ICON™ INTERNATIONAL COUNCIL ON NANOTECHNOLOGY

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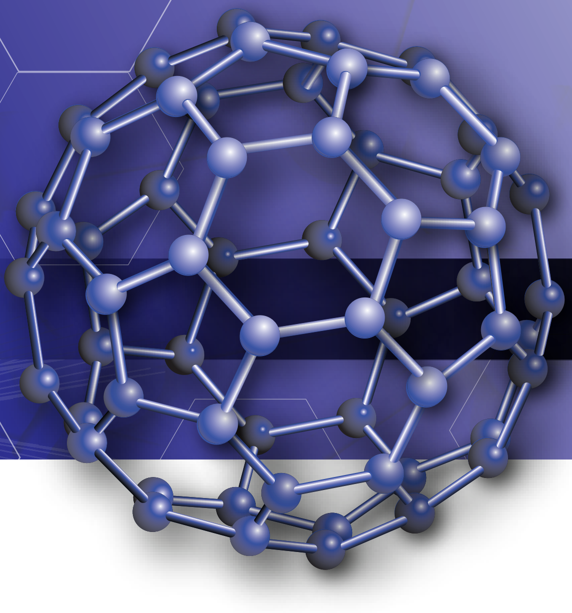

ICON is an international, multi-stakeholder organization whose mission is to develop and communicate information regarding potential environmental and health risks of nanotechnology, thereby fostering risk reduction while maximizing societal benefit.

A Survey of Current Practices in the Nanotechnology Workplace: Condensed Report

Produced for the International Council on Nanotechnology

November 13, 2006

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I. Foreword

This document summarizes key findings of a survey performed by researchers at the University of California, Santa Barbara for the International Council on Nanotechnology (ICON). The original, full report (Gerritzen, G., Huang, L., Killpack, K., Mircheva, M., Conti, J., Appelbaum, R., Herr Harthorn, B., Delmas, M., and Holden, P.A. 2006. *A Review of Current Practices in the Nanotechnology Industry Phase Two Report: Survey of Current Practices in the Nanotechnology Workplace*) is available at http://icon.rice.edu. This abbreviated document was authored by ICON based on the full report and includes the executive summary from the full report; table and figure numberings correspond to the numbering in the full report.

II. 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.

III. 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 fine particles, novel risks associated with new properties cannot easily be anticipated. 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 occupational health and safety, waste handling, risk management, monitoring, and product stewardship. This study begins to fill the strong need for a global 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 three 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 then are analyzed, focusing on trends in practices

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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.

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.

IV. Methodology

How the Survey was Developed and Administered

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. A spreadsheet (Appendix B) facilitated development of questions most closely-aligned with the stated goals. The spreadsheet was organized by survey question, and stated 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 contained 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. 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 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.

During the period of July 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. During the period of data analysis and writing of this report, 19 additional completed questionnaires were returned to the UCSB researchers through a third party in China. Since these data were collected outside of either UCSB or ICON, and because they were obtained from one geographically-consolidated pool of respondents in China, the results are included within the last Appendix of this report and are analyzed separately and discussed. 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. 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.

How Organizations Were Recruited to Take Part in This Survey

The participant pool was selected from within the nanomaterials industry, including academia, research institutions, and manufacturing, with a major emphasis on the latter. The 337 prospective participants 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.

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 can be found in the full report at http://icon.rice.edu.

How the Data Were Analyzed

All responses initially were organized into a database by question number. All identifying information was stripped from the responses prior to aggregation by question. Data analysis began by generating descriptive statistics for each question. If the question was open-ended, the responses were coded based on dominant categories identified in the data. 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. Incomplete web-based survey responses were discarded.

V. Results

Sample Characteristics

Highest response rate was from Asian organizations familiar with NCBI. 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 (31%), while the response rates in the North America and the European Union 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, nine organizations outside of the US, the EU and Asia were contacted (Australian, and Israeli organizations); of these, three Australian organizations participated producing a response rate of 33%.

Table 1: Response Rate by Geographic Location

Contact	Response	Response Rate (%)	Region
178	25	14%	**North America**
81	25	31%	**Asia**
69	11	16%	**EU**
9	3	33%	**Other**
337	64	19%	**Total Contacts**

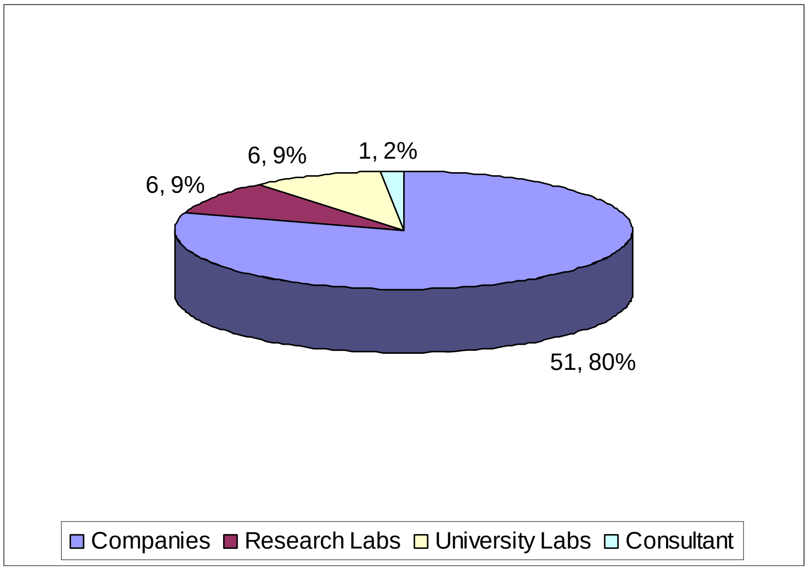
Methods of Data Collection: Sample Bias and Response Rate

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 summary, responses provided for non-verbal surveys were less detailed and had higher non-response rates than those from telephone interviews.

