few details were provided, and non-responses were frequent, which makes comparisons of findings difficult. For example, various forms of engineering controls were reported (Table B 6), and in particular, eleven respondents (61%) reported using fume hoods when working with nanomaterials. This is similar to the primary data where fume hoods were the most frequently reported engineering control followed by glove boxes and cleanrooms. However, no respondents reported their fume hood class and only one reported having exhaust filtration with the fume hood.

Table B 6: Reported engineering controls in supplementary dataset

	# of Organizations
Cleanroom	6
Fume hood	11
Biological safety cabinet	3
Laminar flow bench	3
Glove box	6
Glove bag	1
HVAC	2
Closed piping system	2

Thirteen respondents (72%) indicated they have PPE recommendations for their employees when working with nanomaterials, whereas 80% of Asian organizations reported having PPE recommendations in the primary data. These recommendations were reported to be company policy at only six of the organizations. Two reported that their recommendations were voluntary. Four reported not having PPE recommendations and one did not respond to this question. When asked about specific PPE recommendations (e.g., clothing, gloves, eye protection, respiratory protection), few details were provided. Seven respondents simply said that work clothes were not taken home. One respondent recommended a “cotton working suit,” and another recommended a cotton or Tyvek lab coat. Seven respondents did not provide any information and three stated only “yes” when asked specifically about clothing. In terms of gloves, one respondent recommended latex gloves that cover the forearm, two recommended rubber gloves, and another recommended “medical safety gloves.” Five respondents simply stated “yes” and nine did not respond. In terms of eye protection, goggles (3) and safety glasses (3) were recommended by a small number of organizations. One respondent recommended full face coverage when working with nanomaterials (as well as safety glasses and/or goggles). Two respondents recommended not wearing contact lenses while working with nanomaterials. Eight respondents provided no information on eye protection. Finally, when asked about respiratory protection, only two respondents mentioned the use of dust masks; all others were non-responses. Seven respondents (39%) reported using respirators when handling nanomaterials and six did not use respirators. In comparison, 68% of Asian organizations reported using respirators in the primary data. Only one respondent provided a reason for not using respirators, which was that all operations are contained in a fume hood and glove box. Only one respondent provided details on the respirator filter used (N95 and N100). One respondent stated the respirator was chosen for convenience; otherwise no reasons were provided. Change-out and disposal schedules included: everyday (1), weekly (1), monthly (1), and every 5-10 times used (1). In general, it is difficult to compare the aforementioned PPE recommendations with those in the primary Asia data because a majority of questions in the supplemental data were left unanswered or descriptions provided were vague.

Beliefs about Impediments towards Health and Safety Management

Only nine organizations responded when asked, “Are there impediments to your organizations ‘health and safety’ management with respect to nanomaterials, and are there plans to address these concerns?” Four organizations stated there were no impediments, while five described impediments. All five organizations reporting impediments also stated that there is a lack of information which prevents improvements in their health and safety programs. In addition, two of these organizations stated that costs of program implementation were also a concern. This result was similar to that which was reported in the primary report (Table B 7) where lack of information, and to a lesser extent, cost concerns were the most frequently cited impediments.

Table B 7: Comparison of reported impediments to management of ‘health and safety’ programs

	# of respondents	# which reported impediments	% which reported lack of information	% reported cost concerns
Primary data	53	39	43%	11%
Supplementary data	9	5	55%	22%

Waste Management

Responses to questions about waste management were quite similar in both datasets. Of the eight responses to questions about the handling of nano-spills, six reported handling nano-spills the same as spills that do not contain nanomaterials (33%), one reported not having had any spills and one organization described agglomerating the nanoparticles. The respondent did not indicate how this is done. In the primary dataset about 53% of the organizations indicated they handled spills containing nanomaterials the same as conventional hazardous chemical spills. A similar percentage of organizations in the supplementary dataset separated the nanomaterial waste (39% versus 33%), while a higher percentage or organizations labeled it as containing nanomaterials on the waste containers (44% versus 27%). Similar to the respondents in the primary dataset, three respondents from the supplementary dataset expressed concerns about nanomaterial waste and the need for guidance from the government, upper management or other organizations in the industry.

Monitoring the Work Environment for Nanoparticles

Respondents were asked if their organization monitors the work environment for nanoparticles. Seventeen organizations responded to the question, of which only two reported performing monitoring, which constitutes only 12% of the respondents. One of these responses described using a particle counter more than once per week to monitor the work environment. The second respondent stated more generally that they monitor "nanoparticles in the lab air" at least once per month.

Reported monitoring of the work environment by Chinese organizations in the supplemental dataset was similar to reports by other organizations from Asia in the primary report. Of the population of Asian organizations in the primary report, in which Japanese organizations are relatively overrepresented, 17% indicated performing monitoring. These rates are lower than the 36% of worldwide organizations worldwide that reported monitoring the work environment for nanoparticles in the primary dataset.

Attitudes towards Risk of Nanomaterials Handled

Respondents were asked if they thought there were special risks associated with the nanomaterials handled or produced at their organization. Fourteen of 18 organizations responded to this question, with all stating there are no special risks. Several organizations qualified their responses to this question by stating, for instance, that the organization worked with small quantities (2), that there were no special risks if prescriptive regulation was followed (1), that the nanomaterials handled were embedded in films (1), or that they were awaiting further research before making such a determination (1).

