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Table of Contents

1. Objective	3
2. Methodology.....	3
2.1. Criteria for NP exposure scenarios (step 1)	3
2.1. Gathering data (Steps 2 and 3)	5
2.2. Applying the Focal Point Approach.....	5
2.4. Develop exposure scenarios from existing scenarios and data	7
3. Results.....	7
3.1. Exposure scenarios for workers concerning CMP.....	8
3.2. Exposure scenarios for workers concerning coloured resist	9
3.3. Exposure scenarios for workers concerning generated nanoparticles.....	10
3.4. Exposure scenarios for workers concerning indium phosphide wafer splitting.....	11
3.5. Exposure scenarios for workers concerning alumina silicate ceramic fibre in thermal treatment	11
3.6. Environmental exposure scenarios.....	12
3.7. Focal Point Approach	12
4. Conclusions	14
4.1. Worker exposure	14
4.2. Environmental exposure.....	15
5. Technical Annexes	15
TA1 – Nanomaterial Inventory Excel Spreadsheet Containing Nanomaterial exposure scenarios.....	15

1. Objective

The objective of Task 1.3 in WP1 is to identify typical exposure scenarios out of the material trajectories from material delivery to waste disposal from Task 1.2 which in turn is based on the list of nanomaterials identified in the Task 1.1. The task concerns both exposure scenarios for trajectories of nanomaterials purchased for use within semiconductor manufacturing plants as well as occurrences of potential nanomaterial generation within semiconductor facilities.

2. Methodology

The following steps were defined for Task 1.3 in the project work plan for the identification of the exposure scenarios:

1. Determine criteria for nanoparticle exposure scenarios e.g. boundaries, specificity and depth of detail.
2. Gather data on existing scenarios related to Step 1.
3. Gather data on substance factors, environmental conditions and task factors including Risk Mitigating Measures (RMM's).
4. Apply the **focal point approach** to identify scenarios with potential for exposure to the semiconductor industry.
5. Develop exposure scenarios from existing scenarios and data.
6. Perform a gap analysis on information and data needed for scenarios meeting criteria from step 1 (the Proposal states criteria from step 2, but the criteria are in step 1)

Step 6 will be reported in a separate deliverable D1.4 "Gap analysis on information and data for NP exposure scenarios in semiconductor industry", as stated in the Proposal.

The Excel template developed to house the Nanomaterial Inventory information from Task 3.1 and the information on the identified trajectories from Task 3.2 was expanded with additional worksheets to identify the typical relevant exposure scenarios. The excel template is included in this deliverable under chapter 6. Technical Annexes as TA1.

2.1. Criteria for NP exposure scenarios (step 1)

Criteria for the exposure scenarios were developed from a discussion of a proposal in the Excel template. The following criteria were discussed and determined:

1. Appropriate level of aggregation to come to typical exposure scenarios for the semiconductor industry:

As explained in the deliverable for the previous task, D1.2 “A List of Associated Tasks, Activities and Operations Where Exposure Might Occur”, analysis found a significant similarity between the tasks and operations in the trajectories, especially in Chemical Mechanical Polishing (CMP). As a result it has been decided to group similar tasks/operations per main type of trajectory. For the use of CMP in semiconductor industry it was decided that the trajectories of the different partners with semiconductor manufacturing could be integrated to a single set of tasks and operations, a large part shared by all the partners and some unique for one or two partners.

For the generated nanoparticles, a number of the trajectories are similar in the tasks and operations and hence the typical scenarios, but differ in the type of process and hence the composition of possible nanoparticles generated. It was decided to also aggregate those trajectories into one single set of tasks and operations.

Three trajectories, one nanomaterial purchased and two nanomaterials generated had large parts of the trajectories dissimilar to any of the other trajectories and were not aggregated but exposure scenarios were identified for these trajectories individually.

