Samsung Worker Exposure Characterization Study

Methods, Results and Conclusions

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1 Introduction

ENVIRON International Corporation ("ENVIRON") conducted a Worker Exposure Characterization Study ("the Study") to evaluate occupational worker exposures associated with tasks performed on semiconductor wafer fabrication and testing and assembly operations of Samsung Electronics Co. Ltd. ("Samsung"). The goal of the Study was to conduct a complete evaluation of current-day exposures on contemporary and historical generation wafer fabrication lines and the current generation test and assembly line and determine the degree to which occupational exposures were controlled to levels below Occupational Exposure Levels ("OELs") that have been promulgated by appropriate and relevant regulatory and advisory bodies, in particular those promulgated by the Korea Occupational Safety and Health Agency ("KOSHA") and the American Conference of Governmental Industrial Hygienists ("ACGIH"). The Study was conducted using rigorous scientific methodologies that are reliable, relevant and reproducible. The Study design developed by ENVIRON was consistent with methodologies developed and endorsed by the American Industrial Hygiene Association ("AIHA").

The Exposure Characterization Study was conducted as a consultative effort to Samsung by ENVIRON with critical peer review from an independent panel of distinguished occupational health and risk assessment scientists currently engaged at prestigious American universities ("the Scientific Advisory Panel" or "Panel"). The Study has been subject to critical review at milestone points by the Panel. The Panel has reviewed methodologies, results and conclusions and provided peer review and critical feedback to the ENVIRON study team to assure that the methods used and results provided are relevant, reliable and reproducible in accordance with key components of the scientific method.

The Study involved Line 5 and Line 12 wafer fabrication lines in Samsung's Giheung and Hwaseong facilities, respectively, and the Line 1 test and package line at the Onyang facility.

2 Background

2.1 Samsung Semiconductor Process

The Study involved Samsung operated semiconductor manufacturing facilities located in the Republic of Korea in Giheung, Hwaseong and Onyang. Two types of semiconductor manufacturing facilities were assessed: two separate wafer fabrication lines and one testing and assembly line. Wafer fabrication facilities manufacture semiconductor devices as individual die (i.e. chips) on silicon wafers of varying sizes. Currently operating high-volume wafer fabrication facilities use wafers of either 200 millimeters ("mm") or 300 mm in diameter. Currently operating facilities that utilize 200 mm wafers were typically constructed and begun operations in the early to mid 1990s through the late 1990s. Facilities that utilize 300 mm wafers were typically constructed and commenced operations beginning in the late 1990s to early 2000s up to present.

Semiconductor devices are manufactured on wafers utilizing eight (8) distinct process areas, each area performing a certain set of manufacturing operations utilizing a defined set of equipment, process chemicals/gases and input energies (e.g., non-ionizing radiation). The process areas utilized in semiconductor wafer fabrication commonly consist of:

- Chemical-Mechanical Planarization ("CMP")
- Chemical Vapor Deposition ("CVD")
- Clean (also referred to as Wet Etch in semiconductor industry publications)
- Diffusion
- Etch
- Implantation
- Photo (also referred to as Photolithography in semiconductor industry publications)
- Thin-Films Metal

ENVIRON included manufacturing lines from both the 200- and 300-mm generation in the Study: Samsung's Line 5 is a wafer fabrication facility located in Giheung that utilizes 200 mm wafers; Line 12 is a wafer fabrication facility located in Hwaseong that utilizes 300 mm wafers.

Testing and assembly semiconductor manufacturing facilities process completed silicon wafers of semiconductor devices to separate wafers into individual die, package them as individual products (i.e. chips) in an end-use configuration and test them for proper functionality. In order to complete the testing and assembly process, up to thirteen (13) process areas are utilized, each performing a certain set of process steps utilizing a defined set of equipment, process chemicals/gases and input energies (e.g., marking lasers). Depending on the product being produced not all process areas may be utilized. Testing and assembly process areas may consist of the following:

- Assembly – Backlap
- Assembly – Sawing
- Assembly – Die Attach
- Assembly – Plasma
- Assembly – Wire Bonding
- Packaging – Molding
- Packaging – Marking
- Packaging – Trim Sort Form
- Packaging – Tin Plating
- Packaging – Solder Ball Attach
- Test – Monitor Burn-in Testing ("MBT")
- Test – Testing
- Test – Marking Visual Packing ("MVP")

In all of Samsung's operations there are two essential categories of work – Normal operations, where operators perform the tasks supporting and required by the operations listed above; and Maintenance, which involves maintenance activities for the specific tools and process equipment and typically in the semi conductor industry has a higher exposure potential due to the worker being intimately engaged with the tools at the time of maintenance.

2.2 Samsung Industrial Hygiene and Exposure Control Programs

Samsung maintains a robust internal industrial hygiene program. Samsung has a record of protecting the health and safety of its employees at its operations worldwide and ENVIRON understands that Samsung promotes the health and safety of all its employees, as well as those of its suppliers by making all factories fully compliant with the OHSAS18001 standard. Samsung's industrial hygiene program is resourced with professionals that are Samsung employees as well as involving third party consultants such as the Korean Health and Safety Research Institute. These consultants have performed semiannual industrial hygiene studies required under Korean law from the late 1990s to current-day.

2.3 Study Design and Methodology

This Study was conducted to validate the effectiveness of Samsung's occupational health protection efforts by evaluating the veracity and integrity of their exposure control efforts embodied in developed and implemented engineering and administrative controls.

ENVIRON conducted the Study in a manner consistent with the overall study design previously developed by ENVIRON and reviewed by the Scientific Advisory Panel. The overall study has been approached in three stages. The three stages and their associated tasks are summarized in Table 1 below and consist of a qualitative evaluation of Samsung operations of interest, a quantitative data collection to further characterize exposures during the performance of

identified tasks and, finally, interpretation of the results of both the qualitative and quantitative assessments combined to present a complete worker exposure characterization model for the manufacturing lines of interest to the Study.

Table 1 – Study Design by Stage

	Task Number	Task Description
Stage 1 Qualitative Study Design	I	Study Design, Conceptual Manufacturing Model, and Qualitative Risk Assessment (QLRA) Template
	II	Site Visits
	III	Development of Similar Exposure Group (SEG)-specific QLRAs
	IV	Stage 1 Summary Report and Recommendations
	V	Data Reconstruction Feasibility Assessment
Stage 2 Quantitative Data Collection	VI	Development of Quantitative Exposure Monitoring Sampling Plan
	VII	Collection of Quantitative Exposure Monitoring Data
	VIII	Compilation and Evaluation of Quantitative Exposure Monitoring Data
Stage 3 Data Interpretation, Study Conclusions and Final Report	IX	Evaluation and Compilation of Collective Worker Exposure Data
	X	Develop Final Report

At the outset of the project ENVIRON visited the facilities of interest for the study to conduct a preliminary facility review of representative manufacturing lines to gain an initial understanding of Samsung operations to aid in refinement of the study design.

To assure the scientific rigor and objectivity required for the Study, ENVIRON approached the worker exposure characterization in accordance with the standardized and validated approach developed by the American Industrial Hygiene Association ("AIHA"). This approach is detailed in the publication titled *A Strategy for Assessing and Managing Occupational Exposures*[1], which has been developed to provide a consistent and rigorous approach to exposure and risk assessment.

2.4 The AIHA Strategy

The AIHA strategy provides an overall framework for managing occupational exposures through the application of concepts provided in a systematic manner. Key concepts that were utilized in the Study include conducting qualitative risk assessments ("QLRAs") to identify operations, tasks and chemicals/physical agents of interest, definition of similar exposure groups ("SEGs"), collection of quantitative exposure monitoring data to further characterize employee exposures and the development of exposure profiles by SEG according to established exposure categories defined in comparison to established OELs.

[1] Ignacio, J.S., and W. Bullock: A Strategy for Assessing and Managing Occupational Exposures, 3rd ed. Fairfax, CA: American Industrial Hygiene Association, 2006.

The concept of an SEG is central to overall strategy as it divides workers into groups based on their expected comparable/similar potential exposures while performing a given task (e.g., normal operations or maintenance activities) and the chemicals/physical agents of interest. Chemical and physical agents of interest are typically defined by those process chemicals/gases utilized in the process, anticipated or confirmed by-products formed during operations, maintenance chemicals utilized and/or physical agents such as non-ionizing or ionizing radiation that are used or formed during operations. Therefore, SEGs are defined by task and chemicals/physical agents of interest and allows for the determination and management of employee exposures by that defined group. Once the SEGs are defined the remaining assessment and management of exposures are conducted for those respective groups.

2.5 The Scientific Advisory Panel

From the onset of the project an overriding goal of the Study has been to develop and implement an approach that provides scientific rigor to the study while ensuring objectivity and integrity of the work product. To promote this goal ENVIRON assembled a Scientific Advisory Panel ("Panel") to provide critical review and comments for ENVIRON's use. Two members of the Panel visited and reviewed the lines of interest in August 2010.

At each milestone the Panel provided review of ENVIRON's work plans, work product and results and provided critical review, direction and suggestions to the project. The Panel has reviewed and provided input on the overall quality, appropriateness and applicability of the methodologies employed and the results and conclusions developed during this Study.

3 Study Design

As discussed previously, ENVIRON approached the Study in three stages, each building on and incorporating the results of the previous work. Each Stage is discussed in detail below.

3.1 Stage 1 – Qualitative Assessment Methods

The Stage 1 - qualitative assessment phase of the Study involved four (4) major tasks:

- Development of the Conceptual Manufacturing Model ("CMM") and Qualitative Risk Assessment ("QLRA") template;
- Site visits to the Giheung, Hwaseong, and Onyang facilities to gather the information and data needed for the development of qualitative risk assessments;
- Identification of the similar exposure groups ("SEG")
- Performance of SEG - specific QLRA process and identification of tasks with moderate or high priority ratings (PR) for which additional quantitative assessment would be recommended;

3.1.1 Conceptual Manufacturing Model and QLRA Template

ENVIRON, in partnership with Samsung, compiled existing data and conducted initial interviews to better understand the data sets. For this task Samsung provided the following types of information to aid in this process:

- Previously collected employee exposure monitoring data for the facilities of interest, including analytical methods utilized, sampling durations, sample types (e.g., area or breathing zone), chemical analytes, functional areas/tools monitored, tasks being performed, and results.
- A listing of tools utilized for each process area at each facility.
- An inventory of process and maintenance chemicals utilized and a summary of any known or anticipated by-products formed during tool operation.
- Hazard assessments previously performed [e.g., Personal Protective Equipment ("PPE") assessments] for tool operations or maintenance.
- PPE requirements by tool during operations and maintenance.
- Staffing models to complete preventive maintenance tasks

The compiled data was used to develop a Conceptual Manufacturing Model ("CMM") presenting Samsung's manufacturing process flow, unit operations and potential worker exposures that may occur during the manufacturing process on the lines of interest.