The reporting that there were no special risks with the nanomaterials handled contrasts strongly with the findings of the primary report. In the primary dataset 38% of the respondents described no special risks, while 22% stated they did not know or there was not enough information available. Forty percent cited concerns such as the risk of inhalation, potential toxicity, flammability and potential explosivity.

Methods for Determining Risk of Nanomaterials

Respondents were asked how they determine if there are risks associated with the nanomaterials handled or produced at their organization (Table B 8). Respondents were provided with a series of prompts, followed by an open-ended question for sources not listed. Only eleven organizations provided any response to the prompts. Similar to the findings of the primary report, scientific literature was the most frequently cited source for determining risks associated with nanomaterials. This method is followed by government regulations and industry guidelines. Organizations in the supplemental data set more frequently reported consultation with experts rather than either governmental regulations or industry guidelines. One respondent stated in response to the open-ended question that MSDS are used for determining risk.

Table B 8: Methods used for determining risks associated with nanomaterials handled

# of Organizations	
10	Review scientific literature
7	Consult experts
5	Consult government regulations
5	Consult industry guidelines
4	Benchmarking
3	Toxicity testing
1	Other

Toxicity Testing

Respondents were asked if their organization performed toxicity testing. Fifteen organizations responded to the question, of which only two (13%) reported performing toxicity testing. This result is lower than reported toxicity testing in the primary report, which described 23% of responding organizations as performing toxicity testing and an additional 11% as outsourcing toxicity testing to a third party.

Product Stewardship

Participating organizations were asked what type of guidance information they provided for their products containing nanomaterials and if this information was available to the public. Fourteen organizations responded (Table B 9). In some instances, respondents stated they provided more than one type of guidance document. The most frequently cited guidance information was the product information sheet (13), followed by technical instructions (8). This contrasts strongly with the findings of the primary report which found that MSDS were the most frequently provided guidance document. None of the respondents stated if this information was available to the public.

Table B 9: Types of guidance provided to customers for safe use of nano-product

Guidance for Safe Use	# of Organizations
Product info. sheet	13
Technical instructions	8
MSDS	4
Accompanying letter	2
No response	4
No product	1

Respondents were also asked what type of guidance information they provided to their customers for the safe disposal of their nano-products (Table B 10). Fewer organizations (10) responded to this question than the question inquiring about guidance for safe use. The most frequently reported guidance was to recommend recycling (4), followed by a take back program (3), and indication that the product was not hazardous (3). No respondents specifically described their nano-products as containing hazardous waste. Two respondents stated that pending additional information regarding toxicity, they would recommend disposal as hazardous waste. One organization specifically stated they provided no guidance information for safe disposal.

These results contrast with the findings of the primary report. Respondents most frequently described not providing any formal guidance, followed by recommendation of disposal as hazardous waste.

Table B 10: Types of guidance provided to customers for safe disposal of nano-product

Guidance for Safe Disposal	# of Organizations
Recommend recycling	4
Take back program	3
Not hazardous	3
Hazardous waste	0
Other	4
No response	8
No guidance	1

Discussion

The supplemental data represents a small number of organizations handling nanomaterials in China in one city and thus cannot be considered representative of China as a whole or of Asia. This is likely due to the collection method, which relied primarily on a third party to collect written responses to the questionnaire and in one case a response was submitted through the web-based survey. These methods of data collection did not allow for probing questions or clarifications which may have contributed to the lower response rate per question. The network used by the third party to select Chinese organizations for participation is not known, and therefore the sample selection can not be considered random. Though it is unknown how respondents were selected by the third party, most likely the respondents are personal contacts of the third party, who works at a research institute. This may explain the high participation by universities and research labs, as well as the high response rate, which was 100% according to the third party's statement.

There are several differences, besides geography, between the two sample populations that must be noted. The supplemental data was largely represented by university labs, whereas the primary report was largely private companies. In addition, participating organizations in the supplemental data were generally younger and described handling nanomaterials in various phases in different frequencies compared with the primary dataset. Therefore, differences other than geography may contribute to differences in reported practices.

In comparison to the findings of the primary report, Chinese organizations, in general, reported most practices in lower frequency. Chinese organizations described having fewer EHS programs and nano-specific EHS programs, less frequent training of employees on handling nanomaterials, fewer respondents believed there were risks associated with the nanomaterials handled, fewer described monitoring the work environment for nanoparticles, and fewer reported performing toxicity testing.

In addition to fewer reported practices, there were other differences in the two datasets, primarily differences in approaches towards product stewardship. In the supplemental dataset, the use of product information sheets was more frequently reported for the guidance of safe use of nanomaterial containing products, rather than MSDS. Regarding end of life concerns, the respondents in the supplemental data more often recommended recycling, offered take back programs, or described their nanoproducts as not hazardous as opposed to the primary data, which most often reported no formal guidelines and to a lesser extent, recommended disposal as hazardous waste.

There were several similarities between the two datasets. Both sets of data similarly described beliefs about impediments towards health and safety management, reported similar waste handling practices, and similar use of sources for determining risks associated with nanomaterials. Also organizations in both datasets reported similar preferences for engineering controls and strong majorities of organizations had PPE recommendations for their employee. In both instances, however, the data from Chinese organizations are marked by higher rates of non-responses and less is known about the reasons for their choices.