2. Appropriate level of description of the scenario including boundaries and assumptions where relevant:

It was decided the description should ideally be on such a level where it makes clear the mechanism of exposure and source of the material available for exposure in such a way that the amount available for exposure and the level of dispersion can be estimated. Relevant boundaries and assumptions are mentioned in the description or added to the relevant factor or condition.

3. Chemical substance factors, task factors and environmental conditions taken into account in the typical exposure scenarios

It was decided to collect information on the following factors and conditions for the exposure scenarios:

- amount present in process
- amount available for dispersion
- level of dispersion (based on the potential for aerosol or dust generation according to ISO/TS 12901)
- resulting exposure (amount or exposure band according to ISO/TS 12901)
- type of exhaust and containment
- PPE to prevent inhalation
- Control band according to ISO/TS 12901

The exposure amount or concentration is usually not known from measurements, in those cases the exposure band according to ISO/TS 12901 can give an estimate of exposure, based on the amount of nanoparticles available for exposure and the potential for aerosol and/or dust generation of the task or process involved.

To compare the circumstances and risk mitigating measures the control band, based on the type of risk mitigating measures, according to ISO/TS 12901 is also given where relevant.

For the environmental exposure, next to the scenarios identified from the trajectories, the Focal Point Approach is used to identify relevant typical scenarios.

The result of this step is used in the format for the data gathering of step 2 and 3.

2.1. Gathering data (Steps 2 and 3)

Step 2 and 3 were performed in parallel.

The Excel template, that was developed to house the Nanomaterial Inventory information and the trajectories of Nanomaterial, was expanded with a further worksheet to incorporate the data on the exposure scenarios. It can be found under Section 6. Technical annexes as TA1 – Nanomaterial Inventory Excel Spreadsheet Containing Nanomaterial exposure scenarios.

The task and operations with possible exposure identified in the WP1 task 1.2 were aggregated as discussed in Step 1, and data was collected on the details of the exposure scenario and possible boundaries and assumptions. As in the previous task all partners with experience in semiconductor manufacturing were invited to enter information relating to description and the exposure factors. When a data entry field was left blank, partners were requested to indicate if the reason was that no information was readily available or if the information was withheld as confidential. Responses were compiled into one spreadsheet and the information was reviewed and further updated over the course of five teleconference meetings that were held with WP 1 participants over the course of month six to thirteen. The worksheet also contains the factors agreed upon, and each partner was asked to list the factors for the scenarios.

2.2. Applying the Focal Point Approach

According to the DOW the focal point approach would be applied to identify scenarios with potential for exposure from the semiconductor industry, based TNO's experiences from the FutureNanoNeeds project. The approach is based on existing life cycle inventory methodologies and application of material flow analysis.

As the scope of the project is not the whole life cycle, but only addresses the "in house" exposure/release, and the mapping of the relevant 'in house' occupational exposure scenarios was already done, there is no added value for focal point approach.

An identified gap within the task is the release of nanoparticle to environment via the waste water treatment plant (WWTP). It is assumed, based on the table with exposure scenarios (from D1.2) and the results from the environmental exposure scenarios identified in this task (see Sec. 3.6), that the CMP process is the most contributing process with respect to presence of nanoparticles in the waste water. And additionally that the amount of nanoparticles from other processes is negligible compared to the CMP process.

The modeling of a WWTP is done using the Ecoinvent tool¹. Input for the tool is the composition of the waste water stream. As not all the details are available, a stepwise approach was followed. In step 1 the most accurate, actual data are used. However when this was not feasible, proxies are made to estimate the amount of nanoparticles from the CMP slurry as well as from generated nanoparticles.