Respondent Characteristics

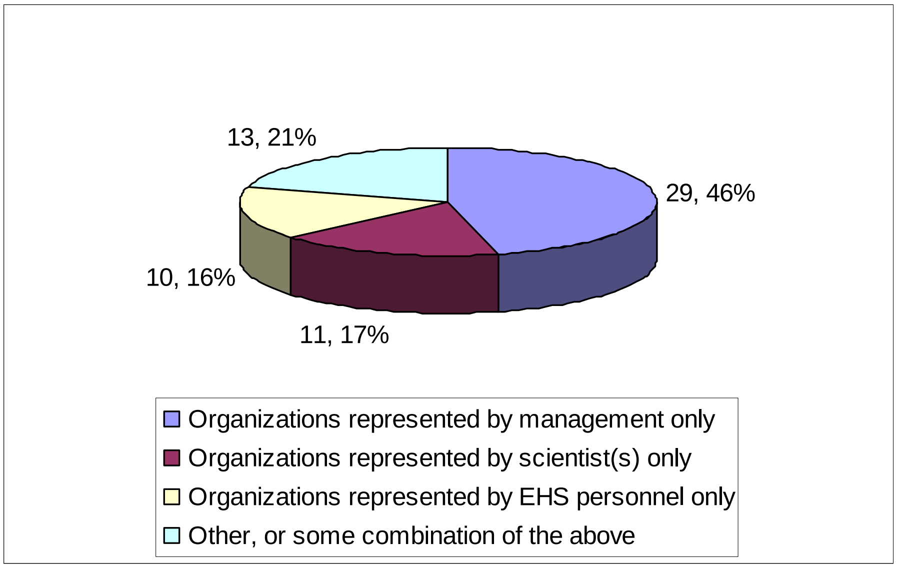
Private Sector Companies Comprised Majority of Respondents. A large majority of the respondents (80%) was from private sector companies (Figure 1). An equal share of research and university labs (9% each) also participated. Research labs were characterized as being non-academic organizations involved in nanomaterials research and funded either by the government or private sources. University labs were considered as 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: Most organizations were represented by Management. The representatives of the organizations 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

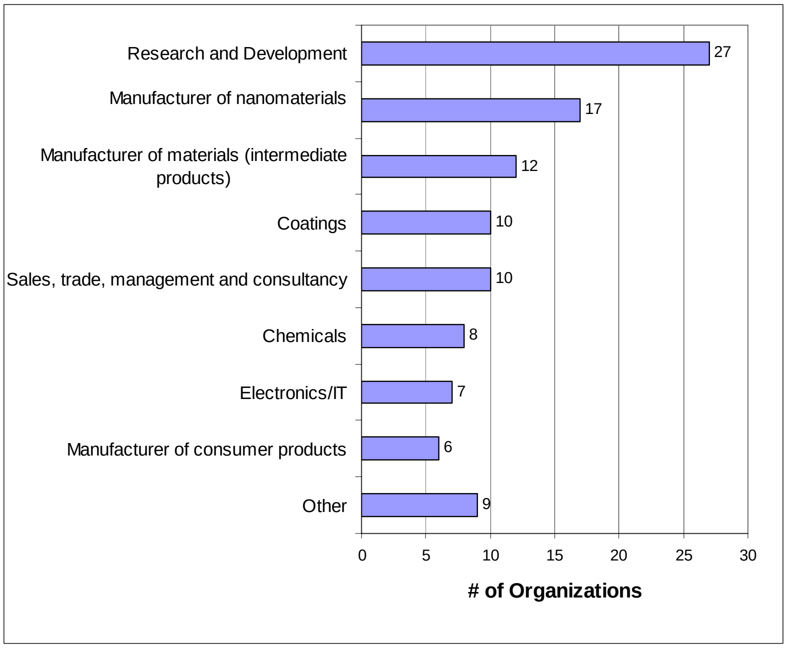


Business Description of Participating Organizations: Most organizations were involved in R&D. Eight business categories were identified, which were not mutually exclusive such that an organization may fall into multiple categories. The categories were:

- Research and Development of nanomaterials
- Manufacturer of nanomaterials.
- 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.

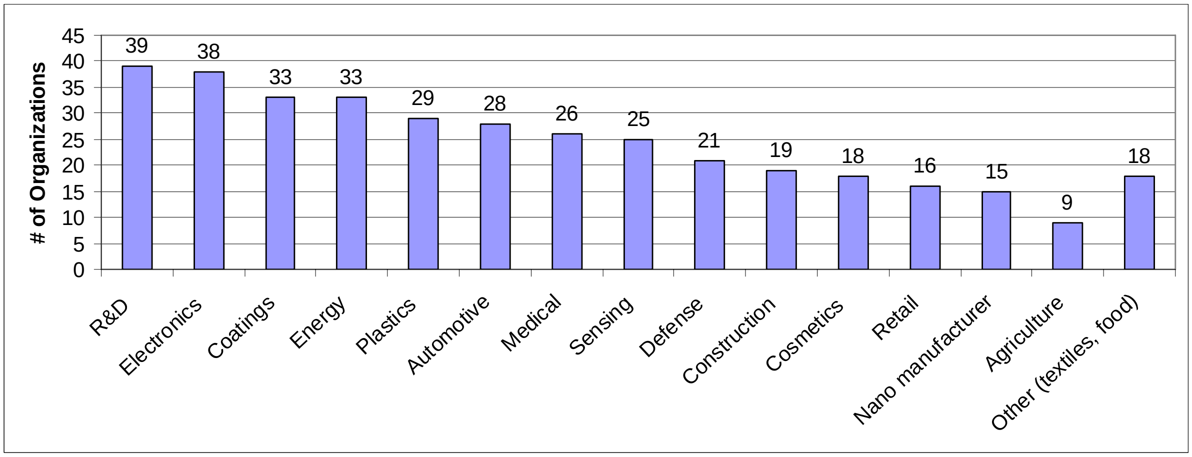
A second question asked participant organizations to describe their business as it related specifically to nanomaterials: were they a manufacturer, user, and/or researcher and developer of nanomaterials? Over 90% of the respondents indicated they were involved in R&D activities related to nanomaterials, while 67% used or applied nanomaterials and 56% manufactured nanomaterials. 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 3).