This research provides an initial survey of EHS and product stewardship practices in the Chinese nanomaterials industry. In general, the findings based on responses from Chinese organizations, given the qualifications stated above, reinforce the general findings of the primary report. The findings presented here provide the basis for future research into the EHS and product stewardship practices of Chinese nanotechnology organizations and how they compare to practices throughout the global industry.

Appendix C: Question Analysis Spreadsheet

version 19 of the questionnaire				
Question	**The Question**	**Why ask this question?**	**What kind of information do we expect?**	**What's the format? (open-structure**
1a	To begin, what is your title?	- A warm-up - confirm that we are talking to the right person	A position title	open-ended text
1b	and what are your responsibilities?	- same as above - to get a sense of the specific organizational context of this person	a listing of various duties, projects, etc	open-ended text
2	Is your company involved in the manufacturing, development and/or use of nanomaterials? If so, which of the following activities best describe your company?	- confirm relevance of the interview '- to determine their relationship to nanomaterials	Whether the company is in R&D, a user, a manufacturer or some combination of the above	categorical
3	What are the core markets for your nanomaterials and/or products containing nanomaterials?	this is data for agrregating; will provide a breakdown for the report showing who participated;	Identification of industries to which they sell their nanoproducts possible other category	categorical, open-ended
4a	How many people work in your entire organization?	to determine size of organization; for aggregating responses	number or range of number	number
4b	How many nanomaterial manufacturing, research and distribution sites does your organization have?	to gain a sense of the "centralization" of a company	number or range of number	number
4c	How many people work at your particular site (or lab)?	to gain understanding of potential indirect exposure	number or range of number	number
4d	Approximately how many people at your site directly produce, use or distribute nanomaterials?	to gain understanding of potential direct exposure	number or range of number	number
5	Within your organization, how many full-time equivalent employees provide Environmental Health and Safety support to nanotechnologies?	to get size of EHS team	number or range of number	number
6a	What different types of nanomaterials are produced or handled at your company/facility (or lab)?	for aggregation purposes	listing of types of nanomaterials. We provide a short list with possible other catgory	categorical
6b	What is the primary elemental makeup in each nanomaterial you listed?	to identify whether they are dealing with known potentially toxic materials	elemental titles (e.g. cadmium, silica)	categorical, open-ended
6c	What is the dimension of each nanomaterial you listed?	to know the dimension of each nanomaterial	selection of category we provide	categorical
6d	What is the phase of the listed nanomaterials (e.g., solid, liquid, gas), and is the phase the same throughout handling or does it vary?	To identify the phases on the nanomaterial when it is being handled	solid, liquid or gas or some combination of a multiple of these	categorical
6e	When the nanomaterial(s) is in a solid phase, is it fixed in a “matrix” or in the form of discrete particles?	to assess the hazard of a solid	fixed or discrete	categorical
7a	Does your company (or lab) implement a “nano-specific” EHS program?	to see if EHS program has specialized above and beyond law	yes/no	categorical
7b	Does your nano-EHS program vary depending on the specific nanomaterial being handled? If so, how?	want to know if practices vary by nanomaterials	yes/no	categorical
7c	Is there something about the characteristics of the nanomaterials you work with that has led you to implement these different programs?	want to know which characteristics of nanomatierals affected the type of EHS program	discussion of nanoparticle characteristics; we provide basic categories	categorical; open-ended
7d	Does your nano-EHS program vary by site?	to see if EHS practices change by location	yes or no	categorical
7e	Why don’t you implement a “nano-specific” EHS program?	If no on 7a, why?	various	open-ended text
8a	Does your company/facility (or lab) offer “nano-specific” EHS training for your employees?	do they offer specifc nano training?	yes/no	categorical
8b	What topics are covered in this training?	what TOPICS are different from standard EHS training programs	open-ended discussion of general topics of training. We tell them that we'll discuss specific practices later	open-ended text