1. Actual data: amount of waste water per 1 m² of polished wafer; and its composition especially with respect to nanoparticles, both from purchased and generated nanoparticles.
2. Proxies:
 - (a) Proxy to estimate amount of **purchased nanoparticles** in waste water:
 - Amount of CMP slurry per 1 m² of polished wafer, and the composition of the slurry.
 - Amount of water needed to dilute the slurry
 - Amount of water needed to wash the wafers
 - (b) Proxy to estimate amount of **generated nanoparticles** in waste water
 - Composition of the layer on wafer, amounts per 1 m² of wafer.
 - Estimation of percentage of the layer which is polished away.
 - Amounts of water as requested under 2 (a)

The data were collected via questionnaires, which were sent to the partners. The data is processed and collected in a summary document (attached at Technical Annex).

The Ecoinvent WWTP model is based on an typical/average EU waste water treatment plant. One part of the sludge is incinerated (53%), the other part spread on agricultural land (47%). These values are used for an average/typical European scenario. According to Dutch law, spreading is not allowed and all sludge is incinerated. Both scenario are applied to the specific NXP case.

The WWTP model, and the linked solid waste incineration model, indicate emission to the following compartments:

- Air - direct digester gas emission plus emission from sludge incineration.
- Water (river) - sewer overload discharge plus direct wastewater treatment plant emission plus emission from sludge incineration.
- Water (ground) - emission from sludge incineration.
- Soil - emission from sludge spreading.

¹ Doka Calculation Tool for Municipal Wastewater Treatment Plant WWTP For Ecoinvent 2000, Programmed by Gabor Doka, 2002, Doka Life Cycle Assessments, Zurich

2.4. Develop exposure scenarios from existing scenarios and data

The result of the previous steps were discussed and descriptions clarified on some of the less common scenarios in the responses to the compiled spreadsheet and during the meetings. The results are scenario descriptions with factors governing exposure seen as the relevant typical scenarios for the semiconductor industry.

3. Results

In the preceding task the material trajectories with associated tasks and operations were identified and opportunities for exposure of workers or the environment to nanomaterials used or generated assessed. Also information on the duration and frequency of these opportunities for worker or environmental exposure was gathered and assessed. In this task, the scenarios are specified and information is gathered and assessed on the magnitude of the exposure, the third factor determining exposure. Six partners submitted information on the exposure scenarios within their facilities: L Foundry, NXP IMEC, Intel, Soitec, and ST.

The trajectories contained a total of 107 tasks and operations. From this, after aggregation a total of 41 relevant typical exposure scenarios were identified.

Nanomaterial exposure scenarios	Worker exposure	Environmental exposure
Related to CMP slurries	16	6
Related to Coloured resist	9	1
Related to nanoparticles generated in process	5	1
Related to nanoparticles generated from alumina silicate ceramic fibre isolation material through thermal treatment	3	n.a.

Table 3.1: Exposure scenarios related to type of material

During the process of information gathering it became clear most detailed exposure scenario information is available for the scenarios concerning CMP-slurries. However there is no exact information on the amount or concentration of particles released (mass or number). The substance factors categories “amount available for release” and “dispersion” are chosen as broad categories to reflect this lack of exact information. In addition to this there is also no exact information on the substance factor “amount in process” available for nanoparticles generated, resulting in the same broad categories.

3.1. Exposure scenarios for workers concerning CMP

From the CMP trajectories after aggregation 16 typical relevant typical exposure scenarios for workers were identified and detailed.

From those trajectories 5 have been identified in normal operating mode:

1. During (dis)connecting packaging: exposure to mechanical dispersion of dried CMP-fluid on cap of package or on dip-tube or connector.
2. During slurry preparation (in low volume): exposure to dispersion of aerosols, spills or adding particles as powder.
3. Use of polishing lab equipment with delivery of slurries by dispenser.
4. During collection of empty drums or pails: exposure to dispersion of wet or dry residues.
5. During removal of dried sludge or solid from filter in filter-press: exposure to mechanical dispersion of dried out slurry or filter-cake.