Based on the CMM and the AIHA strategy, ENVIRON developed a Qualitative Risk Assessment ("QLRA") template to systematically assess the exposure risk of current manufacturing and related maintenance activities to confirmed or potential chemical hazards. The CMM provided the ENVIRON team and Panel with a sufficiently detailed understanding of Samsung's

manufacturing process as it relates to chemical usage, machine/employee interface and worker tasks in order to formulate Similar Exposure Groups ("SEGs"), which are the basis for evaluating worker exposure in Samsung's manufacturing settings.

The developed QLRA template was used to qualitatively assess the exposure risk associated with worker tasks associated with a given SEG, relevant chemicals of interest and assign each task a priority rating reflecting the likelihood additional quantitative data collection would be recommended. The QLRA template contains the following sections and relevant subsections:

1) Similar Exposure Group (SEG) Definition
    a) General Fab, Assembly Test, Packaging Environmental Conditions
    b) Tool/Process Information
    c) Process Chemicals/Gases
    d) Byproducts (known and expected)
    e) Maintenance Chemicals
    f) Description of SEG Tasks
    g) SEG Classifications (e.g., Operator, Equipment Engineer, or Vendor Field Service Engineer)/Number of Employees in SEG classification
    h) Applicable Operating SOP
    i) Applicable Preventive Maintenance (PM) Standard Operating Procedures (SOPs).
2) Chemical Inventory by SEG/Stage 1 Qualitative Risk Assessment
    a) Tabular assessment of risk for each task in the SEG resulting in a Priority Rating for each associated process chemical/gas, by-product and maintenance chemical. The evaluation was performed by assessing each chemical's health effect rating (1-4) versus its exposure potential as defined by the product of its dispersion potential (1-4), control (1-4) and the frequency/duration rating of the task (1-5).
3) Additional Information
    a) Odor Profile/Info
    b) Summary of Engineering Controls (ventilation, interlocks/isolation, controlled access, bulk chemical/bulk gas delivery and others)
    c) Summary of Administrative Controls
    d) Other Observations.
4) Assessment Summary
    a) Summary of QLRA Outcomes
    b) Listing of tasks with Moderate or High Priority Ratings
    c) Routine Re-assessment Recommendation

d) Identification of IH Performing and Reviewing Assessment

e) Date of Assessment.

5) Reference: QLRA Phase 1 Process/Forms

a) Tabular Format of Section 2

b) Health Effects Rating Criteria

6) Reference: QLRA Phase 2

a) Dispersion Rating Criteria Table

b) Level of Control Rating Criteria Table

c) Frequency and Duration Rating Criteria Table

d) Exposure Rating Calculation Table

e) Priority Rating Matrix (Health Effects Rating vs. Exposure Rating)

3.1.2 Qualitative Data Collection

ENVIRON visited the Samsung facilities in July and August 2010 to collect additional information on current fabrication and packaging and test operations via detailed facility reviews conducted at the respective manufacturing lines in South Korea. The following objectives were associated with the site visits:

- Direct observation of worker tasks associated with operations and maintenance activities in the facilities of interest.
- Interviews with Samsung Engineers to gather additional detail related to worker tasks performed, chemicals/by-products used or likely to be present, exposure controls implemented and an understanding of SEG and SEG classifications employee numbers.
- Documentation of current workplace controls implemented (e.g., local exhaust ventilation, documented work practices and PPE).
- Evaluation of process information (i.e. process chemistries).
- Finalization of SEGs and SEG classifications.
- Assessment of existing employee exposure data, development of a historical exposure profile and collaboration with key Samsung staff.
- Identification of additional data not collected during the site visit but provided subsequently by Samsung.
- Standard Operating Procedure ("SOP") data such as frequency/duration of tasks, staffing for each task and PPE utilized.

3.1.3 Development of SEG specific QLRAs

ENVIRON utilized data from the tasks described above to complete a qualitative risk assessment ("QLRA") for each SEG for each facility based on the template. A statistical

sampling of approximately 25% of all completed QLRAs (including all QLRAs with Moderate Priority Ratings) were reviewed by the Panel to provide a peer review process towards ensuring scientific rigor of the outcomes and conclusions.

3.2 Stage 2 – Quantitative Data Collection Methods

Initial Quantitative Data Collection

Based on the QLRA outcomes of Stage 1, quantitative exposure data was identified to further characterize worker exposures at Line 1-Onyang, Line 5-Giheung and Line 12-Hwaseong. Task specific and full-shift chemical employee exposure data for both personal breathing zone and area monitoring was identified for those SEGs and their related specific tasks/chemicals determined to have a moderate priority rating according to the qualitative assessments, those tasks/chemicals for which data gaps may exist, or those tasks/chemicals selected to validate qualitative assessment outcomes (by selecting a number of 10% to 15% of all tasks assessed).

Chemical exposure monitoring was conducted for employees performing the identified tasks, and was comprised of either Samsung Operators, Samsung Engineers, or third-party/vendor employees. Quantitative exposure assessments were conducted in accordance with established analytical methods (e.g., NIOSH Manual of Analytical Methods or similar), using calibrated equipment with all samples submitted to and analyzed by US laboratories accredited by the American Industrial Hygiene Association.

3.2.1 Stage 2 of the project consisted of three tasks described below.

3.2.1.1 The Quantitative Exposure Monitoring Sampling Plan

For the initial Stage 2 sampling plan, quantitative exposure monitoring for process chemicals, maintenance chemicals and anticipated/confirmed by-products was identified for the following three scenarios:

Tasks and associated process chemicals, maintenance chemicals and likely/known by-product chemicals with moderate or high priority ratings developed during Stage 1 QLRA performance. For such tasks identified, two (2) full-shift and two (2) or more task specific breathing samples were planned for each task/chemical identified. This sampling approach provided for a total of four (4) or more samples for each task in order to ensure adequate statistical power to support the exposure characterization. Additionally, this approach allows for the determination of potential exposures during the performance of the actual task as well as potential exposures related to a given eight (8) hour work shift. Typically, these planned samples involved sampling and analysis for multiple chemical analytes ranging from one (1) to seven (7) analytes for a given task.

Chemicals of interest that have not been previously monitored during task performance as part of Samsung's existing exposure monitoring program. These samples were planned to be collected during the performance of tasks in addition to full work-shift samples that may have already been monitored by Samsung. Samsung maintains a robust industrial hygiene monitoring program that formed the basis of the Stage 1 QLRA process. However, in the QLRA process it was noted that certain chemical analytes of interest have not been previously

quantitatively assessed. These samples would provide data for those chemicals that have not been previously assessed.

Tasks and associated process chemicals, maintenance chemicals and likely/known by-product chemicals with trivial or low risk rankings developed during Stage 1 QLRA performance. These samples were planned to validate the accuracy, reliability and appropriateness of the QLRA methodology employed and the professional judgments utilized in the assessment of all worker tasks of interest. Based on the AIHA model previously referenced a minimum of 10% of the total number of tasks assessed would need to be quantitatively sampled to provide sufficient validation of the QLRA outcomes. However, validation samples were planned to be collected to accomplish a minimum of 20% of the total number of tasks assessed. Accordingly, the following validation samples were identified:

- For full-shift tasks to be validated (e.g., normal operations) two (2) to four (4) personal breathing zone samples and/or two (2) area samples would be collected.
- For less than full-shift tasks to be validated, two (2) to four (4) task specific breathing zone samples would be collected to ensure adequate statistical power to support the exposure characterization.
- Typically, all of these planned samples involved sampling and analysis for multiple chemical analytes ranging from one (1) to seven (7) analytes for a given task.

Over and above the chemical analytes associated with the three instances described, four additional analytes of particular interest were monitored: formaldehyde, benzene, 1,3 butadiene and ethylene oxide. All of these chemicals have been reported to be associated with certain occupational health concerns. These analytes were included in the Stage 2 sampling plans and data collection was conducted for these analytes in the same fashion as other chemical analytes. Methods associated with chemical exposure monitoring described in more detail below. .

Measurement of two physical agents of interest (ionizing and non-ionizing radiation) was to be conducted to assess ambient physical agent concentrations in production and maintenance areas. Real-time physical agent measurements were collected using calibrated instrumentation in a fashion to allow for comparison of results to established occupational exposure limits (e.g., ACGIH Threshold Limit Values).

All quantitative exposure assessments were to be conducted in accordance with established and validated analytical methods, or their equivalent (e.g., NIOSH Manual of Analytical Methods and US OSHA Methods) and all samples were to be analyzed by independent AIHA Accredited Laboratories in the United States.

3.2.1.2 Supplemental Quantitative Data Collection

Following implementation of the initial Stage 2 sampling plan, a supplemental sampling plan was developed to further characterize certain chemical and physical agent exposures of interest based on the results obtained from the initial quantitative data collection event and feedback from KOSHA observers from the initial quantitative data collection event.

The additional quantitative exposure monitoring was planned to further evaluate the potential presence of three chemical analytes (ethylene oxide, formaldehyde and ozone) that were identified during initial Stage 2 quantitative data collection event. As discussed previously, none of these chemicals are used in the manufacturing processes and there is no chemical mechanism for their formation in the manufacturing process. Due to unanticipated and/or unexplainable detections of some of these analytes during the initial collection event, the additional data collection effort was planned to validate and further characterize potential employee exposures to these analytes in the same process areas that were previously monitored during the initial Stage 2 data collection. The additional data was further collected using both diffusion and active sampling methodologies in a side-by-side fashion to allow for a comparison of results obtained from the two sampling methods, to determine if there were any method-specific variations of concern.