8c	Where do you obtain information and guidelines for your “nano-specific” EHS practices?	identify sources of ideas and information for nano practices	open-ended discussion of the sources that they draw on to develop their nanomaterial EHS program	open-ended text
8d	Do all employees in your company/facility (or lab) who handle nanomaterials receive this training?	to see if all handlers receive training	yes/no	categorical
8e	When and/or how often do employees receive “nano-specific” training?	to know how frequently training occurs	We provide categories of time periods; possible other categorty	categorical - open-ended
8f	Do you hire a consultant to assist with planning and/or conducting your “nano-specific” training?	want to know about outsourcing of training	yes/no	categorical
8g	If so, can you provide us with the name of the company?	Which companies are consulting on best pratices	the name of a company	open-ended text
8h	Why don’t you offer “nano-specific” EHS training?	why no nano-specifc training	various answers	open-ended text
8i	Why would somebody not receive this training?	(If no on 9d), to understand why someone would not receive nanotraining	various answers	open-ended text
9	What amounts of nanoparticles do your employees typically work with at a time?	To gauge the volume of nanomaterials being worked with	we provide a range of answers	categorical
10a	What types of engineering controls do you use to prevent or minimize worker exposure to nanoparticles?	To understand the use of engineering controls	list of engineering controls	categorical/ open-ended
10b	Are exhaust filtration systems being used in your fume hoods?	to acertain if exhaust filtration systems are used	yes/no	categorical
10c	Why has your organization chosen these engineering control measures?	to understand the rationale behind the use of this equipment	something that will link saftey practices to materials being handled	open-ended
11a	Do you have established protocols for cleaning or decontaminating equipment used for nanomaterial applications?	to determine whether there are specific cleaning protocols related to nanomaterials	yes/no	categorical
11b	If yes, what are they?	to extract what those cleaning protocols are	various	open-ended
12a	Do you have recommendations for your employees regarding clothing that should or should not be worn in the lab while working with nanomaterials?	to determined whether the company makes recommendations regarding clothing for nanomaterial EHS	yes/no	categorical
12b	Please tell me about these choices and the reasons for making them.	IF yes, to 12 a, then to understand the rationales behind clothing decisions	various answers	open-ended text
12c	Is there a reason why you do not have recommendations regarding clothing?	If no to 12a, then to understand the rationales behind not having clothing recommendations	various answers	open-ended text
13a	Do your employees use respirators while handling nanomaterials?	to determine whether employees use repsirators	yes/no	categorical
13b	What type of respirator is typically used?	to determine which respirators are used	respirator specifications	
13c	Why was this particular respirator chosen?	to understand the rational behin the selection of a respirator	something that will connect the specifc type of respirator to the particular handling of a nanomaterial	open-ended text
13d	Is there a reason why employees do not use respirators?	To determine why employees may choose to not wear a respirator	various answers	open-ended text
14a	Do you have recommendations for your employees about wearing gloves?	to determine if the company makes recommendations on appropriate gloves for handling nanomaterials	yes/no	categorical
14b	Please tell me about these choices and the reasons for making them.	To understand the rational behind the particular choice of gloves	various answers	open-ended text
14c	Is there a reason why you do not have recommendations for gloves?	If the company does not make recommendations, to understand why	various answers	open-ended text
15a	Do you have recommendations for your employees about wearing eye protection?	To determine whether the company makes recommendations about eye protection	yes/no	categorical
15b	Please tell me about these choices and the reasons for making them.	If yes on 15a, to understand the rationale behind the use of this equipment	somehting that will link eye protection to particular material being handled	open-ended text
15c	Is there a reason why you do not have recommendations for eye protection?	If no on 15a, to understand the rationale	various answers	open-ended text
16	Are the PPE recommendations mentioned thus far company policy?	To confirm that the PPE discussed is company policy versus election by employees	yes/no	categorical
17	Does your company/facility (or lab) employ any unique or novel protection strategies to reduce employee exposure to nanomaterials that we missed?	To determine whether there are PPE practices that we have not asked about	various answers	open-ended text

18a	Are there specific procedures used in your company/facility (or lab) for cleaning up spills containing nanomaterials?	To determine whether the company has specific practices for cleaning up nanomaterial spills	yes/no	categorical
18b	How do you clean up these spills? and what specifically is different from spills that do not contain nanomaterials?	If yes to 18a, to understand HOW spills are cleaned up and how that differs from spills not involving nanomaterials	description of how spills are cleaned up and how that varies from spills that don't contain nanomaterials	open-ended
19a	Are separate disposal containers for nanomaterials used (either in the lab or in waste storage areas)?	To determine how nanomaterial waste is handled in the lab	yes/no	categorical
19b	On your company's waste Manifests, are nanomaterials listed as the bulk material or as "nanomaterial"?	TO determine how nanomaterial waste is treated differently from other waste on waste manifests	yes/no	categorical
19c	Is there anything else that you would like to mention regarding nanomaterial waste disposal in your company/facility (or lab)?	to check and see if we have addressed all relevant issues related to nanomaterial disposal	various answers	open-ended text
20	How are you determining the risks associated with the nanomaterial(s) handled in your company/facility (or lab)?	what are the respondents using for developing their guidelines for risk assessment	we provide a set of possibilities; open-ended	categorical, open-ended
21a	Is there toxicological research being performed (or has it been performed) on the nanomaterial(s) that you use and/or make?	determine whether there has been toxological research on nanomaterials	yes/no	categorical
21b	Who performs (or has performed) this research?	to determine whether they are doing toxicological research in-house	name of a company or literature	open-ended
22a	Does your company/facility (or lab) monitor ambient levels of nanoparticles in the workplace?	want to know if they have an ambient monitoring program in place	yes/no	categorical
22b	What measurement equipment is used? and what range of particle sizes are detected?	what equipment is used to measure ambient particle levels and what sizes are detected	names of types of equipment and their specificifications for particle size	open-ended
22c	Why was this equipment chosen?	why particular equipment was chosen	various	open-ended
22d	How frequently is ambient monitoring of nanoparticles performed?	want to know how frequently monitoring occurs	We provide time period categories	categorical
22e	Why don't you monitor ambient nanoparticle levels?	If no on 22a, to understand the rationale	various	open-ended
23a	Does your company monitor worker health as a result of working with nanotechnologies?	do they monitor worker health	yes/no	categorical
23b	What is specifically monitored?	to understand methods used for worker health monitoring	various	open-ended
24	Does your company (or lab) have "nano-products" that are either currently on the market or in development? A "nano-product" can be defined as a product that contains nanomaterial, and/or nanomaterial that is sold and/or changes hands.	to know whether they have nano-products; to determine whether to proceed with other product stewardship questions	yes/no	open-ended
25a	Do you provide guidance to customers regarding the safe use of your nano-product(s)?	to see if they proivde guidance to customers	yes/no	open-ended
25b	What form of guidance information do you provide?	what kind of guidance they provide	something that describes the manner in which information is conveyed to customers	categorical
25c	Is this information made publicly available? If yes, how so?	IS this information available to the public	yes/no; the manner in which the public can have access to this information	categorical, open-ended
25d	Are there applications for which you recommend your nano-product(s) not be used?	to see if there are uses for products that they discourage	yes/no	categorical
26a	Do you provide guidance to customers for the disposal of your nano-product(s)?	to see if guidance on disposal is provided	yes/no	categorical
26b	What type of guidance do you provide?	what type of guidance	description of how they recommend disposal	categorical, open-ended
27	What are the specific issues that make EHS management or overall risk management of nanotechnology particularly difficult? and what would it take to address these issues?	want to know what issues make EHS management of nanotechnology difficult	various	open-ended
28	Are you considering plans to improve nano-specific practices in your organization (facility or lab)? If so, what are your plans?	To understand whether any plans to improve nanomaterial EHS are in the works	yes/no various	categorical open-ended
29	Can you recommend other companies that you think we should interview?	To see if we can generate more interview contacts	various	open-ended
30	Is there anything that we haven't covered in this interview that you think is relevant?	We ask this to see if there is anything that we missed	various	open-ended