Figure 3: Respondent business description



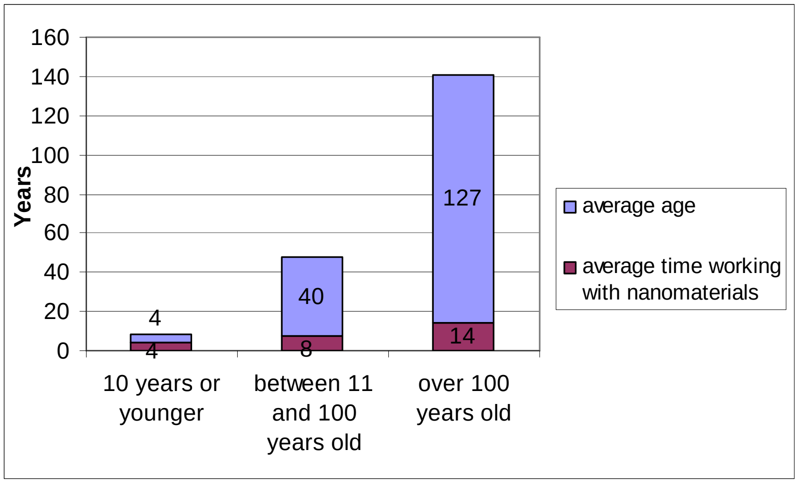
On average, respondent organizations maintained customers in six different industries. The most common customer industries included R&D, electronics, energy, coatings, plastics, automotive, and medical (Figure 5).

Figure 5: Industries of respondents' nanomaterial customers



Age of Respondent Organizations and Duration of Involvement with Nanotechnology: Most Organizations Were <10 Years Old and Had Been Working With Nanomaterials for <10 Years. 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. 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)

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

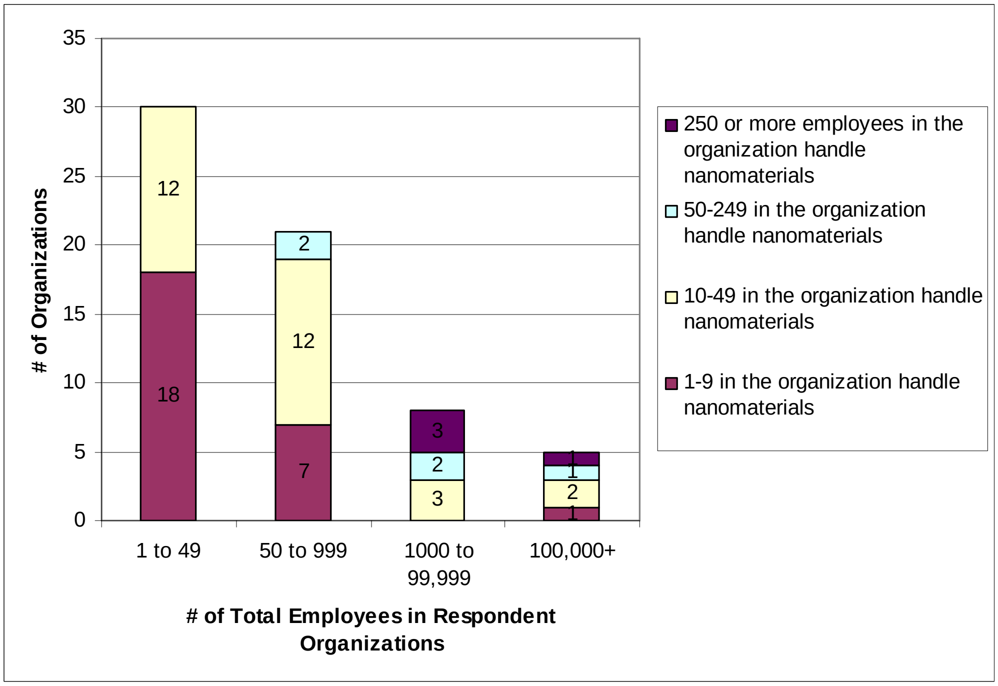


Headquarter locations of the respondents were located in 14 different countries on four continents. Only seven respondents had one or more location where nanomaterials were handled (nanomaterial activity) in a country different from their headquarter location.

Size of Respondent Organizations: Most Responding Organizations Had <50 Employees. Most of the participant organizations were small in size. 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).

Figure 7: Total number of employees vs. number of employees handling nanomaterials



Respondent Description of Nanomaterials: Lack of standardized nomenclature. 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.

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

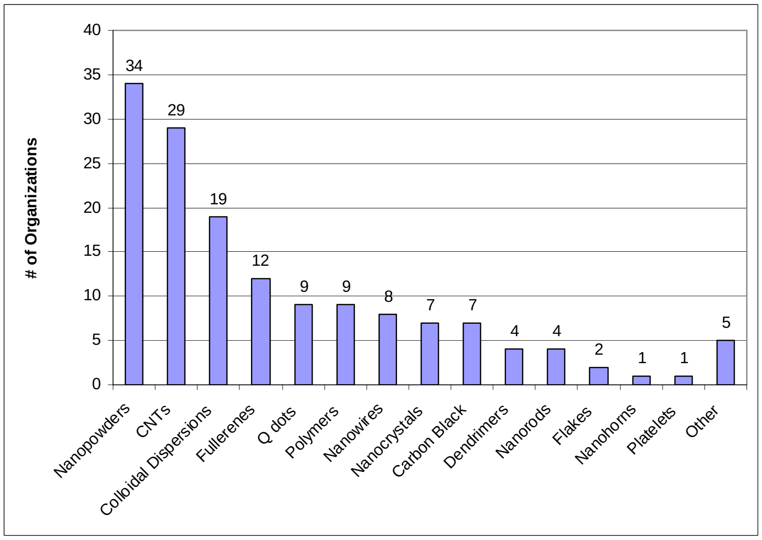
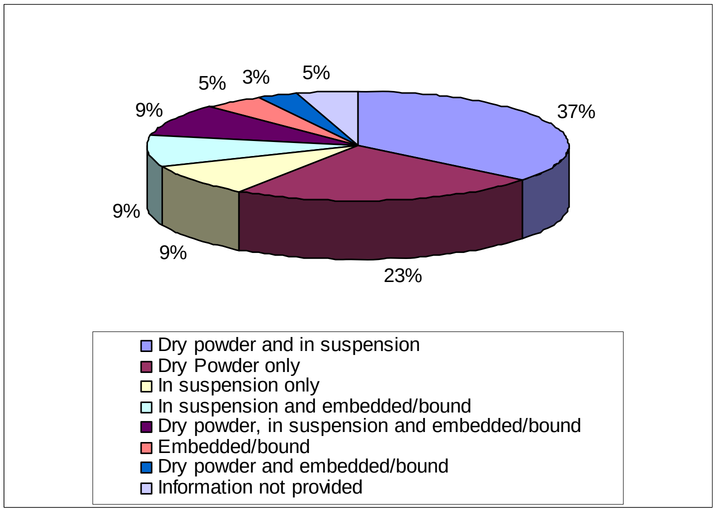