From those trajectories 11 been identified for maintenance, Preventive Maintenance (PM) and Corrective Maintenance (CM), or in accidental operating mode:

6. During transport fall of package resulting in large spill. Exposure direct from aerosols during spill or (more likely) from dispersion of particles from dried out spill residues.
7. During disconnecting package from dispense system the pump pressure is still on with the system resulting in spray of slurry from connector and exposure from inhalation of aerosols.
8. Drum is damaged resulting in leakage in the cabinet. Exposure direct from aerosols (unlikely, cabinet is closed when in use) or (more likely) from dispersion of particles from dried out spill residues during clean up.
9. Exposure from mechanical dispersion (touching, wiping, (un)-screwing) of dried cmp fluid coming from broken supply lines.
10. Exposure from mechanical dispersion (touching, wiping, (un)-screwing) of dried cmp fluid on pump, connectors and appendages during repair or replacement of pump in slurry dispense system.
11. As part of PM the CMP-tool is rinsed and cleaned. Exposure from aerosols during rinsing and cleaning or (less likely) from dispersion of dried out residues in the tool.
12. During pad change exposure from mechanical dispersion of dried out residues on pad, platen, chuck, pad conditioner or other parts.
13. During PM exposure from mechanical dispersion of dried out residues from regular operation or small internal leakages not reached by rinsing and cleaning before PM.
14. During CM exposure from mechanical dispersion of dried out residues from regular operation, broken wafer parts or small internal leakages not rinsed or cleaned enough before CM.
15. Exposure from mechanical dispersion (touching, wiping, (un)-screwing) of dried CMP-fluid in drain or surroundings during repair or replacement of drain.

16. During filter-press maintenance exposure from mechanical dispersion of dried out residues of slurry or filter-cake.

About half (9 from 16) of the exposure scenarios has a low amount of nanoparticles available for exposure and a low dispersion (low potential for dust or aerosol formation).

In operating mode there is only **one** scenario with a higher amount of nanoparticles (> 1 g) available for exposure (**operation nr. 5, removal of dried sludge or solid in operating filter-press**). In maintenance or accidental mode **six** scenarios have a higher amount available for exposure (nr. 6, 7, 8, 10, 15 and 16 in the list above) and one of these (nr. 7 spray accident during disconnecting package) also has a high potential for dispersion through aerosol formation.

With one exception, all scenarios with a higher amount of nanoparticles available for exposure, have a low frequency (*less than once a year up to twice a year*). The exception is scenario nr. 5, the removal of dried sludge or solid in operating the filter-press. The higher amount of nanoparticle available, combined with a high frequency (daily) and short to moderate duration (15 min – 1 h) makes it the scenario with the potential highest exposure dose for workers in the CMP trajectory, especially since the circumstances, natural ventilation and no PPE do not mitigate the possible exposure in this scenario.

For the other relevant exposure scenarios for workers the circumstances differ on ventilation (from natural to cleanroom ventilation, but not on Personal Protective Equipment (PPE)), as PPE to mitigate exposure through inhalation are not used on any of the tasks and operations, with the exception of low volume slurry preparation.

3.2. Exposure scenarios for workers concerning coloured resist

From the **coloured resist** trajectory 9 typical relevant typical exposure scenarios for workers were identified and detailed, of which 4 in normal operating mode:

1. During collection of empty bottles: exposure from dispersion of residues while (dis)connecting bottles.
2. During collection of empty bottles: exposure from dispersion of residues while collecting empty bottles cumulated.
3. During collection of empty bottles: exposure from dispersion of residues while collecting bottles with residual chemical cumulated.
4. During collection of coloured resist waste: exposure from dispersion of residues.

And of which 5 in maintenance, Preventive Maintenance (PM) and Corrective Maintenance (CM), and in accidental operating mode:

5. During cup changing (where the overflow of resist is collected), possible exposition of the worker with coloured resist residues inside the cup. The old cup is removed and placed in a bag. During this operation, the person works closely the cup, inside the equipment.