Appendix D: Initial Contact Email

SUBJECT: ICON-funded survey of current practices

Dear Mr. / Dr./ Ms./ [contact name],

You have been identified as a potential participant in a project funded by the International Council of Nanotechnology (ICON) aimed at determining current health, safety and product stewardship practices within the nanotechnology industry. This email is to request your participation in the subject project which is being carried out by researchers at the University of California, Santa Barbara (UCSB) through a contract with ICON.

For your information and consideration, I attach three documents:

1. a letter of invitation to participate in this study
2. a project endorsement letter from ICON
3. and an Invitation for Interview which contains general information about this survey-based project.

Would you please respond to this email (nanotech@bren.ucsb.edu), indicating your availability for a one hour interview? The project schedule requires that all interviews be conducted during the period June – August, 2006, and we would like to schedule an interview with you at the earliest possible date.

Once we hear from you, we will email a voluntary consent form which is required before we can proceed with the interview. We will request that you fax the signed consent form back to us.

Should you wish to review the questionnaire that will be used during our interview, we can provide that in advance.

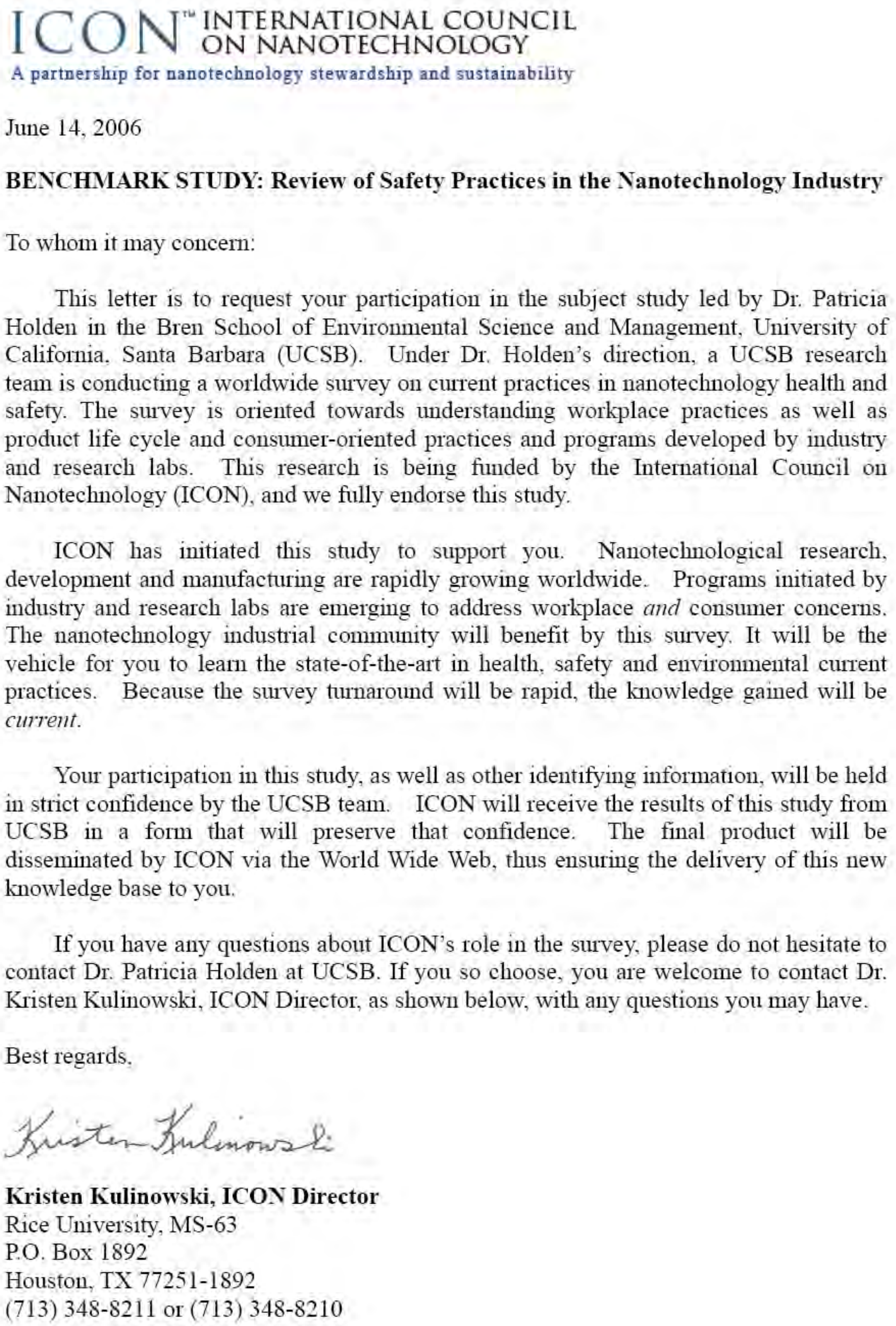
Thank you for your time. Your participation will contribute important baseline information to the safe production and development of nano-scale materials.