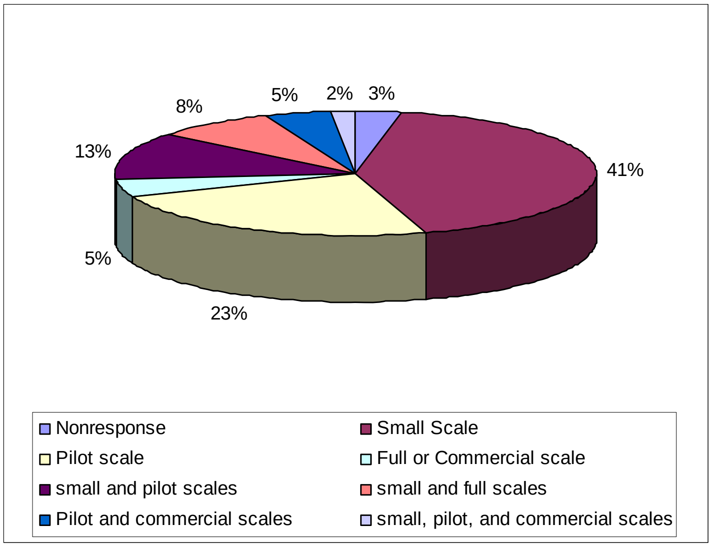
Figure 10: Phases of nanomaterials handled by participants



Respondents were asked to describe the elemental constituents of the nanomaterials handled or produced at their organization. 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).

Respondents indicated whether the nanomaterials handled were in suspension or in solid form. Materials in solid form were differentiated from freely mobile nanomaterials, dry powder or nanomaterials fixed on a matrix or embedded on a surface (Figure 10).

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



The scale of production or handling of nanomaterials also was elicited (Figure 11). A large number (41%) 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.

Summary of Respondent Characteristics

Sixty four organizations participated in this survey, including twenty five organizations from Asia, twenty five from North America, eleven from the European Union, 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

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.

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 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 solution, in suspension, in 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 were more prevalent among USA organizations

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 were more likely offered by companies

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

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

Table 2: Nano-specific EHS programs increased with 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%

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

Table 3: 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%

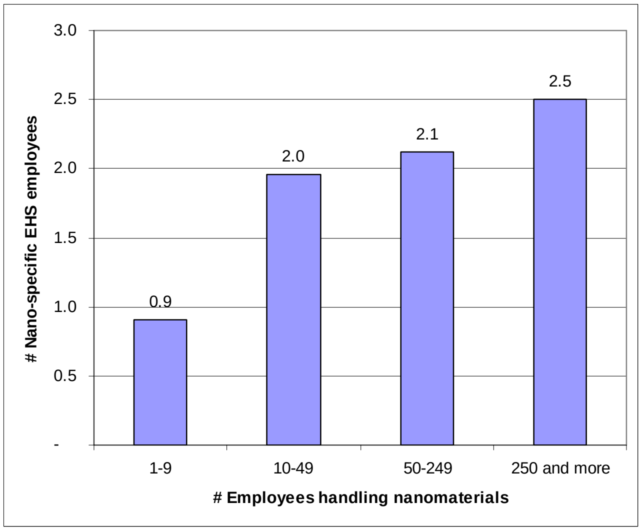
The data suggested that respondents who perceived there were special risks associated with the nanomaterials handled in their organizations were more likely to administer a nano-specific EHS program than both those who did not know and those who believed there was no special risk (Table 9).

Table 9: Nano-specific EHS programs increased with perception 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%

Figure 13: The number of nano-specific EHS employees was positively correlated with the number of employees handling nanomaterials.

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).



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 instructing their employees to 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 tentative 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. This same scheme could be used to reduce exposure to nanomaterials. The first tier emphasizes either substitution or elimination of the material being handled. 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. 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. 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, 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. 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.

Reasons for a Nano-specific EHS Program: Safety and Precaution.

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).

Summary-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: Most organizations offer health and safety programs. 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 was 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.

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: Organizations in the USA were most likely to offer health and safety training

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

There appeared 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: Larger organizations were more likely to offer health and safety training

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

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

Table 14: Organizations having more employees working with nanomaterials positively correlated with health and safety training programs

# of Employees working with nanomaterials	Yes	No	% Yes
1 < 10	13	13	50%
10 < 50	17	11	61%
50 < 250	5	1	83%
>250	3	1	75%

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

Table 16: Prevalence of health and safety training increased with number of years working with nanomaterials

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 perceived 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 increased according to risk perception

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

Training Description/Training Programs. 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. 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.

Summary-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. Organizations with larger numbers of employees handling nanomaterials, with older nano-divisions, higher perception 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. Nine specific responses describing plans to improve their organization's nano-specific EHS program were the following:

- Seek assistant 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.

Summary-Organizational characteristics play a significant role in determining whether an organization has an EHS program and training related to nanotechnology. It could be expected that larger and older organizations have more resources, as well as a more developed EHS program in place. However, it is difficult to presume “nano-specific” EHS programs are more developed among larger and older organizations because nanotechnology is new and developing rapidly and the impact of nanomaterials on worker health and the environment is largely unknown. Instead, <u>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.</u> 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.

<u>“Nano-specific” Engineering Controls</u>

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.

Fume hoods

Two thirds (43) of participating organizations reported using fume hoods in the handling of nanomaterials. Over half (32 of 51) of the 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, 90% of organizations with fifty or more employees handling nanomaterials reported using fume hoods.

Table 20: Reported use of fume hoods by number of employees handling nanomaterials

	Number of organizations	Number using fume hoods	Percent
1-9 employees	26	14	54%
10-49 employees	27	19	74%
50-249 employees	6	5	83%
250 or more employees	5	5	100%

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; highest use reported by European organizations

Region	No. of orgs	No. using fume hood	%
Asia	25	13	52%
Europe	11	9	82%
North America	25	19	76%
Other	3	2	67%

There appeared to be no large difference in the use of fume hoods resulting from the amount of nanomaterials used at a given time. 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).