6. During nozzle cleaning with solvents and wipes, possible exposition with coloured resist residue, wipes put in waste bag. During this operation, the person works closely to the nozzle, inside the equipment.
7. During drain cleaning inside equipment with solvents and wipes, possible exposition with coloured resist residue inside lines, wipes put in waste bag. During this operation, the person works half-body inside the equipment.
8. During corrective maintenance (pumps or filter changing) activity, exposure from mechanical dispersion (touching, wiping, (un)-screwing) of dried resist fluid on pump or filter during repair or replacement of such materials.
9. During transport, fall of package resulting in spill. Exposure direct from aerosols during spill or (more likely) from dispersion of particles from dried out spill residues.

With the exception of scenario nr. 7, the amount of nanoparticles available for exposure is low (< 1g) and in all scenarios the potential for aerosol or dust generation is low. As a number of scenarios (nr. 1, 2 and 6) have a high frequency (daily) it is expected the highest possible exposure is either during drain cleaning in the inside of equipment or with the different stages of empty bottle collection.

For the exposure scenarios for workers the circumstances differ on ventilation as well as PPE. For the scenarios related to maintenance (nr. 5 – 8) cleanroom ventilation or exhaust is available and PPE are used. For the empty bottle collection part of the scenarios is with natural ventilation. No PPE to mitigate exposure through inhalation used. This makes the possible exposure for the worker unmitigated and therefore it is expected the most relevant exposure in this trajectory is related to the empty bottle collection.

3.3. Exposure scenarios for workers concerning generated nanoparticles

For the generated nanoparticle trajectories after aggregation 5 typical relevant typical exposure scenarios for workers were identified and detailed, all in the maintenance, Preventive Maintenance (PM) and Corrective Maintenance (CM), and in accidental operating mode:

1. During opening and cleaning of the chamber particles are released from the chamber surface. Cleaning is wet but breaking and disturbing layers can disperse dry particles.
2. During opening and disassembly of fore-line particles are released on pipe connections by breaking and disturbing layers.
3. Opening a chamber without pump purge before opening. During opening dry particles in the chamber are dispersed in the air.
4. Opening a scrubber (cyclone type) to remove powder. Powder is disturbed and dispersed by opening and removing mechanically.
5. During opening and disassembly of exhaust ducts containing solid layers or powder particles are released by breaking and disturbing layers or powder.

Of these scenarios all except nr.1, the opening and cleaning of the process chamber, have higher amounts of nanoparticles (> 1 g) available for exposure. The scenarios where a scrubber of the cyclone type (nr. 4) or the exhaust duct (nr. 5) are maintained, in addition to the higher amount also have a high dispersion (high potential for dust or aerosol formation). As the maintenance of a scrubber of the cyclone type has a moderate duration (2h) combined with a high frequency (daily) this makes it the scenario with the potential highest exposure dose. The circumstances with respect to mitigation of exposure, ventilation and PPE in this trajectory are similar for all relevant exposure scenarios for workers.

3.4. Exposure scenarios for workers concerning indium phosphide wafer splitting

For the trajectory wafer splitting of **indium phosphide** (InP) wafers, a process at one of the industrial partners, no exposure scenarios were defined. The process was discontinued shortly after Task 1.2 was finished. As it was not known by other partners and was only a marginal process with no further known distribution in the semiconductor industry, it was decided exposure scenarios for this trajectory were not relevant.

3.5. Exposure scenarios for workers concerning alumina silicate ceramic fibre in thermal treatment

This trajectory is a special case in the sense that it is not related to a semiconductor process, neither in nanoparticles used, nor in nanoparticles generated in the process, but it is related to the use of electrical heater elements with insulation material consisting of **ceramic fibres** in certain tools for thermal treatment (others might use heater lamps or RF-heaters). **This use is not specific for the semiconductor industry, but related to the use of heater elements and as such could be of concern to other industries.**

For the this trajectory 3 relevant typical exposure scenarios for workers were identified and detailed, all in the maintenance, Preventive Maintenance (PM) and Corrective Maintenance (CM) mode