Best regards,

[researcher’s name]

[researcher’s name]
Graduate Student Researcher
Donald Bren School of Environmental Science and Management
University of California, Santa Barbara

Appendix E: ICON Letter of Support



ICON™ INTERNATIONAL COUNCIL ON NANOTECHNOLOGY
A partnership for nanotechnology stewardship and sustainability

June 14, 2006

BENCHMARK STUDY: Review of Safety Practices in the Nanotechnology Industry

To whom it may concern:

This letter is to request your participation in the subject study led by Dr. Patricia Holden in the Bren School of Environmental Science and Management, University of California, Santa Barbara (UCSB). Under Dr. Holden's direction, a UCSB research team is conducting a worldwide survey on current practices in nanotechnology health and safety. The survey is oriented towards understanding workplace practices as well as product life cycle and consumer-oriented practices and programs developed by industry and research labs. This research is being funded by the International Council on Nanotechnology (ICON), and we fully endorse this study.

ICON has initiated this study to support you. Nanotechnological research, development and manufacturing are rapidly growing worldwide. Programs initiated by industry and research labs are emerging to address workplace *and* consumer concerns. The nanotechnology industrial community will benefit by this survey. It will be the vehicle for you to learn the state-of-the-art in health, safety and environmental current practices. Because the survey turnaround will be rapid, the knowledge gained will be *current*.

Your participation in this study, as well as other identifying information, will be held in strict confidence by the UCSB team. ICON will receive the results of this study from UCSB in a form that will preserve that confidence. The final product will be disseminated by ICON via the World Wide Web, thus ensuring the delivery of this new knowledge base to you.

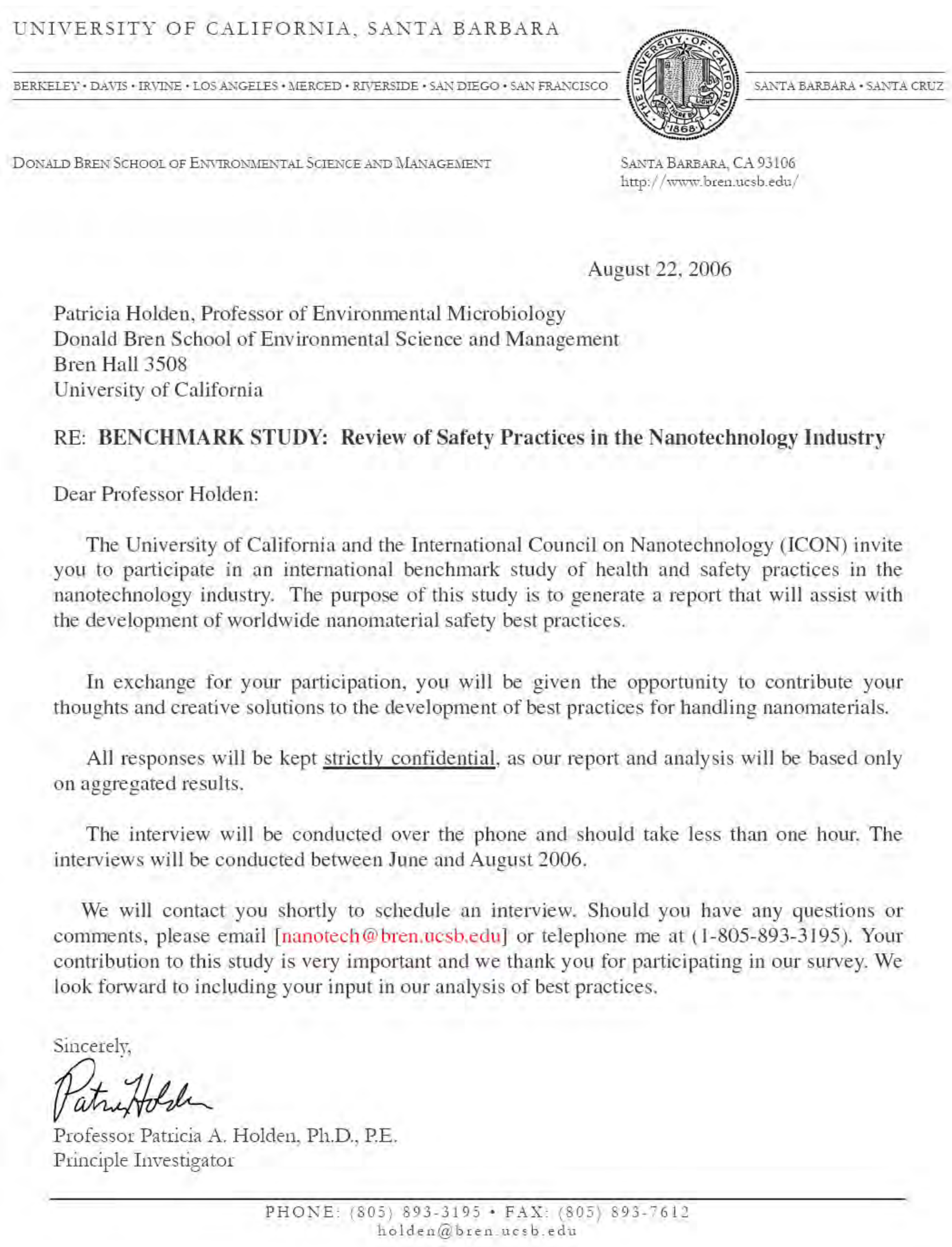
If you have any questions about ICON's role in the survey, please do not hesitate to contact Dr. Patricia Holden at UCSB. If you so choose, you are welcome to contact Dr. Kristen Kulinowski, ICON Director, as shown below, with any questions you may have.