Table 22: Reported use of fume hoods by nanomaterial type

	No.	Fume hood	%
Nanopowder	34	23	68
Carbon Nanotubes	29	20	69
Dispersion	19	14	74
Fullerenes	12	10	83
Q dots	9	9	100
Polymer	9	6	67
Nanowires	8	8	100
Nanocrystals	7	7	100
Carbon Black	7	5	71
Other	17	15	88

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. 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)

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

Category	Phase	Use of fume hood	%
Dry powder/solution	23	17	74
Dry Powder only	15	7	47
Solution only	6	3	50
In solution/embedded/bound	6	5	83
Dry powder, in solution, and embedded/ bound to a surface	6	6	100
Embedded/bound to a surface only	3	3	100
Dry powder and in a matrix	2	0	0
Missing	3	na	na

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.

Glove boxes and glove bags

Thirty two organizations reported utilizing glove boxes for handling nanomaterials and twelve reported using glove bags. 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. 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. Glove bags were used less overall, with only 12 out of 64 organizations reporting their use.

Table 24: Use of glove boxes and glove bags highest in organizations with >250 employees

No. Employees	No. of orgs.	No. using glove box	%	No. using glove bag	%
1-9	26	10	39	3	12
10-49	27	14	52	4	15
50-249	6	4	67	2	33
250 or more	5	4	80	3	60

North American organizations had the highest frequency (64%) of reporting the use of glove boxes in their nanomaterial operations. 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.

Glove boxes were 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 more clear 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, although the trend is less clear.

Table 26: Reported use of glove boxes and glove bags highest with organizations working with < mg amounts of nanomaterials

	Number of organizations	Reports of Glove Boxes	Percent	Reports of Glove Bags	Percent
Less than one kilogram	38	20	53	6	16
Less than one gram	23	11	48	3	13
Less than one milligram	10	6	60	3	30
Greater than one kilogram	26	11	42	5	19
Only less than one gram	11	5	46	2	18
Only one kilogram or greater	11	1	9	1	9

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	59	8	24
Carbon Nanotubes	29	17	59	7	24
Colloidal Dispersions	19	9	47	7	37
Fullerenes	12	9	75	4	33
Quantum Dots	9	7	78	3	33
Polymers	9	5	56	3	33
Nanowires	8	7	88	3	38
Nanocrystals	7	6	86	4	57
Carbon Black	7	6	86	4	57
Other	17	9	53	9	53

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	57	5	22
Dry powder only	15	8	53	1	6.7
In suspension only	6	1	17	0	0
In solution and embedded/bound	6	3	50	1	17
Dry powder, in suspension, and embedded/bound to a surface	6	5	83	3	50
Embedded/bound to a surface only	3	1	33	2	67
Dry powder and embedded/bound	2	0	0	0	0

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. Although 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.[6] 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

Companies reported the use of cleanrooms most frequently. Cleanrooms were used in operations of various sizes but most 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: Cleanroom use increased with number of employees handling nanomaterials

	Number of organizations	Number using cleanroom	Percent
1-9 employees	26	6	23
10-49 employees	27	10	37
50-249 employees	6	2	33
250 or more employees	5	4	80

North American organizations were the most frequent users of cleanrooms (Table 30).

Table 30: Use of cleanrooms highest in USA organizations

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).

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[6] 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 econstruction." *Science* 296 (April 26):705.

Table 31: Cleanroom use highest with handling of <mg amounts of nanomaterials

	Number of organizations	Number using cleanroom	Percent
Less than one kilogram	38	18	47
Less than one gram	23	9	39
Less than one milligram	10	7	70
Greater than one kilogram	26	5	19
Only less than one gram	11	1	9.1
Only one Kilogram or Greater	11	1	9.1

Four of six organizations working with nanomaterials as a dry powder, in suspension and embedded/bound to a surface used a cleanroom (Table 32). These reports reinforce the 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
Dry Powder only	6	0	0
In suspension only	3	1	33
In suspension and embedded/bound	23	9	39
Dry powder, in suspension, and embedded/bound to a surface	6	4	67
Embedded/bound to a surface only	2	0	0
Dry powder and in a matrix	6	3	50

Cleanrooms were used with a variety 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.

Table 33: Reported use of cleanrooms by nanomaterial type

	Number	Number using cleanroom	Percent
Nanopowders	34	12	35
Carbon Nanotubes	29	11	38
Colloidal Dispersions	19	6	32
Fullerenes	12	7	58
Quantum Dots	9	4	44
Polymers	9	3	33
Nanowires	8	4	50
Nanocrystals	7	5	71
Carbon Black	7	3	43
Other	17	4	24

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. 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 increased with number of employees handling nanomaterials

	Number of organizations	HVAC	Percent
1-9 employees	26	6	23
10-49 employees	27	10	37
50-249 employees	6	3	50
250 or more employees	5	4	80

Twelve of 25 North American organizations reported using separate HVAC systems, which was comparable to European organizations. Asian organizations reported the lowest use of separate HVAC systems (5/25).

Separate HVAC systems were used by organizations working with a variety of different amounts of nanomaterials at any one time. Organizations that worked with a variety of amounts reported greater usage. Separate HVAC systems were used by organizations that worked with nanomaterials in a variety of phases (Table 37).

Table 37: Reported use of HVAC systems highest when handling nanopowders

Category	Number or organizations	Number using HVAC	Percent
Dry powder and in suspension	15	5	33
Dry powder only	6	0	0
In suspension only	3	1	33
In suspension and embedded/bound	23	9	39
Dry powder, in suspension, and embedded/bound to a surface	6	3	50
Embedded/bound to a surface only	2	0	0
Dry powder and embedded/bound	6	4	67

Many organizations working with nanocrystals (5/7) and nanowires (5/8) reported using a separate HVAC system. 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.

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. 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. Twenty of 64 organizations reported using a separate drain for their nanomaterial operations. Thirteen of 20 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. Nine of 25 Asian organizations used a closed piping system, which was similar to that reported by European organizations. North American organizations appeared to be the least likely to use this control (6/25).

Closed piping systems were reported at greater frequency by organizations working with larger amounts of nanomaterials. Eleven of 26 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.