Supplemental quantitative data was also collected for non-ionizing radiation in the extremely low frequency ("ELF") range, at approximately 60 hertz (Hz). Non-ionizing radiation measurements obtained during initial Stage 2 data collection for frequencies utilized by manufacturing equipment (e.g., radio frequency ("RF") and microwave ranges (from 56 kilohertz (KHz) to 2.45 gigahertz (GHz). Real-time measurements of non-ionizing radiation in the ELF range were collected using calibrated instrumentation in manufacturing areas of the lines of interest.

3.2.1.3 Collection of Quantitative Exposure Monitoring Data

Quantitative exposure monitoring for chemicals and physical agents was conducted in accordance with the initial and supplemental sampling plans. For the initial Stage 2 data collection an ENVIRON field team conducted the site assessments associated with Stage 2 to collect the quantitative data. The initial site work occurred from January 10, 2011, to January 25, 2011, and included 13 full days of sampling at Samsung Lines 1, 5 and 12 in South Korea.

For the supplemental Stage 2 quantitative data collection an ENVIRON field team of three members conducted follow-up site visits to collect the additional data. The supplemental site visit occurred from April 5, 2011, to April 9, 2011, and included 3 full days of sampling at Samsung Lines 1, 5 and 12 in South Korea.

Chemical exposure monitoring was conducted for employees performing the identified tasks and consisted of Samsung Operators, Samsung Engineers and third-party/vendor employees (i.e., PM Engineers). These samples consisted of personal breathing zone, simulated personal breathing zone and area samples collected during the performance of the tasks of interest identified in the initial and supplemental sampling plans. Tasks of interest included full work-shift normal operations typically consisting of sample durations of approximately 480 minutes (8 hours) and preventive maintenance ("PM") tasks with varying sample durations depending on the PM task length. The task being conducted by the given employee type (e.g., Samsung Operator, Samsung Engineer or vendor employee) defined the SEG. Additionally, for nearly all PM task samples that were collected, full work-shift samples were also collected for the individuals that performed the PM task to assess the potential exposure to the spectrum of target analytes over the entire work-shift. During the initial data collection site visit there were three instances when full work-shift samples were not collected: when the employees that conducted the task were primarily office workers and the task performance was the only

potential exposure of the day, when a full work-shift sample was already collected for the employee(s) as they were already being monitored for another task and when the employees worked atypical work-shift hours in order to cover employee vacations.

In order to collect both PM task samples and full work-shift samples, full work-shift sampling equipment (i.e. SKC Airchek 52 precision industrial hygiene sampling pumps) and associated sampling media was placed on the employees tasked with performing the PM task by an ENVIRON field team member at the beginning of the worker's shift and collected at the conclusion of their work-shift by an ENVIRON field team member. When the PM task actually occurred an ENVIRON field team member placed the PM task sampling equipment and associated sampling media on the employee that was conducting the PM task. Due to the large amount of sampling equipment required to collect quantitative data during PM tasks and the full work-shift for a given employee, the common practice in the field was to remove the full work-shift sampling equipment and associated sampling media and replace it with the PM task sampling equipment and associated sampling media while the PM task was being performed. During this time the full-work shift sampling equipment and associated sampling media was placed in the immediate area where the PM task was being performed to continue to collect the full work-shift samples in the form of a simulated breathing zone sample.

While the PM task was performed the ENVIRON field team member(s) observed the task and recorded relevant information into field notes. Field note information collected during PM task observation included the PM task name, task duration, the date, analytes of interest, sampling equipment IDs, sampling media IDs, the associated analytical methods utilized, exposure controls used such as local exhaust ventilation and personal protective equipment (PPE), maintenance chemicals in use, manufacturing equipment IDs, work area locations, employee names and job titles, as well as any other relevant observations during the performance of the task that may assist in the subsequent interpretation of the sampling data. Once the PM task was completed the PM task samples were concluded by removing and discontinuing the use of the sampling equipment and securing the associated sampling media. At this time the full work-shift sampling equipment and associated sampling media was placed back onto the employee(s) to collect data for the remainder of the shift as personal breathing zone samples.

For full work-shift samples the sampling equipment and associated sampling media was removed from the employee and placed in the employee's work area during breaks/meals or other times when the employee was required to leave the cleanroom environment to provide characterization of a "reasonable worst case" exposure scenario. In nearly all instances the sampling equipment and associated sampling media remained in operation during this time. Upon returning to the cleanroom environment, the sampling equipment and related sampling media was placed back onto the employee. All interruptions to the full-shift monitoring were noted in the field notes.

As part of the initial Stage 2 quantitative data collection site visit only, sampling during normal operations in certain process areas consisted of full work-shift samples that were collected over three consecutive shifts (e.g., day-shift, swing-shift and grave-yard-shift). This sampling was conducted for the Tin Plating process area on Line 1 and the Implantation and Clean process areas for Lines 5 and 12. For these samples two types of Samsung workers were sampled for

each shift - a Normal Operations-Operator and a Normal Operations-Engineer. During shift change the sampling equipment was transferred from the off-going shift's employee to the on-coming shift's employee and the battery was replaced to ensure the sampling equipment would remain operational for the entire shift. However, during shift change the sampling media was changed for one of the two SEGs (employee types) sampled while the sampling media was not changed for the other SEG (employee type) sampled. This resulted in 4 work-shift samples for the given process area, 3 from one SEG (employee type) sampled with durations of approximately 480 minutes each and 1 from the other SEG (employee type) sampled with a duration of approximately 1,440 minutes (three 480 minute shifts).

In some instances area sampling data was also collected for normal operations tasks as was the case during the initial Stage 2 data collection site visit during which samples were collected for the Molding, Sawing, Backlap, MVP, MBT, Marking, Trim/ Sort/ Form, Solder Ball Attach and Die Attach process areas for Line 1 and Photo, CMP, Diffusion, Etch, Thin Films-Metal and CVD process areas for Lines 5 and 12. For the supplemental Stage 2 data collection site visit this process of sample collection was also utilized for the Tin Plating process area of Line 1 and the CVD process area of Lines 5 and 12. In these instances sampling equipment and associated sampling media was strategically placed in work areas where normal operations occurred and in locations where Samsung Operators may encounter the highest potential exposure during their work-shift (e.g., near load/unload portions of manufacturing equipment). The sampling media associated with the area samples was placed at distances above the ground approximating typical locations of an Operator's breathing zone (e.g., between 1 to 2 meters above the floor). Area samples typically consisted of sample durations of approximately 480 minutes (8 hours).

All quantitative exposure assessments were conducted in accordance with established and validated analytical methods, or their equivalent (e.g., NIOSH Manual of Analytical Methods and US OSHA Methods). Two types of validated quantitative analytical methods were utilized during the initial and supplemental data collection site visits, diffusion (i.e. passive) and active sampling approaches. Diffusion sampling methods rely upon passive air movement across the sampling media that is placed in the worker's breathing zone or in the work area of interest. Diffusion sampling was conducted by removing the passive sampling media (i.e. badge) from its protective packaging, exposing the media's sample area to the ambient environment by removing its protective cover and placing the media in the worker's breathing zone or work area. At the conclusion of the sampling event the passive sampling media was removed from the worker's breathing zone or work area, capped to conclude the sampling by protecting the sampling media from the ambient environment and secured for subsequent shipment to the analytical laboratory. Sample ID numbers, the sampling date and time on (when the media was exposed to the ambient environment), time off (when the media was capped) and total sampling time in minutes was recorded on the sampling media in the work environment where sampling was conducted. Sampling equipment (e.g., precision industrial hygiene sampling pumps) used during the collection of the active quantitative data was calibrated with a primary standard prior to and following each sample collected. Sampling media was obtained directly from the analytical laboratory and was stored, used and shipped in accordance with guidance associated with the related analytical method (e.g., certain media required refrigeration to occur during shipment and storage). In addition to samples collected during the tasks of interest, field blank samples for both active and diffusion sampling methods were also collected to assess

interferences that may occur due to an artifact associated with the sampling media itself or its handling in the field. All resulting samples and their chain of custody forms were then submitted to and analyzed by Galson Laboratories or their associated subcontract laboratories, all of which are accredited by the American Industrial Hygiene Association.

In addition to quantitative chemical exposure data, real-time physical agent measurements were also collected for ionizing and non-ionizing radiation. Both physical agents were measured during normal operations in operating and service areas of all three lines. For Line 1 all areas of Packaging, Assembly and Test were assessed for ionizing and non-ionizing radiation. For Lines 5 and 12 process areas that utilize or generate ionizing radiation (e.g., Implantation) and/or non-ionizing radiation at radio and microwave frequencies (e.g., Diffusion, Etch, Thin Films-Metal and CVD) were assessed. All process areas in Lines 5 and 12 were assessed for non-ionizing radiation at extremely low frequencies. Real-time physical agent measurements were taken and recorded on field data sheets by Craig Torres, MS, CIH of ENVIRON during the initial Stage 2 data collection site visit and Craig Torres, MS, CIH and Dr. James Poole, CIH of ENVIRON during the supplemental Stage 2 data collection site visit. Measurements were taken at approximately 5 centimeter ("cm") distances from sources of physical agents (e.g., RF generators, microwave magnetrons, delivery cables, RF matches, implanter beam-line locations, electrical power panel/cables, etc.) or likely points of leakage (e.g., chamber lid seams, implanter outer-skin/shielding seams, chamber view ports, load/unload stations, etc.) at heights ranging from ground-level to approximately 2.5 meters above the ground.