1. Opening safety covers. Ceramic fibres from heater insulation laying on surfaces in tool are disturbed and dispersed.
2. Opening safety covers. Electrical disconnection. Removal of the quartz tube. Ceramic fibres from heater insulation laying on surfaces and falling from heater while disconnecting and tube removal in tool are disturbed and dispersed.
3. Opening safety covers. Electrical disconnection. Quartz tube removal. Heater removal. Ceramic fibres from heater insulation laying on surfaces and falling from heater while disconnecting and tube plus heater removal in tool are disturbed and dispersed.

3.6. Environmental exposure scenarios

From the trajectories in total 8 relevant typical exposure scenarios were identified. From these 2 scenarios are related to collection of empty packages or waste from cleaning. This comprises only a small part of the nanoparticles purchased.

Another 5 scenarios are related to nanoparticles in (waste) water, either going to an onsite waste water treatment or going to a municipal waste water treatment. **This is by far the most relevant type of environmental scenario related to the amount of nanoparticles in the aggregated CMP trajectory.**

For the aggregated trajectory of nanoparticles generated in thermal processes the general environmental scenario is from nanoparticles generated and pumped to the exhaust, scrubbed by different techniques depending on process, tool and specific infrastructure of a fab, and eventually emitted to air.

3.7. Focal Point Approach

As explained in 2.3 the focal point approach is applied to the release of nanoparticle to environment via the waste water treatment plant (WWTP).

The information gathering for the focal point approach was more complex than anticipated. At this stage the focal point approach could be applied to the results of NXP. Results of applying the focal point approach will be added for the other industrial partners as they become available.

In Table 1 the composition of the waste water is given, based on the questionnaire filled out by NXP. The waste water contains silica (SiO₂) and tungsten (W). The values are both expressed in gram per litre, as measured in the waste water stream, and expressed in gram per square meter of polished wafer. The latter is the so called functional unit. Relating all numbers to this functional unit makes a fair comparison possible between the various partners and processes.

Table 1 Composition of waste water expressed in g/l and in g/m² of polished wafer

Component	Concentration in waste water		Amount per wafer	
	unit	Value	unit	Value
SiO ₂	g/l	0.054	g/m ²	4 104
W	g/l	0.0002	g/m ²	15

The silica in the waste water is mainly originating from the slurry. According to the industrial partner 12 g of SiO₂ per square meter of polished wafer is estimated to be removed by polishing the wafer. This is

negligible compared to the total amount of SiO₂ (4 104 g/m² of polished wafer). The tungsten (W) is 100% generated by polishing.

After the waste water treatment one part of the sludge is incinerated in a municipal solid waste incinerator (MSWI) and the other part is spread on agricultural ground. As mentioned in sector 2.3, the average ratio in the EU is 53 vs 47% and in the Netherlands 100% is incinerated. For the NXP case, located in the Netherlands, emissions are given in Table 2 and Table 3, for a typical EU and a Dutch scenario, respectively.

Emissions of Si to the air are limited and even zero for tungsten. Emission to the air are from the incineration of the sludge. Most of the tungsten is released to the water (river) via the effluent of the waste water treatment plant. The remaining tungsten is released to the water (ground) via the incineration process or to the soil when the sludge is spread. When it is not spread emissions to river and ground water are similar. Most of the silicon ends up in the soil, when the sludge is spread; otherwise it is released to the water (river and ground). The Si, which is not emitted to the environment is captured in the slag from the incineration plant.