In summary, 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 used laminar flow clean benches; this was reported more by organizations employing fewer people in the handling of nanomaterials (Table 44). Eleven of 53 organizations employing less than 49 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 increased with 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 was equivalent to 45% of the sample originating in Europe but only 20% of organizations from Asia or North America. In addition, organizations working with smaller amounts of nanomaterials had higher reports of laminar flow clean bench use. Respondents indicated that laminar flow clean benches were used with nanomaterials in a variety of phases and combinations of phases. The highest number of reports of utilizing a laminar flow clean bench came from organizations working with nanomaterials as a dry powder and in suspension (7 of 23). Furthermore, 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.

In summary, 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 64 organizations reported using biological safety cabinets. This control was more frequently cited by organizations older than 25 years (6/ 12) and organizations that had been in the nanotechnology field longer (9/12). The use of safety cabinets appeared to correlate with companies having larger numbers of employees.

Biological safety cabinets were used with nanomaterials in a variety of phases (Table 52).

Table 52: Reported use of biological safety cabinets highest with handling of multiple phases

Phase handled	Number of organizations	Use of biological safety cabinets	Percent
Dry Powder only	15	2	13
In suspension only	6	1	17
Embedded/bound to a surface only	3	0	0
Dry powder and in suspension	23	4	17
In suspension and embedded/bound	6	2	33
Dry powder and embedded/bound	2	0	0
Dry powder, in suspension, and embedded/bound	6	3	50

Biological safety cabinets were used with a variety of types of nanomaterials. The most reports came from organizations working with nanopowders. Ten of 34 respondents reported using biological safety cabinets in their nanomaterial operations.

In summary, 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. *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

Analysis of a subset of total responses offered additional information about the engineering controls utilized in 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 pure 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 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.

- One organization reported using distillation 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.

In summary, 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.

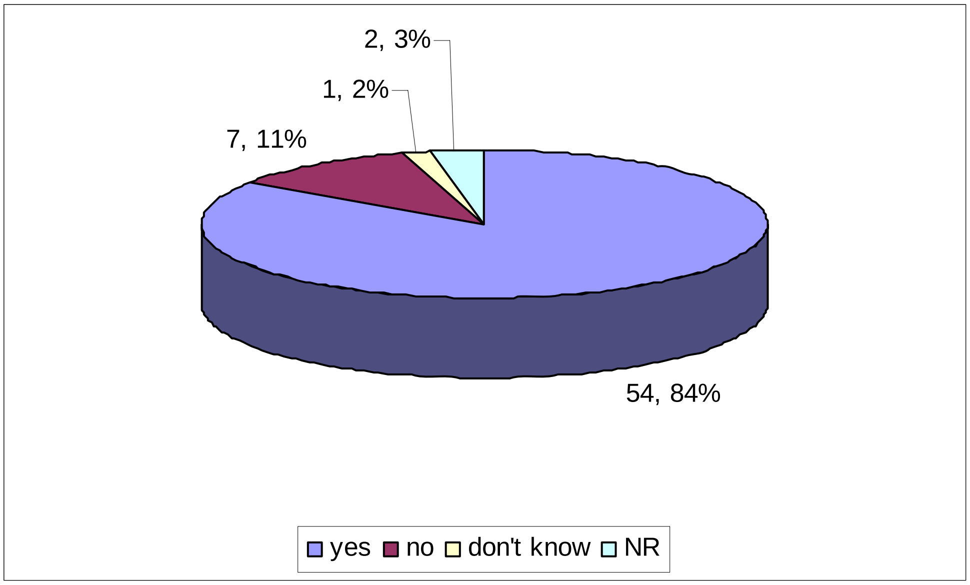
On the other hand, fourteen organizations reported utilizing enclosed systems designed to limit worker exposure. Furthermore, others reported engineering controls to limit other forms or risks associated with nanomaterials, such as the heightened flammability of nano-scale powders. Clearly, a significant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

Figure 17. Most organizations had PPE recommendations for its employees when working with nanomaterials

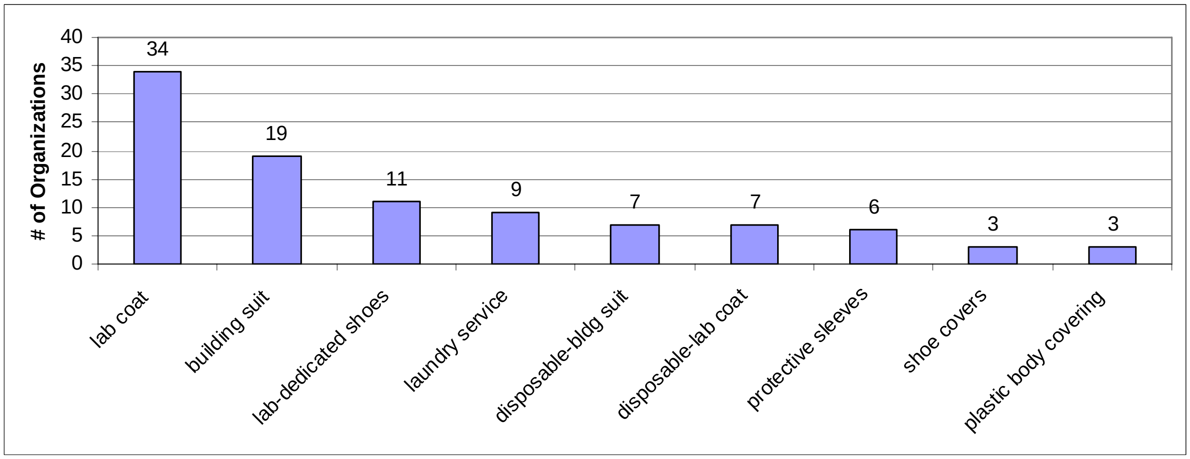


Cross-analyses also were performed on the PPE response data to investigate their relationship with industry, company size and age, geographical location, and material. Results indicated no apparent association between the business type and/or whether the organization manufactured, used, or performed 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 (Figure 18).

Figure 18: Recommended clothing when working with nanomaterials



Gloves

Fifty of the 64 respondents (78%) indicated that recommendations on gloves were provided to employees. 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. 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.

Eye Protection

When asked if their organization had recommendations for eye protection, 48 of the respondents (75%) indicated that such recommendations existed. 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. 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.

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. 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 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 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. 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%. 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.