Ionizing radiation was measured using a Victoreen 190 survey and count rate meter with a Victoreen 489-110D Geiger-Mueller probe. The ionizing radiation instrument was configured and calibrated to measure alpha, beta, x-ray and gamma radiation in units of microRems per hour (µR/hr). Non-ionizing radiation at radio and microwave frequencies was measured using a Holaday HI-4416 Broadband RF meter with an HI-4433-HCH magnetic field probe measuring frequencies ranging from 5 to 300 megahertz (MHz) and an HI-4433-MSE electric field probe measuring frequencies from 500 kilohertz (kHZ) to 5 gigahertz (GHz). The non-ionizing radiation instrument was configured and calibrated to measure radio frequency and microwave non-ionizing radiation in units of milliwatts per square centimeter (mW/cm2) in six minute averages for direct comparison to relevant TLVs. Non-ionizing radiation at extremely low frequencies (ELF) was measured using a Dexsil Field Star FS1000 meter measuring magnetic field frequencies from 55 to 65 hertz (Hz). The ELF meter was configured and calibrated to measure ELF non-ionizing radiation in units of milliGauss (mGauss) to allow for comparison to relevant TLVs.

3.3 Stage 3 – Data Interpretation and Exposure Characterization

ENVIRON evaluated and interpreted the collective qualitative and quantitative worker exposure data (qualitative risk assessment outcomes, existing Samsung quantitative data, and newly collected quantitative data) to develop an overall worker exposure profile for each of the identified Similar Exposure Groups (SEGs) of current Samsung Lines 1, 5 and 12.

The worker exposure profiles for each SEG were developed by drawing comparisons to applicable and appropriate occupational health exposure limits, in particular the American Conference of Governmental Industrial Hygienists' ("ACGIH") Threshold Limit Values ("TLVs")

for individual substances. Additionally, KOSHA established TLVs were compared to other applicable and appropriate standards under consideration to determine if any instances exist where the KOSHA TLV would be more conservative (i.e. protective). It was determined that in two instances the KOSHA TLV is more protective; for fluorine gas (F_2) and ozone (O_3). For these two analytes the KOSHA TLV was used for the SEG analyses. Although worker exposure profiles for each identified SEG will be compared on an individual chemical substance basis, the profile will represent all potential exposures for the given SEG as individual chemical substances were selected to assess the most conservative ("reasonable worst-case") exposures.

Therefore, if it is concluded that the worker exposure profile suggests SEG exposures are trivial or highly or well controlled for the worst-case individual substances of greatest concern, any substances of equal or lesser concern would also be expected to be equally controlled.

Stage 3 of the project consisted of two tasks, the methods for which are described below.

3.3.1 Integration and Evaluation of Collective Worker Exposure Data

Existing worker exposure data (i.e. historic Samsung exposure monitoring results) and worker exposure data obtained, developed or gathered during Stages 1 and 2 of the project were compiled to form a collective data set of qualitative and quantitative data. These data were subsequently divided into similar exposure groups. Stage 3 SEGs were defined by utilizing SEGs previously identified during Stage 1 of the project and collapsing them to allow for the use of existing/historic Samsung exposure monitoring data, which were aligned with process areas of each line. The extent of detail provided with existing exposure monitoring data would only allow for SEGs to be defined as process areas of each line and the task being performed (e.g., Normal Operations or Maintenance[2]). Following the determination of SEGs by process areas and the task being performed, existing and newly collected data were statistically evaluated to verify that valid SEGs were defined. Statistical evaluation of the SEGs indicates that defining SEGs by process area and the task being performed is a valid approach as the resulting distributions were deemed to describe comparable/similar exposures.

SEGs for Normal Operations were defined for all process areas for each Line consisting of a total of 29 SEGs (13 SEGs for Line 1 and 8 SEGs for each of Lines 5 and 12). Sufficient data (defined below), qualitative and quantitative (historic Samsung and newly collected Stage 2 data), were available to define for three SEGs for maintenance activities for Lines 5 and 12 each[3]. Therefore, a total of 35 SEGs were defined for Stage 3 data evaluation and development of exposure profiles.

[2] We do not characterize upset conditions, R&D, process development, etc. in this type of Study. This is a high-volume manufacturing site that is by definition built and maintained to conduct Normal Operations. Other types may happen from time to time, but on a very limited basis (much less than 5% of the time) so these events are not included. It is important to call the Normal Operations to make these distinctions.

[3] There would be other SEGs for Maintenance on these lines but they were not considered relevant based on the QLRAs. Maintenance occurs in every process area. But maintenance was only considered (evaluated) for those instances where priority ratings deemed them to be necessary. Based on the validated QLRAs the other maintenance SEGs would not be of concern.

Once SEGs were defined and validated, the collective worker exposure data for each SEG were evaluated utilizing the Bayesian Decision Analysis ("BDA") approach. The BDA approach is a scientifically recognized and accepted methodology to incorporate various types of process and exposure control knowledge to form more accurate and comprehensive exposure judgments. The BDA approach for occupational health exposure assessment has been presented in various publications including the Journal of Occupational and Environmental Hygiene ("JOEH") article titled *Rating Exposure Control Using Bayesian Decision Analysis*[4]. The BDA approach for occupational exposure provides techniques to incorporate existing knowledge of operations of interest (e.g., historic exposure data and professional/qualitative judgments) referred to as the *prior distribution*, with current (i.e. newly collected) exposure data referred to as the *likelihood distribution*, to develop a mathematically derived decision distribution, referred to as the *posterior distribution*. Each of the distributions (prior, likelihood and posterior) are provided as a set of decision probabilities which characterize the *true* 95th percentile of the exposure distribution which are then assigned one of five exposure categories as defined by the American Industrial Hygiene Association[5]. Inspection of the resulting decision probabilities suggests the *true* exposure profile is most likely to be consistent with the exposure control category with the highest probability (i.e. the exposure profile distribution is most likely to be consistent with the given exposure category definition). Table 2 below provides an adapted explanation of the AIHA exposure control category scheme adapted from a summarized version of the AIHA scheme from the previously cited JOEH article by Hewett, et al 2006[6].

[4] Journal of Occupational and Environmental Hygiene. Rating Exposure Control Using Bayesian Decision Analysis. Paul Hewett; Perry Logan; John Mulhausen; Gurumurthy Ramachandran; Sudipto Banerjee. Exposure Assessment Solutions, Inc., Morgantown, West Virginia, 3M, Minneapolis, Minnesota University of Minnesota, Minneapolis, Minnesota. First published on: 01 October 2006

[5] Hawkins, N.C., S.K. Norwood, and J.C. Rock (eds.): A Strategy for Occupational Exposure Assessment. Fairfax, Va.: American Industrial. Hygiene Association, 1991.

[6] Journal of Occupational and Environmental Hygiene Rating Exposure Control Using Bayesian Decision Analysis. Paul Hewett; Perry Logan; John Mulhausen; Gurumurthy Ramachandran; Sudipto Banerjee. Exposure Assessment Solutions, Inc., Morgantown, West Virginia, 3M, Minneapolis, Minnesota c University of Minnesota, Minneapolis, Minnesota. First published on: 01 October 2006

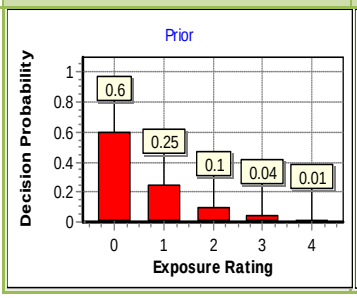
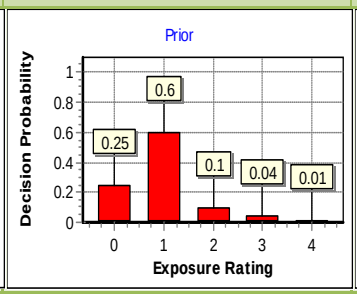
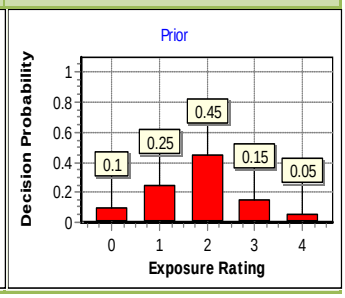
Table 2. AIHA Exposure Categorization Scheme

Exposure Category	Rule-of-Thumb Description	Exposure Profile Description	Recommended Statistical Interpretation
0	Exposures are trivial to nonexistent	The *true* 95th percentile ($X_{0.95}$) is calculated to be <1% of the OEL at a 95% confidence level for anticipated exposures in the SEG.	$X_{0.95} \leq 0.01 \times OEL$
1	Exposures are *highly controlled*	The *true* 95th percentile ($X_{0.95}$) is calculated to be between 1% and ≤ 10% of the OEL at a 95% confidence level for anticipated exposures in the SEG.	$0.01 \times OEL < X_{0.95} \leq 0.1 \times OEL$
2	Exposures are *well controlled*	The *true* 95th percentile ($X_{0.95}$) is calculated to be between <10% and ≤ 50% of the OEL at a 95% confidence level for anticipated exposures in the SEG.	$0.1 \times OEL < X_{0.95} \leq 0.5 \times OEL$
3	Exposures are *controlled*	The *true* 95th percentile ($X_{0.95}$) is calculated to be between <50% and ≤ the OEL at a 95% confidence level for anticipated exposures in the SEG.	$0.5 \times OEL < X_{0.95} \leq OEL$
4	Exposures are *poorly controlled*	The *true* 95th percentile ($X_{0.95}$) is calculated to exceed or be > than the OEL at a 95% confidence level for anticipated exposures in the SEG.	$X_{0.95} > OEL$

Informed prior distributions were developed by two approaches, data-informed priors and QLRA-informed priors. Data-informed priors were preferentially developed and utilized when sufficient and adequately grouped historic Samsung data was available for the given SEG. When appropriate data were available (data set >2 with a sufficiently low geometric standard deviation to allow for BDA calculations), data-informed priors were developed by entering the historic exposure data set into the IHDataAnalyst ("IHDA") software published by Exposure Assessment Solutions, Inc. with a non-informed (i.e. flat) prior to determine the likelihood distribution of the existing data. The resulting likelihood distribution would then be used as the data-informed prior distribution during subsequent analysis of Stage 2 data.