Best regards,

Kristen Kulinowski

Kristen Kulinowski, ICON Director
Rice University, MS-63
P.O. Box 1892
Houston, TX 77251-1892
(713) 348-8211 or (713) 348-8210

Appendix F: Invitation Cover Letter



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DONALD BREN SCHOOL OF ENVIRONMENTAL SCIENCE AND MANAGEMENT   SANTA BARBARA, CA 93106
http://www.bren.ucsb.edu/

August 22, 2006

Patricia Holden, Professor of Environmental Microbiology
Donald Bren School of Environmental Science and Management
Bren Hall 3508
University of California

RE: **BENCHMARK STUDY: Review of Safety Practices in the Nanotechnology Industry**

Dear Professor Holden:

The University of California and the International Council on Nanotechnology (ICON) invite you to participate in an international benchmark study of health and safety practices in the nanotechnology industry. The purpose of this study is to generate a report that will assist with the development of worldwide nanomaterial safety best practices.

In exchange for your participation, you will be given the opportunity to contribute your thoughts and creative solutions to the development of best practices for handling nanomaterials.

All responses will be kept strictly confidential, as our report and analysis will be based only on aggregated results.

The interview will be conducted over the phone and should take less than one hour. The interviews will be conducted between June and August 2006.

We will contact you shortly to schedule an interview. Should you have any questions or comments, please email [nanotech@bren.ucsb.edu] or telephone me at (1-805-893-3195). Your contribution to this study is very important and we thank you for participating in our survey. We look forward to including your input in our analysis of best practices.

Sincerely,

Patricia Holden

Professor Patricia A. Holden, Ph.D., P.E.
Principle Investigator

PHONE: (805) 893-3195 • FAX: (805) 893-7612
holden@bren.ucsb.edu

Appendix G: Invitation for Interview

Donald Bren School of
Environmental Science & Management
University of California, Santa Barbara

ICON™ INTERNATIONAL COUNCIL
ON NANOTECHNOLOGY
A partnership for nanotechnology stewardship and sustainability

Invitation For Interview

What We Are Doing:

The University of California, Santa Barbara has contracted with the International Council on Nanotechnology (ICON) to design and administer a survey examining the environmental, health, and safety practices of companies working with nanomaterials. This survey will be implemented internationally during the summer of 2006. Current practices for managing nanomaterial risks will be discovered through this survey. The results will be aggregated according to nanotechnology industry; ICON will then publicly disseminate the aggregated results. Through disseminating knowledge regarding current best practices, this research will contribute to the safety of workers, consumers, the public and the environment.

Who We Are:

We are a research team at the Donald Bren School of Environmental Science and Management at the University of California, Santa Barbara. Our team is comprised of five graduate students and is led by Dr. Patricia Holden and Dr. Magali Delmas, with support from Dr. Barbara Herr Harthorn (Co-director of the Center for Nanotechnology in Society) and Dr. Rich Appelbaum. The project proposal was solicited by ICON and receives their full support.

ICON is an international, multi-stakeholder organization whose mission is to assess, communicate, and reduce the environmental and health risks of nanotechnology while maximizing its societal benefit.

Topics Covered in the Interview:

- How are companies responding to new challenges posed by nanoparticles?
- What types of training do nanoparticle handlers receive?
- What engineering and personal protective equipment are used in the workplace?
- How are companies monitoring ambient particulate levels?
- How are companies disposing of nanomaterials?
- How are companies determining which approaches to take?
- What product stewardship practices are companies using?
- Where are companies finding information regarding best practices?