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

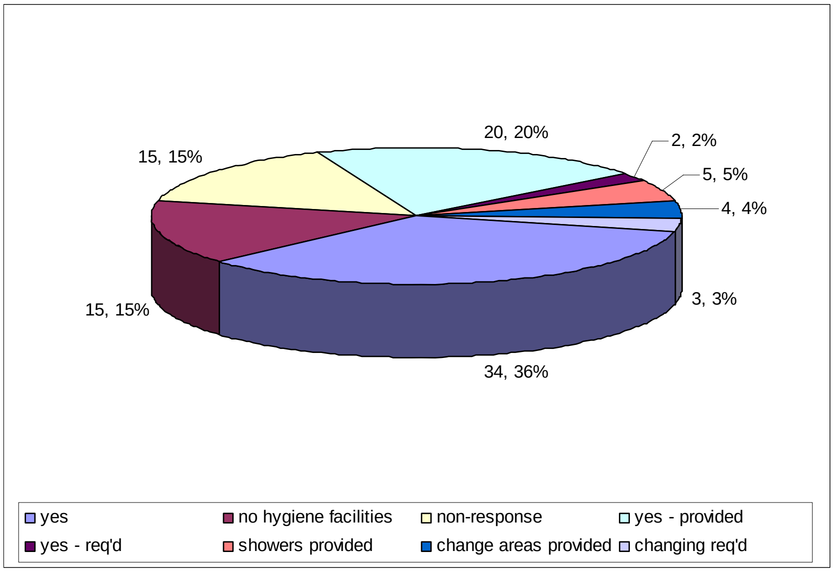
Cross-analyses were performed on the PPE response data to investigate their relationship with industry, company size and age, geographical location, and material. The results indicated that smaller companies generally have been more resourceful in their PPE recommendations. The smaller companies tended 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. Generally, however, all organizations using respirators tended to choose the respirator that tested at the highest filter efficiency in their home country.

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).

Figure 21: Hygiene facilities



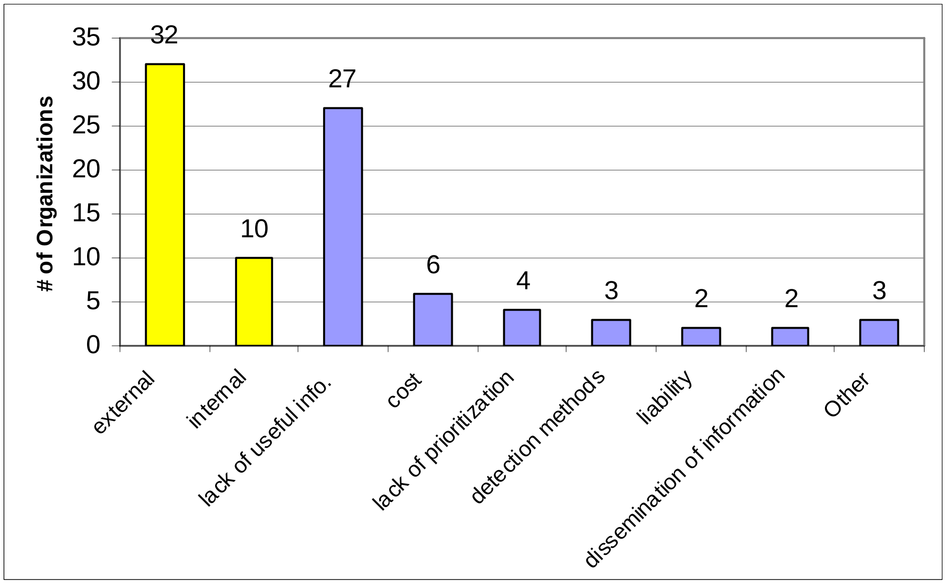
Summary of PPE Recommendations

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.

Perceived 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

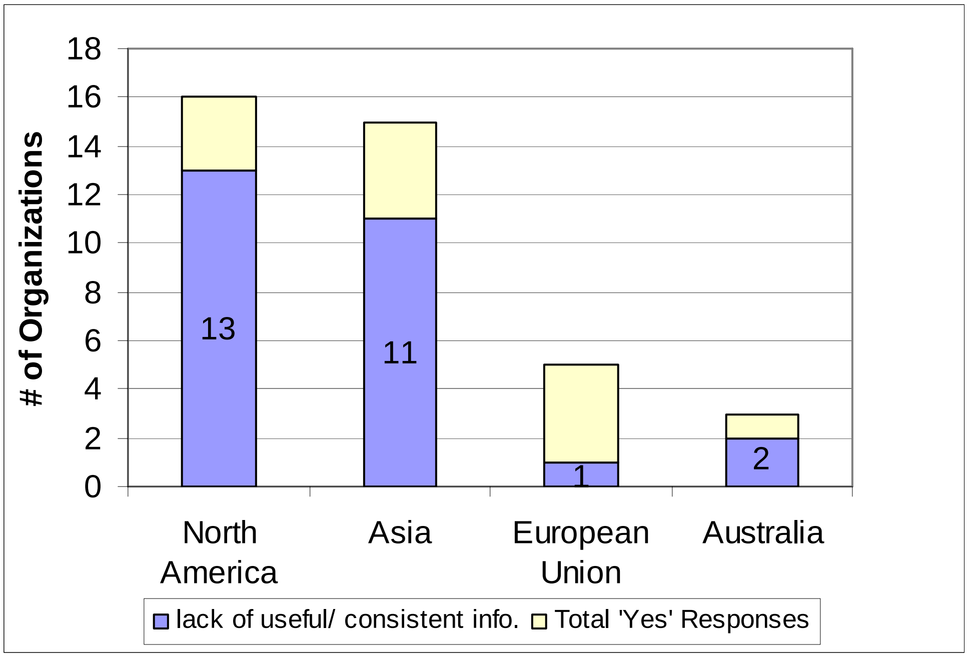


Thirty two organizations described impediments that were external to the organization and ten described internal impediments. These categories were not mutually exclusive and a respondent could describe more than one impediment. Of the external impediments, the most frequently mentioned was the lack 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. One respondent described the lack of information as an impediment. 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.

Respondents from North America, Asia, and Australia were more likely than those in the European Union to describe the lack of information as an impediment (Figure 23).

Figure 23: Responses indicating lack information as an impediment to health and safety management



Smaller companies were more likely than larger organizations to describe cost concerns as an impediment to health and safety management. The largest companies (100,000+ employees) emphasized the lack of useful and consistent information as an impediment.