When appropriate data were not available to develop and utilize data-informed priors, QLRA-informed priors were developed and utilized. QLRA-informed priors were developed as a set of custom professional judgment prior distributions based on QLRA results, one for each priority rating/associated AIHA exposure category represented in the QLRAs previously developed during Stage 1. It should be noted that the QLRA-informed priors were developed before analysis of historic exposure data commenced to limit the development of QLRA-informed priors based on professional judgment of the developer. Subsequent validation of the QLRA-informed priors was then performed utilizing historic exposure data, described in more detail below. Therefore, when a data-informed prior was not available for a given analyte within an SEG, the related QLRA priority rating was referenced and the associated QLRA-informed prior distribution was used. Table 3 below provides the graphical representations of the QLRA-informed prior distributions that were used for each priority rating/associated exposure category.

Table 3. QLRA-informed Prior Distributions

QLRA Priority Rating	Trivial	Low	Moderate
Associated Exposure Category	0	1	2
QLRA-Informed Prior Distribution			

In order to evaluate the sound professional judgments utilized in the development of the QLRA-informed priors, the following validation was performed.

A total of forty two (42) unique SEG-analyte combinations were identified for which Samsung historical exposure data and ENVIRON QLRA Priority Ratings were available. In some instances more than one analyte within a given SEG may be considered, therefore this number can exceed the total number of analytes as this number describes SEGs and analytes assessed within an SEG. Of these 42 combinations, use of the QLRA-informed prior distributions identified associated exposure categories 0, 1 and 2 for 8, 31, and 3 SEG-analyte combinations, respectively. Of these 42 combinations, use of the Samsung historical exposure data-informed prior distributions identified exposure categories 0, 1, and 2 for 26, 14, and 2 chemical-SEG combinations, respectively. Exposure categories 3 and 4 were not identified with the BDA approach using either the QLRA or historical exposure data-informed prior distributions. The detail of the frequency distributions is described in Table 4.

Table 4. Frequency of Exposure Category Classification by BDA Using QLRA-informed Prior Distributions versus Historical Exposure Data-informed Prior Distributions.

	Hazard Category Using Historical Exposure Data-informed Prior Distributions					
Hazard Category Using QLRA-informed Prior Distributions	**0**	**1**	**2**	**3**	**4**	**Total**
0	5	2	1	0	0	8
1	20	10	1	0	0	31
2	1	2	0	0	0	3
3	0	0	0	0	0	0
4	0	0	0	0	0	0
Total	26	14	2	0	0	42

To determine if the QLRA-informed prior distributions predict conservative exposure categories in the BDA approach analysis relative to the historical exposure data-informed prior distributions, the resulting exposure categories are compared in Table 2. Consequently, for 38 of 42 analyte-SEG combinations (90%) of the exposure categories based on QLRA-informed prior distributions are equal to or greater than (e.g. more conservative or protective) exposure categories based on historical exposure data-informed prior distributions. The binomial test with a one-sided "greater than" alternative hypothesis indicates that this percentage is significantly greater than random chance ($p < 0.001$).

Analyses for each QLRA-informed exposure category are also presented in Table 5. There is no evidence at the $p = 0.05$ level to indicate that the QLRA-informed exposure categories 0 and 1 are conservative relative to the historical exposure data-informed exposure categories. However, for QLRA-informed exposure category 2, the interpretation of the p-value is limited by the small sample size.

Table 5. The Event that Historical Exposure Data-informed Prior Distribution Exposure Categories ($Category_{DATA}$) is Equal to or less than the Exposure Category Determined Using a QLRA-Informed Prior Distribution ($Category_{QLRA}$) is more likely than not is Tested Using the Binomial Test.

	Frequency of Occurrence		Binomial Test	
$Category_{QLRA}$	$Category_{DATA} \leq Category_{QLRA}$	$Category_{DATA} > Category_{QLRA}$	$Pr(Category_{DATA} \leq Category_{QLRA})$	p-value
0	5	3	0.63	0.36
1	30	1	0.97	<0.001
2	3	0	1.0	0.125
3	0	0	-	
4	0	0	-	
All Categories	38	4	0.90	<0.001

As indicated in Table 4, when the exposure category based on the QLRA-informed prior distribution is less than that based on the historical exposure data-informed prior distribution, the misclassification is within 1-2 exposure categories. The greatest difference is the event in which the QLRA-informed prior distribution results in exposure category 0 and the historical exposure data-informed prior distribution results in hazard category 2. In this circumstance, the exposure category 2 indicates a very low likelihood of exposure at the OEL. As a result, the analysis suggests that the use of professional judgments encompassed in and represented by the QLRA priority ratings and associated exposure categories should be deemed valid and resulting derived QLRA-informed prior distributions are appropriate for use in the BDA approach.

In the event that an historic exposure data-informed prior distribution or QLRA-informed prior distribution was not available due to an inadequate historic exposure data set or the analyte was not included in the SEG's QLRA, a non-informed (i.e. flat) prior was utilized. A non-informed prior distribution assigns an equal statistical weighting of 0.2 (i.e. 20%) to each of the five exposure categories thereby limiting the BDA analysis output to current Stage 2 data only.

Once a prior distribution for a given analyte within an SEG was selected, the related Stage 2 exposure monitoring data set was input into the IHDA software with the selected prior input as the BDA initial rating. BDA calculations were then performed to integrate the prior distribution and the likelihood distribution to mathematically derive the posterior distribution. The posterior distribution represents the overall decision distribution incorporating previous operations knowledge (historic exposure data or QLRA conclusions) with current exposure data (initial and supplemental Stage 2 data). The resulting posterior distribution was then inspected to identify the exposure category with the highest probability to include the *true* 95th percentile exposure distribution. The exposure category that was identified to have the highest probability was therefore determined to represent the exposure profile of the SEG for the given analyte. This approach is consistent with the process used to determine the overall SEG exposure profile in the Journal of Occupational and Environmental Hygiene (JOEH) article titled *Exposure Modeling in Occupational Hygiene Decision Making*[7].

This process was repeated for all analytes within an SEG with appropriate Stage 2 data (i.e. a data set >2 with a sufficiently low geometric standard deviation to allow for BDA calculations). In instances when appropriate Stage 2 data were not available the following approaches were taken in the order of preference listed below.

- First, if an appropriate historic exposure data set existed for the analyte it was utilized along with a QLRA-informed prior distribution to generate the resulting posterior distribution and related exposure profile.
- If an appropriate historic exposure data set existed for the analyte, but no QLRA priority rating was determined for the analyte and therefore no QLRA-informed prior was available, the historic data was utilized along with a non-informed prior to generate the resulting posterior distribution and related exposure profile.
- In the event that an appropriate historic exposure data set was not available due to an insufficient number of data points and an insufficient number of Stage 2 data points existed within the SEG, the two data sets were pooled for consideration.
- After pooling the historic exposure data and Stage 2 data the resulting combined data set was inspected to determine if an appropriate data set existed (i.e. a data set >2 with a sufficiently low geometric standard deviation to allow for BDA calculations).
- If an appropriate data set did exist, the pooled data set was utilized along with the related QLRA-informed prior distribution to generate the resulting posterior distribution and related exposure profile.

In all instances of appropriate pooled data being utilized, a related QLRA-informed prior distribution was available and used. If the pooled data did not result in an appropriate data set or if there was not sufficient data to be pooled the QLRA priority rating the associated exposure category was selected to represent the exposure profile for the given analyte in the SEG.

[7] Journal of Occupational and Environmental Hygiene. Exposure Modeling in Occupational Hygiene Decision Making. Monika Vadali; Gurumurthy Ramachandran; John Mulhausen. Division of Environmental Health Sciences, School of Public Health, University of Minnesota, Minneapolis, Minnesota, 3M Company, St. Paul, Minnesota. First published on: 01 June 2009

At this juncture the collection of resulting analyte specific exposure profiles within a given SEG were inspected to identify the exposure profile(s) falling into the highest exposure category. The exposure profile(s) falling in the highest exposure categories were then selected to represent the overall exposure profile for the SEG of interest. Therefore, for a given SEG it could be stated that exposures to all anticipated chemicals within the SEG (process chemicals, anticipated or known by-products and analytes otherwise monitored) would be expected to be at or below the worst-case exposure profile(s) (i.e. the highest exposure profile(s)). It should also be noted that chemical analytes were selected to be included in the Stage 2 sampling plans based on Stage 1 results with the intent to identify those analytes of highest concern on the basis of their associated health effects and exposure potential. Thus, if a given exposure category is determined for the highest concern analytes of interest for an SEG, those analytes of equal or lesser concern in the SEG could also be concluded to be equally or more so controlled. Furthermore, resulting SEG specific worker exposure profiles have the ability to be compiled amongst process areas within a given Line to form collective worker exposure profiles.

Historic and Stage 2 quantitative data were utilized to determine prior, likelihood and posterior distributions, and therefore exposure profiles, primarily consisted of work-shift (approximately 6 to 8 hours in duration) exposure data. For Normal Operations SEGs only work-shift duration samples or longer were collected historically and during Stage 2. For Maintenance SEGs only task duration and work-shift duration samples were collected for each analyte assessed. However, for the purposes of determining exposure profiles for Maintenance SEGs, work-shift duration samples were preferentially utilized. This was the case for the following reasons, First, many of the OELs used to draw comparisons are based on 8-hour time weighted average ("TWA") exposures; therefore, use of work-shift duration exposure data provide the most valid comparison. Additionally, work-shift duration (i.e. over an 8-hour shift) samples provide the ability to assess an individual's overall exposure to a given chemical of concern which may occur over multiple tasks throughout the work-shift. Finally, for almost every instance historic exposure data for vendors (who primarily perform maintenance tasks) was only collected for work-shift durations.

Task duration samples were not altogether excluded from the determination of SEG exposure profiles. In the instances where short-term exposure limits (STELs) or ceiling limits existed for analytes assessed during task duration samples a comparison of task duration exposure data were compared to applicable OELs. For instances when an appropriate data set existed (i.e. a data set >2 with a sufficiently low geometric standard deviation to allow for BDA calculations), this comparison was performed by utilizing a QLRA-informed prior distribution along with task duration Stage 2 exposure data to generate the resulting posterior distribution and related exposure profile. The resulting exposure profile would then be compared to exposure profiles determined using work-shift duration exposure data. If the task duration exposure profile was less than or equal to the work-shift duration exposure profile the work-shift duration exposure profile would not be rejected, and the exposure profile would therefore be considered valid. For all such instances the work-shift duration exposure profiles were not rejected due to task duration exposure profiles and were therefore work-shift duration exposure profiles were deemed to be valid.