Table 2 Emissions to environmental compartments in g/l wastewater; NXP – EU scenario (53% incinerated and 47% spread)

Element	unit	Air	Water (river)	Water (ground)	Soil
Si	g/l	2.93E-05	1.51E-03	1.09E-03	1.11E-02
Si	g/m ²	2	115	83	844
W	g/l	-	1.07E-04	4.61E-05	4.62E-05
W	g/m ²	-	8	4	4

Table 3 Emissions to environmental compartments; NXP – NL scenario (100% incinerated)

Element	unit	Air	Water (river)	Water (ground)	Soil
Si	g/l	5.51E-05	1.52E-03	2.06E-03	0
Si	g/m ²	4	115	156	0
W	g/l	-	1.11E-04	8.69E-05	0
W	g/m ²	-	8	7	0

The Ecolnvent model uses so called transfer coefficients for the individual elements (like Si, W) to calculate the distribution over the various environmental compartments. It doesn't take into account the material itself (e.g. SiO₂) and its size (e.g. nano). For SiO₂ its likely that it will remain as SiO₂, but not likely in its nano size.

4. Conclusions

The identified relevant exposure scenarios from this task will serve as the basis to select candidate exposure scenarios for deeper consideration within the other parts of the NanoStreeM project. They come from the aggregated trajectories for CMP and nanoparticles generated and from two standalone trajectories.

4.1. Worker exposure

The CMP slurry is a well-established nanomaterial within the semiconductor sector. The vast majority of nanomaterial trajectories listed in the previous task fall into this category, and after aggregation of these trajectories it gives rise to almost half of the relevant scenarios for worker exposure identified in this task. It also has been the subject of previous investigation into exposure from nanoparticles by several partners in this consortium, leading to the ESIA document 'Risk Management/Assessment approaches to Chemical Mechanical Planarization (containing nanoparticles)' published in June 2015.

Nevertheless, the CMP slurry related scenarios give important new insights into the tasks and operations giving rise to the highest possible exposure to workers. In the aggregated CMP trajectory the tasks and operations outside the CMP process in the cleanroom, such as operating the filter press in the waste water treatment, are very relevant with respect to the possible exposure dose. **This result underlines the importance of mapping all tasks and operations in the trajectories and from there identify the relevant exposure scenarios.**

The same holds true for the trajectory related to coloured resist. In this trajectory the exposure scenario with the highest possible worker exposure appears to be related to the handling of empty bottles. One of the maintenance tasks on the tools using the coloured resist could potentially lead to high exposure but as this potential it is already recognised RMM's are used mitigating possible exposure. This again stresses the importance of meticulous mapping of all tasks and operations in the trajectories.

In the tasks and operations from the aggregated trajectory of nanoparticles generated in thermal processes, as was expected, relevant scenarios were related to maintenance. **But again the scenario with the highest possible exposure for workers was related not to the process tool in the cleanroom, but to the daily emptying of scrubbers in the subfab.**

In the trajectory concerning alumina silicate ceramic fibre in thermal treatment all exposure scenarios are related to maintenance of the tool. As explained in 3.5 this trajectory is not directly related to the semiconductor processes involved, but to the **use of insulation material consisting of ceramic fibres** in certain tools for thermal treatment. Therefore, it can be expected that exposure to these fibres is related to tasks involving contact with the insulation material in maintenance.

For the selection of scenarios from this aggregated trajectory to be considered in the other work packages, it will be important to have more information about the nanomaterials generated. The

chemistry involved, the process and the tool type give rise to a broad spectrum of possible nanomaterials that can be generated.

4.2. Environmental exposure

The release of materials to the environmental compartments (air, water, soil) has been modelled by the EcolInvent wastewater treatment plant model. The model is limited as it calculates on an elemental base, not on a material level. The model cannot identify whether a molecule (e.g. SiO₂) changes or not during e.g. incineration.

For the NXP case, emissions of Si and W are calculated for an average European and a Dutch scenario. Emissions to the air are limited for both Si and W. In the Dutch scenario spreading of the sludge is not allowed, and there is no release to the soil. W and Si mainly ends up in the water (ground/river).

5. Technical Annexes

TA1 – Nanomaterial Inventory Excel Spreadsheet Containing Nanomaterial exposure scenarios

Added as a separate entries