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).

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

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.

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, followed by a lack of prioritization of EHS concerns.

Waste Management of Nanomaterials

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.

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.

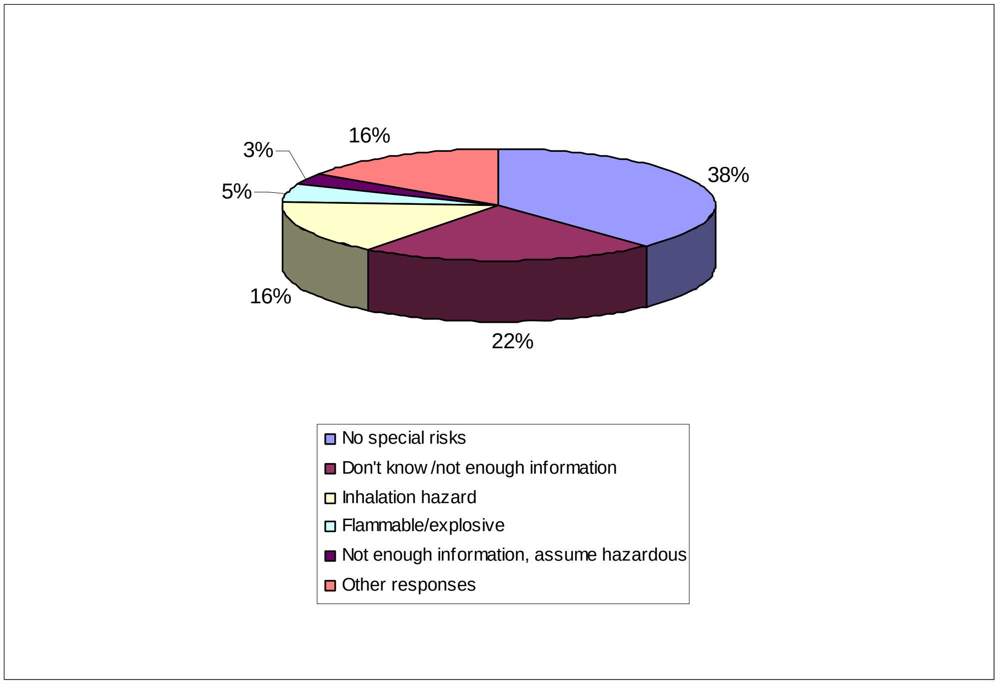
Monitoring the Work Environment for Nanoparticles

Summary-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.

Perception of 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. Sixteen percent stated that they believed their nanomaterials may pose an inhalation hazard. Additional responses included: flammability or explosive nature of materials (3), assume material is hazardous (2), concern for possible effect 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.

Figure 33: Described risks of nanomaterials handled at participating organizations



Summary of Perception of Risk of Nanomaterials Handled. The most frequent response to the question of any risks that handled nanomaterials may pose was that there were no special risks. This response was most frequently described by respondents whose job title could be characterized as administrative or management. EHS-related employees were most likely to state the there was not enough available information to determine the risks. Other less frequently cited concerns included inhalation exposure and potential for flammability of materials.

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 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 33).

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-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?" 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 the European Union were the most likely to perform or outsource toxicity testing to a third 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, followed by product information sheets.

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 the European Union 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.

VI. 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.

The geographic location of participating organizations had implications for respondents' perceptions 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 perceive this as an impediment. Including both in-house and outsourced toxicological testing, the EU 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%).

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.

Older organizations were 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.

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.

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.

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).

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	

This represents ~16% of the 950[7] 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 66 companies were contacted. This represents a contact rate of less than 22% of the companies in Asia. Estimates

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[7] NanoVIP Nanotechnology International: companies, profiles and links. Nanovip.com 2006. http://www.nanovip.com/directory/International/index.php.

of the total number of research and university labs working with nanomaterials in Asia could not be found.

In the European Union, 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 the EU handling nanomaterials could not be identified. However, it is likely only a small fraction of these labs were contacted.

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%.

The response rate of the study was similar to those of comparable studies. A study by Delmas and Toffel that assessed environmental management practices[8] reported a 17.2% 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.[9] However, this study only targeted Australian nanoscience research groups using the Australian Research Council's network. A Japanese study[10] 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 the EU 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

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

[9] 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.

[10] http://staff.aist.go.jp/kishimoto-atsuo/nano/nanomanagement.htm

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.

Organizational representatives influenced 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., 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 perception and impediments. According to our survey data, managers were less likely to perceive 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.

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. 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. Overall, 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.

VII. Limitations of this Study and Recommendations for Future Research

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.

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 the 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 already 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[11]. 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.

VIII. Conclusions

The aim of this study was to reveal current practices at nanomaterial labs regarding occupational health and safety, product stewardship and environmental 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

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[11] 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>

well. Overall, the study included organizations of all sizes, ages, industries and using a variety of nanomaterials.

The survey results generally revealed that labs 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 dust generated by nanomaterials.

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 handled 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 was 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.

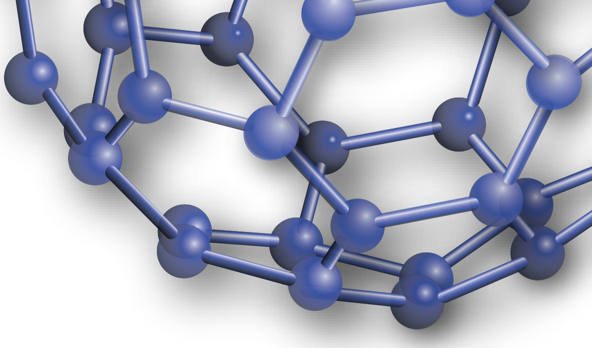
University labs described more internal impediments, such as cost concerns or lack of EHS priority for improving EHS practices, than research labs or companies.

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.

IX. Acknowledgements

This research was funded and supported by ICON and the Best Practices subcommittee of ICON. ICON member Mike Garner contributed significantly to the development of the contact list, as did ICON member Tracy Godfrey. Keith Swain of DuPont Chemicals 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 Office of National Nanoscience and Nanotechnology Program in Taiwan for providing contact information. 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.

The unabridged report is available at http://icon.rice.edu.



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.

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