If an appropriate data set did not exist, individual task duration exposure data points were compared to applicable STEL or ceiling limits to determine if exceedances occurred. If no exceedances of STEL or ceiling limits occurred, the work-shift duration exposure profile would not be rejected and would therefore be considered valid. Likewise, for all such instances the work-shift duration exposure profiles were not rejected due to task duration exposure profiles and were therefore deemed valid.

To supplement the use of the BDA approach to determine SEG exposure profiles, relevant, traditional statistical measures of central tendency of the data were also considered. For each SEG that utilized exposure data (whether historic or Stage 2 quantitative data) to determine the exposure profile using the BDA approach, measures of central tendency (e.g., mean and/or median) were also calculated. These statistical measures were considered for each determining analyte(s) within an SEG (i.e. the analyte(s) with the highest exposure category) by comparing the measure(s) of central tendency with the BDA exposure profile for consistency. If the measure(s) of central tendency was/were within or below the exposure category of the BDA derived exposure profile the BDA exposure profile would not be rejected and would therefore be considered valid. For all such instances the-BDA derived exposure profiles were not rejected due to a lack of agreement between the BDA approach and traditional statistical measures.

It should be noted that while treatment of left-censored data (i.e. non-detectable exposure data)[8] does not impact the results from the BDA approach, it does have the potential to impact the calculation of traditional statistics measures. For instances when the Maximum Likelihood Estimate ("MLE") approach was allowable by the data set of interest, as described in the Annals of Occupational Hygiene article titled *A Comparison of Several Methods for Analyzing Censored Data*[9] it was used as the preferred substitution method for the non-detect data point. When MLE was not allowable, the analytical method's limit of detection divided by two (LOD/2) was used as the substitution method for that data point.

To characterize worker exposures to physical agents of interest (e.g., ionizing and non-ionizing radiation), real-time measurements were compared to applicable ACGIH TLVs for the related agent for each Line. Ionizing radiation was measured in all process areas of Line 1, including the only known source of ionizing radiation on the Line (QE Inspection Room) where an x-ray inspection tool is used periodically in an enclosed, dedicated room. On Lines 5 and 12, ionizing radiation was measured in the Implantation process area where x-ray radiation is generated as a by-product of the extremely high voltages used in ion implanters (Brehmstrahlung or breaking radiation). The x-ray radiation is only produced when the ion implanters are operational and actively implanting dopant ions into the silicon substrate of the wafers. Ionizing radiation was measured while implanters were in the operational implantation state and in areas where potential leakage would be expected to the be the highest (at the outer tool surface of the

[8] Left-censored data consists of exposure monitoring data that are below detectable concentrations according to the sampling and analytical methods employed (i.e. non-detectable). There are several methods that have been employed to include left-censored data during statistical analysis. The approaches employed for this Study are described herein.

[9] Ann. Occup. Hyg., Vol. 51, No. 7, pp. 611–632, 2007. A Comparison of Several Methods for Analyzing. Censored Data. Paul Hewett and Gary H. Ganser. Exposure Assessment Solutions, Inc., Morgantown, West Virginia; Department of Mathematics, West Virginia University, Morgantown, West Virginia. Received 5 March 2007; in final form 17 August 2007

interlocked and lead-shielded access panels, specifically near seams or other junctures of the access panels, at a distance of approximately 5 centimeters). These measurements would provide the worst-case worker exposure estimates to ionizing radiation in Lines 5 and 12, as power density of ionizing radiation declines rapidly as distance is increased. This phenomenon is described by the scientifically accepted principle of Newton's Inverse Square Law. Ionizing radiation measurements are evaluated as a range of the measurements recorded during the assessment of each Line. Comparison to the applicable ACGIH TLV for ionizing radiation was performed by selecting the highest recorded value in the range of measurements and calculating the estimated annual dose by multiplying the rate by 2,000 hours. The resulting estimated reasonable worst-case annual dose was then compared to the TLV.

Non-ionizing radiation in radio and microwave frequencies was measured in all process areas of Line 1. On Lines 5 and 12, radio frequency and microwave non-ionizing radiation was measured in process areas where this type of energy is utilized by process equipment (Diffusion, Etch, Thin-Films Metal and CVD). Measurements were collected while process equipment was operational and non-ionizing radiation was in use. Measurements were obtained in six minute averages to allow for direct comparison to relevant TLVs at 5 centimeter distances from areas of the process equipment with the highest potential for leakage as previously described. Similar to ionizing radiation measurements, these measurements would provide reasonable worst-case worker exposure estimates to radio frequency and microwave non-ionizing radiation in Lines 5 and 12, as power density of non-ionizing radiation declines as distance is increased according to Newton's Inverse Square Law. Non-ionizing radiation measurements are provided as a range of measurements recorded during the assessment of each Line.

Non-ionizing radiation at extremely low frequencies ("ELF") was measured in all process areas of all three lines of interest in both processing and service areas of the lines. Real-time measurements were obtained near sources of ELF energy at 5 cm distances (e.g., power panels and electrical cables) and locations where ELF energy was in use or being transported (e.g., at process equipment power connections and any cable chases or trays). Non-ionizing ELF radiation measurements are provided as a range of measurements recorded during the assessment of each Line.

4 Study Results

The results of the Bayesian Decision Analysis evaluation of the consolidated data sets yield a statistically robust model of exposures on the subject lines with appropriately high r-squared (r^2) values indicating SEGs are reasonably defined according to data agreement. These results represent the reasonable worst case scenario – that is, statistically, the 95th percentile evaluation – for exposure to workers in given tasks (i.e., SEGs) in the Samsung manufacturing lines of interest.

A summary of the final results is provided below by line.

4.1 Onyang Line 1

For Onyang Line 1, the Test and Assembly facility, a total of 13 SEGs were defined and assessed. Results for all 13 SEGs indicate that all chemical exposure profiles of the SEGs are consistent with Categories 0 or 1. Therefore, exposures to all anticipated chemicals within the Line 1 SEGs (process chemicals, anticipated or known by-products and analytes otherwise monitored) would be expected to be at or below 10% of their related OELs at least 95% of the time. Accordingly, all Line 1 SEGs defined and assessed are found to be either "trivial" (i.e. little or no exposure with little or no inhalation contact) or "highly controlled" (i.e. <10% of the OEL) chemical exposures.

Table 6 presents summarizes the results of the exposure characterization for Line 1 by SEG, the task performed, the overall Exposure Profile, the justification (i.e. what information and data used to develop the Exposure Profile) and determining analyte (i.e. the analyte(s) with the highest exposure category in the SEG).

Table 6. Onyang Line 1 Results Summary

SEG	Task	Overall SEG category: Exposure Profile	Justification	Determining Analyte(s)
Assembly - Back Lap	Normal Operations	1	BDA - QLRA, Pooled Historic/Stage 2 Data[1]	NH_3
Assembly - Sawing	Normal Operations	0	BDA - QLRA, Pooled Historic/Stage 2 Data[1]	1,1 Dichloro-1-fluoroethane
Assembly -Die Attach	Normal Operations	1	BDA - QLRA, Pooled Historic/Stage 2 Data[1]	1,1 Dichloro-1-fluoroethane, Ag
Assembly - Plasma	Normal Operations	0	QLRA[2]	Ar
Assembly -Wire Bonding	Normal Operations	0	QLRA[2]	N/A
Packaging - Molding	Normal Operations	0	BDA - QLRA, Stage 2 Data[3]	Phthalic anhydride, Sb, Maleic Anhydride

SEG	Task	Overall SEG category: Exposure Profile	Justification	Determining Analyte(s)
Packaging - Marking	Normal Operations	0	BDA - QLRA, Pooled Historic/Stage 2 Data[1]	Cyclohexanone
Packaging - Trim Sort Form	Normal Operations	0	BDA - QLRA, Stage 2 Data[3]	1,1-Dichloro-1-fluoroethane
Packaging -Tin Plating	Normal Operations	1	BDA - QLRA, Historic Data, Stage 2 Data[4]	H_2SO_4, KOH, Pb
Packaging - Solder Ball Attach	Normal Operations	1	QLRA[2]	Ag
Test - MBT	Normal Operations	1	BDA - QLRA, Pooled Historic/Stage 2 Data[1]	Pb
Test - Testing	Normal Operations	1	QLRA[2] BDA - Historic Data[5]	Liquid N_2 1,1 Dichloro-1-fluoroethane
Test - MVP	Normal Operations	0	BDA - Stage 2 Data[6] BDA - Historic Data[5]	Total VOCs 1,1 Dichloro-1-fluoroethane, 1,2-Dichloroethane, IPA

[1] = BDA - QLRA, Pooled Historic/Stage 2 Data indicates that the BDA approach was utilized to determine the Exposure Profile of the SEG and that a QLRA-informed prior distribution was used along with pooled historic and Stage 2 data to derive the posterior distribution of the determining analyte(s).
[2] = QLRA indicates that an appropriate exposure data set was not available to conduct the BDA approach and that the QLRA priority rating and its associated exposure category was used to determine the Exposure Profile of the SEG of the determining analyte(s).
[3] = BDA - QLRA, Stage 2 Data indicates that the BDA approach was utilized to determine the Exposure Profile of the SEG and that a QLRA-informed prior distribution was used along with Stage 2 data to derive the posterior distribution of the determining analyte(s).
[4] = BDA - QLRA, Historic Data, Stage 2 Data indicates the BDA approach was utilized to determine the Exposure Profile of the SEG and that for some of the determining analytes a historic exposure data-informed prior was used and for other determining analytes a QLRA-informed prior distribution was used both along with Stage 2 data to derive the posterior distribution of the determining analyte(s).
[5] = BDA - Historic Data indicates that the BDA approach was utilized to determine the Exposure Profile of the SEG and that a non-informed prior distribution was used along with historic exposure data to derive the posterior distribution of the determining analyte(s).
[6] = BDA - Stage 2 Data indicates that the BDA approach was utilized to determine the Exposure Profile of the SEG and that a non-informed prior distribution was used along with Stage 2 exposure data to derive the posterior distribution of the determining analyte(s).