There's Value in Participating:

Participants can benefit by influencing the debate in current health and safety practices in the nanotechnology industries. This is a benchmark project, and participants will learn how, comparatively, they are approaching health and safety. Workplace safety and product stewardship will be reported on in the aggregate and will not be tied to specific companies. Confidentiality of the participants, products and company will be guaranteed. The project is high-visibility and sponsored by industry.

How to Participate:

The telephone interview will initially require up to 1 hour, with a possible similar follow-up time. Prospective participants will receive a project information package including a letter of invitation, a copy of ICON's press release, and an ICON letter of project endorsement. We also encourage prospective participants to contact us directly regarding interview scheduling by either emailing nanotech@bren.ucsb.edu or by calling Dr. Patricia Holden at (805) 893-3195.

Appendix H: Consent Form

Consent to Participate in an Interview or Survey Regarding Health and Safety Practices in the Nanotechnology Industrial Workplace

The Study. You and your company have been selected for an interview concerning health and safety programs and practices in nanotechnology industrial workplaces. In this interview, we want to learn about your company and its products, you as a respondent, and health and safety programs and practices in your nanotechnology workplace. This research is being directed by Professor Patricia A. Holden, Ph.D., in the Bren School of Environmental Science and Management at the University of California at Santa Barbara.

Participation. Your participation is entirely voluntary. The interview will last approximately an hour and a half. The interview will be audio recorded with your approval. You are free to decline to respond to any question you do not wish to answer, and you may terminate the interview and your participation in the study at any time.

Confidentiality. Study records will be kept confidential. We will ask for your name, but a pseudonym will be used if you prefer. At the end of the project, all collected information will be aggregated so that your identity and that of your company is removed from the final report. After the project, the records will be stored in a secure and confidential manner at UCSB.

☐ I wish for my birth name to be used in the study.

☐ I wish to be assigned a pseudonym for all documentation and data storage.

Questions. If you have questions or comments or want more information, you may contact via e-mail or phone: Professor Patricia Holden at the Bren School of Environmental Science and Management (805) 893-3195, email holden@bren.ucsb.edu . If you have any questions about your rights as a research participant, please contact Kathy Graham at UC Santa Barbara (805) 893-3807.

If you would like to participate in the study, please sign below.

Signature of participant ____________________ Date ____________________

Name (printed) ____________________

Please sign and fax to: (805) 715-3413

Appendix I: UCSB Internal Confidentiality Protocol

1. Rules

- Company contact information will not be shared with anybody outside the project team.
- Raw survey data will not be shared with anybody outside the project team.
- The final data provided to ICON for public dissemination will be aggregated and will not contain identifying company information.
- If confidentiality of any contact information is compromised, that information will be removed from the database and will not be included in the final project.
- All members of the project team will sign a copy of this Internal Confidentiality Protocol, which will be held by the Principal Investigator.

2. Procedures

- The line of confidentiality begins with the first contact, or receipt of contact information of a company. The company name, contact information, and survey data will be deemed confidential.
- All exchange of confidential data will be made through a password protected, “high” level encryption e-mail account: nanotech@bren.ucsb.edu.
- If one of the team members receives confidential data directed to their e-mail account, they will immediately forward the email to the nanotech@bren.ucsb.edu account and delete the e-mail from their account.
- There will be a file assigning an ID number to every surveyed company. This file will be password protected and encrypted. The survey response data will be in a separate, password protected and encrypted file. This file will contain company IDs, but no other identifying information such as names or addresses.
- All contact data and survey data will be stored in a password protected folder on the Bren server.
- The survey data will be aggregated by the structure of the nanomaterial and the elemental composition. We will ensure a sufficient population of data within each category to prevent identification of participants. ICON will receive the aggregated data. We will write the final report based upon the aggregated data.

I, the undersigned, agree to abide by the Internal Confidentiality Protocol.

Signed Name Date

Printed Name

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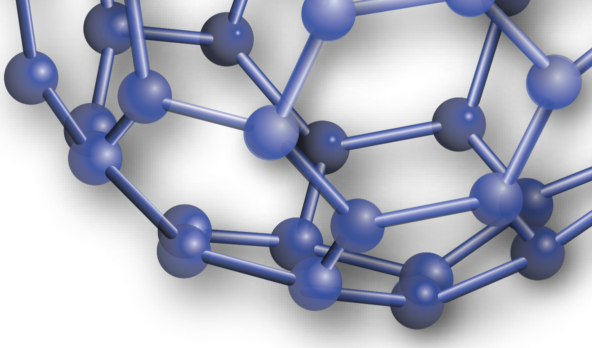

Based at Rice University, ICON is an international, multistakeholder organization whose mission is to develop and communicate information regarding the potential health and environmental risks of nanotechnology, thereby fostering risk reduction while maximizing societal benefit. The council has evolved into a network of scholars, industrialists, government officials and public interest advocates who share information and perspectives on a broad range of issues at the intersection of nanotechnology and environment, health and safety. ICON has grown from an affiliates program of the Center for Biological and Environmental Nanotechnology, which has been designated by the U.S. National Science Foundation as a nanotechnology center of excellence.

http://icon.rice.edu/