Table 7 presents a summary of the physical agents measured on Line 1. Results of the physical agent measurements indicate a "well controlled" work environment where the 95th percentile exposures are expected to be less than 50% of the respective OEL.

Table 7. Onyang Line 1 Physical Agents Results Summary

Physical Agent Measured	Locations Measured	Range of Measurements	ACGIH TLVs
Non-ionizing Radiation – Radio Frequency	All Process Areas	E Field: ND - 8.2 V/m H Field: ND - 0.022 A/m	61.4 - 1842 V/m 0.3 - 47 A/m
Non-ionizing Radiation – Microwave	All Process Areas	ND - 0.018 mW/cm^2	81.7 mW/cm^2
Non-ionizing Radiation – ELF	All Process Areas	E Field: ND - 573 V/m H Field: ND - 0.0036 mT	25000 V/m 1 mT
Ionizing Radiation	All Process Areas	1.6 x 10^{-5} to 2.77 x 10^{-4} mSv/hr Estimated Annual Dose = 0.55 mSv	50 mSv (in any single year)
Ionizing Radiation	QE Inspection Room	7.0 x 10^{-5} to 1.0 x 10^{-4} mSv/hr Estimated Annual Dose = 0.2 mSv	50 mSv (in any single year)

4.2 Giheung Line 5

For Giheung Line 5, the 200mm wafer fabrication facility, a total of 11 SEGs were defined and assessed. Results indicate that 9 of the 11 chemical exposure profiles of the SEGs are consistent with Categories 0 or 1. Therefore, exposures to all anticipated chemicals within those 9 Line 5 SEGs (i.e. process chemicals, anticipated or known by-products and analytes otherwise monitored) would be expected to be at or below 10% of their related OELs at least 95% of the time. Accordingly, these 9 Line 5 SEGs are considered to be trivial or highly controlled chemical exposures.

Results for the remaining two Line 5 SEGs indicate chemical exposure profiles consistent with the Category 2 profile for Line 5 Implantation-Normal Operations and Line 5 Implantation-Maintenance. Therefore, exposures to all anticipated chemicals within these two Line 5 SEGs (process chemicals, anticipated or known by-products and analytes otherwise monitored) would be expected to be at or below 50% of their related OELs at least 95% of the time. These two Line 5 SEGs defined are considered to be well controlled chemical exposures.

Table 8 presents a results summary for Line 5 by SEG, the task performed, the overall Exposure Profile, the justification (i.e. what information and data used to develop the Exposure Profile) and determining analyte (i.e. the analyte(s) with the highest exposure category in the SEG).

Table 8. Giheung Line 5 Results Summary

SEG	Task	Overall SEG category: Exposure Profile	Justification	Determining Analyte(s)
Clean	Normal Operations	1	BDA - QLRA, Historic Data, Stage 2 Data[1]	H_2O_2, H_2SO_4, HF, IPA
CMP	Normal Operations	1	BDA - Historic Data, Stage 2 Data[2]	H_2O_2
CVD	Normal Operations	0	BDA - Historic Data, Stage 2 Data[2]	Ethylene Oxide[5], HF, NH_3, O_3
CVD-Vendor	Maintenance	0	BDA - Historic Data, Stage 2 Data[2]	HF
Diffusion	Normal Operations	1	BDA - Historic Data, Stage 2 Data[2]	HCl
Etch	Normal Operations	1	BDA - QLRA, Historic Data, Stage 2 Data[1]	Cl_2, HF
Implantation	Normal Operations	2	BDA - Historic Data, Stage 2 Data[2]	H_2O_2
Implantation-Vendor	Maintenance	2	BDA - QLRA, Historic Data, Stage 2 Data[1]	PH_3
Photo	Normal Operations	0	BDA - QLRA, Historic Data, Stage 2 Data[1]	2-heptanone, Ethanolamine, IPA, PGMEA
Thin Films-Metal	Normal Operations	1	BDA - Stage 2 Data[3]	H_20_2
Thin Films-Metal-Vendor	Maintenance	1	BDA - QLRA, Stage 2 Data[4]	Dimethylamine

[1] = BDA - QLRA, Historic Data, Stage 2 Data indicates the BDA approach was utilized to determine the Exposure Profile of the SEG and that for some of the determining analytes a historic exposure data-informed prior was used and for other determining analytes a QLRA-informed prior distribution was used both along with Stage 2 data to derive the posterior distribution of the determining analyte(s).

[2] = BDA - Historic Data, Stage 2 Data indicates the BDA approach was utilized to determine the Exposure Profile of the SEG and that a historic exposure data-informed prior distribution was used along with Stage 2 data to derive the posterior distribution of the determining analyte(s).

[3] = BDA - Stage 2 Data indicates that the BDA approach was utilized to determine the Exposure Profile of the SEG and that a non-informed prior distribution was used along with Stage 2 exposure data to derive the posterior distribution of the determining analyte(s).

[4] = BDA - QLRA, Stage 2 Data indicates that the BDA approach was utilized to determine the Exposure Profile of the SEG and that a QLRA-informed prior distribution was used along with Stage 2 data to derive the posterior distribution of the determining analyte(s).

[5] = This analyte is not associated with the process but was evaluated by ENVIRON as it could be associated with occupational diseases of concern. Although the results for this analyte were all non-detectable, BDA outcomes determine it to be a determining analyte for the given SEG where it was measured.

Table 9 presents a results summary of the physical agents measured on Line 5. Results of the physical agent measurements support a well controlled work environment without expected OEL exceedances.

Table 9. Giheung Line 5 Physical Agents Results Summary

Physical Agent Measured	Locations Measured	Range of Measurements	ACGIH TLVs
Non-ionizing Radiation – Radio Frequency	Diffusion, Etch, Thin Films-Metal and CVD	E Field: ND - 11.2 V/m H Field: ND - 0.03 A/m	61.4 - 1842 V/m 0.3 - 47 A/m
Non-ionizing Radiation – Microwave	Diffusion, Etch, Thin Films-Metal and CVD	ND - 0.033 mW/cm^2	81.7 mW/cm^2
Non-ionizing Radiation – ELF	All Process Areas	E Field: ND - 1917 V/m H Field: ND - 0.041 mT	25000 V/m 1 mT
Ionizing Radiation	All Process Areas	2.0×10^{-7} to 2.58×10^{-4} mSv/hr Estimated Annual Dose = 0.52 mSv	50 mSv (in any single year)

4.3 Hwaseong Line 12

For Hwaseong Line 12, the 300mm wafer fabrication facility, a total of 11 SEGs were defined and assessed. Results indicate that all chemical exposure profiles of these SEGs are consistent with Categories 0 or 1. Therefore exposures to all anticipated chemicals within the Line 12 SEGs (process chemicals, anticipated or known by-products and analytes otherwise monitored) would be expected to be at or below 10% of their related OELs at least 95% of the time. Accordingly, all Line 12 SEGs are considered to be either trivial or highly controlled chemical exposures.

Table 10 presents a results summary for Line 12 by SEG, the task performed, the overall Exposure Profile, the justification (i.e. what information and data used to develop the Exposure Profile) and determining analyte (i.e. the analyte(s) with the highest exposure category in the SEG).

Table 10. Hwaseong Line 12 Results Summary

SEG	Task	Overall SEG category: Exposure Profile	Justification	Determining Analyte(s)
Clean	Normal Operations	1	BDA - QLRA, Historic Data, Stage 2 Data[1]	H_2O_2, H_2SO_4, HF
CMP	Normal Operations	0	BDA - QLRA, Historic Data, Stage 2 Data[1]	HF, NH_3, Ammonium Hydroxide
CVD	Normal Operations	1	BDA - Historic Data, Stage 2 Data[2]	O_3
Diffusion	Normal Operations	1	BDA - QLRA, Historic Data, Stage 2 Data[1]	HCl, PH_3
Etch	Normal Operations	1	BDA - QLRA, Stage 2 Data[3]	HF
Etch-Vendor	Maintenance	1	BDA - QLRA, Stage 2 Data[3]	HCl, HF
Implantation	Normal Operations	1	BDA - Historic Data, Stage 2 Data[2]	H_2O_2, PH_3
Implantation-Vendor	Maintenance	1	BDA - QLRA, Historic Data, Stage 2 Data[1]	AsH_3, H_2O_2, HF
Photo	Normal Operations	0	BDA - QLRA, Historic Data, Stage 2 Data[1]	2-heptanone, Ethanolamine, IPA, PGMEA, Benzene[4], HCHO[4]
Thin Films-Metal	Normal Operations	1	BDA - Historic Data, Stage 2 Data[2]	H_20_2
Thin Films-Metal-Vendor	Maintenance	1	BDA - QLRA, Stage 2 Data[3]	HF

[1] = BDA - QLRA, Historic Data, Stage 2 Data indicates the BDA approach was utilized to determine the Exposure Profile of the SEG and that for some of the determining analytes a historic exposure data-informed prior was used and for other determining analytes a QLRA-informed prior distribution was used both along with Stage 2 data to derive the posterior distribution of the determining analyte(s).

[2] = BDA - Historic Data, Stage 2 Data indicates the BDA approach was utilized to determine the Exposure Profile of the SEG and that a historic exposure data-informed prior distribution was used along with Stage 2 data to derive the posterior distribution of the determining analyte(s).

[3] = BDA - QLRA, Stage 2 Data indicates that the BDA approach was utilized to determine the Exposure Profile of the SEG and that a QLRA-informed prior distribution was used along with Stage 2 data to derive the posterior distribution of the determining analyte(s).

[4] = This analyte is not associated with the process but was evaluated by ENVIRON as it could be associated with occupational diseases of concern. Although the results for this analyte were all non-detectable, BDA outcomes determine it to be a determining analyte for the given SEG where it was measured.

Table 11 presents a results summary of the physical agents measured on Line 12. Results of the physical agent measurements support a well controlled work environment without expected OEL exceedances.

Table 11. Hwaseong Line 12 Physical Agents Results Summary

Physical Agent Measured	Locations Measured	Range of Measurements	ACGIH TLVs
Non-ionizing Radiation – Radio Frequency	Diffusion, Etch, Thin Films-Metal and CVD	E Field: ND – 15.7 V/m H Field: ND - 0.04 A/m	61.4 - 1842 V/m 0.163 - 163 A/m
Non-ionizing Radiation – Microwave	Diffusion, Etch, Thin Films-Metal and CVD	ND - 0.065 mW/cm^2	10 - 81.7 mW/cm^2
Non-ionizing Radiation – ELF	All Process Areas	E Field: ND - 673 V/m H Field: ND - 0.0052 mT	25000 V/m 1 mT
Ionizing Radiation	All Process Areas	1.0×10^{-7} to 2.81×10^{-4} mSv/hr Estimated Annual Dose = 0.56 mSv	50 mSv (in any single year)

5 Discussion

Of the 35 similar exposure groups (SEGs) defined and assessed for Lines 1, 5 and 12 collectively, Study results indicate 33 of the 35 SEGs defined (94%) were found to exhibit Category 0 or 1 exposures. Therefore, exposures to all anticipated chemicals within 94% of the Line 1, 5 and 12 SEGs (process chemicals, anticipated or known by-products and analytes otherwise monitored) would be expected to be at or below 10% of their related OELs at least 95% of the time. In other words, these results indicate that 94% of the SEGs defined and assessed are consistent with trivial or highly controlled chemical exposures.

The remaining two SEGs - Line 5 Implantation-Normal Operations and Line 5 Implantation-Maintenance - were consistent with Category 2 exposures. Therefore, exposures to all anticipated chemicals for all Line 1, 5 and 12 SEGs (process chemicals, anticipated or known by-products and analytes otherwise monitored) would be expected to be at or below 50% of their related OELs at least 95% of the time. In other words, these results indicate that all of the SEGs defined and assessed are consistent with trivial, highly controlled or well controlled chemical exposures.

5.1 Highly Controlled Exposures

ENVIRON evaluated exposures to currently used process chemicals on Line 1 a Test and Assembly facility, Line 5 a 200 mm wafer fabrication facility and Line 12 a 300 mm wafer fabrication facility. Exposures evaluated included operator exposures under normal working conditions and maintenance activities as performed by either Samsung engineers or third party vendor engineers. It should also be noted that exposures related to the performance of Maintenance tasks were assessed without taking into account the additionally protective effect of respiratory protection that is worn during maintenance tasks. Therefore, the resulting exposure profile for Maintenance SEGs represents a highly conservative (i.e. the exposure is if anything overestimated) estimation of employee exposures related to these activities.

As discussed earlier, ENVIRON focused on Similar Exposure Groups – groups of workers where occupational exposures are expected to be essentially equivalent, based on tasks involved, either normal operations or maintenance. For the Samsung lines, the SEGs correlated with the unit process areas involved in manufacturing – CMP, CVD, Clean, Diffusion, Etch, Implantation, Photo and Thin Film Metals for the wafer manufacturing operations, and assembly, packaging and testing operations for Test and Assembly. Chemicals and agents of concern that ENVIRON evaluated were determined from ENVIRON's evaluation of a comprehensive list of chemicals used in each of the SEGs and chemicals byproducts generated in the production process. In addition ENVIRON evaluated several chemicals which are not associated with the process but could be associated with occupational diseases of concern: formaldehyde, benzene and ethylene oxide. ENVIRON also evaluated physical agents of concern, namely ionizing and non-ionizing radiation either generated in the implantation process area or utilized in various process areas, respectively.

ENVIRON demonstrated that benzene and ethylene oxide did not exist in the manufacturing workplace. All previous and newly collected exposure monitoring data for benzene indicate non-detectable concentrations. Results for ethylene oxide are discussed below. Formaldehyde

was detected in low concentrations in the Line 1 Packaging-Tin Plating SEG during initial and supplemental Stage 2 data collection. However, when evaluation of exposures to formaldehyde in this SEG were assessed using the BDA approach, the resulting exposure profile for formaldehyde was consistent with trivial exposures (i.e. less than 1% of related OEL at least 95% of the time).

As previously mentioned in the Supplemental Quantitative Data Collection Section (see section 4.1.4.2 above), additional monitoring data was collected to further characterize employee exposures to ethylene oxide in order to accurately characterize the SEG exposure profiles. The additional monitoring data was collected for comparison with data collected for two SEGs on Line 5 CVD and Line 12 CVD, during the Stage 2 data collection event.

Results from the additional sampling event for ethylene oxide were non-detectable for both active and passive sampling methods. This coincided with an independent internal laboratory review of the data and quality control information for the initial sampling event and the subsequent issuance of the updated analytical reports reflecting the non-detectable status of the results. The non-detectable results of the initial and additional sampling events were used as the basis for the exposure profile characterization.

For the remaining chemicals which are used or generated as byproducts, and the physical agents of concern, results of the SEGs which were defined and assessed for Lines 1and 12 indicate that all of the tasks being performed under conditions of both Normal operations and Maintenance activities are highly controlled exposures – that is, we expect that exposures to employees performing tasks on these lines will be below 10% of the OEL at least 95% of the time. These results are indicative of both a high level of engineered controls built into the system, effective general ventilation of the lines and good work procedures and training such that operators do not put themselves in the position of being exposed. Given this level of control, it is unlikely that exposures ever approach the OEL for any of the 8 process areas in the current generation (i.e. 300 mm wafer) fabrication lines or on the test and assembly line. These results are consistent with results reported in the literature for occupational health exposure in the semiconductor industry.

For Line 5, the prior generation 200 mm wafer fabrication line, results of the SEGs which were defined and assessed indicate that all of the tasks being performed under conditions of both Normal operations and Maintenance activities are also highly controlled exposures – that is, we expect that exposures to employees performing tasks on these lines will be at or below 10% of the OEL at least 95% of the time – with the exception of certain activities in the Implantation bays, which as discussed below are considered to be well-controlled exposures – that is, chemical and physical agent exposures are expected to be at or below 50% of the OEL at least 95% of the time. As with Lines 1 and 12, these results are indicative of both a high level of engineered controls built into the system, effective general ventilation of the lines and good work procedures and training such that operators do not put themselves in the position of being exposed. ENVIRON also believes that it is unlikely that exposures on any of the operations in Line 5 would ever exceed the OEL in any of the Line 5 process areas.

5.2 Line 5 Implantation Vendor SEG

Results for the Line 5 Implantation Vendor SEG indicate chemical exposure profiles that are consistent with Category 2 – that is, exposures to all anticipated chemicals within this would be expected to be at or below 50% of their related OELs at least 95% of the time. The Line 5 Implantation Vendor SEG is considered to be well controlled chemical exposure.

Specifically, BDA analysis indicates that phosphine is the determining analyte and that the *true* 95th percentile of the exposure distribution is most likely to be consistent with Category 2 as that category contained over 76% probability of possessing the true 95th percentile exposure distribution of the SEG. It should also be noted that exposures related to the Line 5 Implantation-Vendor SEG associated with the performance of Maintenance tasks were assessed without taking into account the additionally protective effect of respiratory protection that is worn during maintenance tasks. Therefore, the resulting exposure profile for this and all other Maintenance SEGs represents a highly conservative (i.e. the exposure is if anything overestimated) estimation of employee exposures related to the Line 5 Implantation-Vendor SEG.

5.3 Line 5 Implantation SEG

Results for the Line 5 Implantation SEG indicate chemical exposure profiles that are consistent with Category 2 – that is, exposures to all anticipated chemicals during normal operations would be expected to be at or below 50% of their related OELs at least 95% of the time. The Line 5 Implantation SEG is considered to be well controlled chemical exposure.

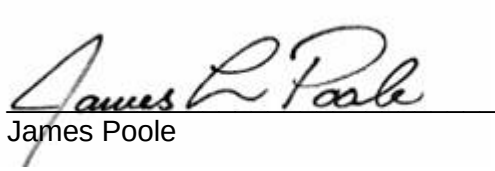
Specifically, BDA analysis indicates that hydrogen peroxide is the determining analyte and that the *true* 95th percentile of the exposure distribution is most likely to be consistent with Category 2 as that category contained over 60% probability of possessing the true 95th percentile exposure distribution of the SEG.

6 Conclusions

Based on the Study results, ENVIRON concludes that the Samsung Lines 1, 5, and 12 semiconductor wafer fabrication and test and assembly processes are "well controlled work environments" as AIHA defines that term – that is, on the whole, exposures are expected to be less than 50% of the respective OEL for each chemical or agent of concern at least 95% of the time - in terms of potential exposures to chemical substances (raw materials, waste products and by-products) and physical agents (e.g., ionizing radiation and non-ionizing radiation at radio, microwave and extremely low frequencies). Further, the majority of the processes on these lines - 94% of those evaluated – are trivial or highly controlled work environments, that is, exposures are expected to be less than 10% of the respective OEL for each chemical or agent of concern in those processes. Occupational exposure limits established by authoritative governmental and non-governmental agencies for the chemical substances and physical agents in question would not be expected to be exceeded in the reasonable worst case scenario.

The overall Study results validate the effectiveness of Samsung's industrial hygiene programs at Lines 1, 5, and 12. These results indicate the IH programs have been effectively developed and implemented to control current-day potential employee exposures to levels that are estimated to be trivial, highly controlled or well controlled in all assessed instances. The Study results are also consistent with results of Samsung's existing exposure monitoring data, indicating that Samsung's current industrial hygiene monitoring regime is accurately assessing the exposure potential of the workplace.

Final Report: Samsung Worker Exposure Characterization Study

Author/Lead Investigator (signature): 
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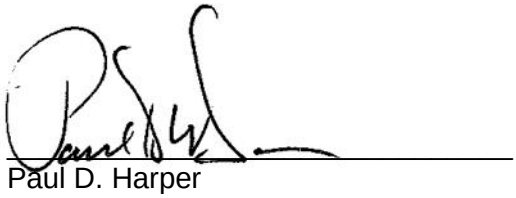
Author/Director (signature): 
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Date: October 28, 2011

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