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Produced by the NASA Center for Aerospace Information (CASI)
FACILITY SAFETY STUDY

A REPORT FOR NASA
MARSHALL SPACE FLIGHT CENTER

CONTRACT # NAS8-32812

PREPARED BY
INTEGRATED CIRCUIT ENGINEERING CORPORATION
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OCTOBER 1979
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1. BACKGROUND
1. BACKGROUND

Under NASA Contract # NAS8-38812 ICE prepared the following material regarding safety of NASA's in-house microelectronic's facility. This is the FED operation which is located in Huntsville, Alabama. The following material represents the various studies, reports, and recommendations which were requested during the course of the contract.
2. INDUSTRY HEALTH STANDARDS
OCCUPATIONAL HEALTH STANDARDS

I. EMPLOYEE HEALTH MONITORING

Employees with a potential exposure to chemicals or compounds which pose a potential threat to their physical health and well-being shall be physically monitored on a regularly scheduled basis. This program will be administered by the Safety Department and carried out by the Medical Department.

II. MONITORING OF THE WORK ENVIRONMENT

The work environment where these substances are used shall be monitored on a regularly scheduled basis as required by government regulations or by our own schedules whichever are most stringent. Recordkeeping requirements as required by government regulations is the responsibility of the Safety Department.

III. CHEMICALS AND/OR COMPOUNDS WHICH POSE A POTENTIAL THREAT TO PHYSICAL HEALTH AND WELL-BEING

A. Human Carcinogens

1. Arsenic Trioxide
2. Asbestos, All Forms
3. Bis (Chloromethyl) Ether
4. Chromite Ore
5. Nickel Sulfide Roasting Fume & Dust
6. Particulate Polycyclic Aromatic Hydrocarbons
7. 4-Aminodiphenyi (P-Xenylamine)
8. Benzidine
9. Beta-Naphthylamine
10. 4-Nitrodiphynyl
11. Vinyl Chloride

B. Suspected Human Carcinogens

1. Antimony Trioxide
2. Benzene
3. Benz (A) Pyrene
4. Beryllium
5. Cadmium Oxide
6. Chloroform
7. Chromates of Lead and Zinc
8. 3,3' - Dichlorobenzidine
9. Dimethylcarbamyl Chloride
III. (Continued)

B. Suspected Human Carcinogens

10. 1,1 - Dimethyl Hydrazine
11. Dimethyl Sulfate
12. Epichlorhydrin
13. Hexamethyl Phosphoramide
14. Hydrazine
15. MOCA
16. 4,4' - Methylene Dianiline
17. Monomethyl Hydrazine
18. Nitrosamines
19. Propane Sulfone
20. Beta-Propiolactone
21. Thallium
22. Vinyl Cyclohexene Dioxide

C. Heavy Metals

1. Lead
2. Boron Compounds
3. Phosphorus Compounds
4. Chromates
5. Mercury
6. Nickel Compounds

IV. NOTIFICATION OF USE

All operating departments, areas, laboratories, engineering areas, etc. that use or contemplate using any of the substances listed in III above, must report such use or contemplated use to their respective safety departments annually. Discontinued use must also be reported when it occurs. Using departments shall request an Annual Safety Permit in the form of an equipment label on a calendar year basis.

V. APPROVAL TO PURCHASE

Except for process chemicals approved for routine use and purchased in bulk, all other purchases of the substances listed in III above, shall be approved by the respective safety department to assure proper practice before purchase and delivery.
### OPERATOR MEDICAL CHECKS*

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>NATIONAL</th>
<th>INTERSIL</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic Trioxide</td>
<td>30 days</td>
<td>45 days</td>
<td>90 days</td>
<td>60 days</td>
</tr>
<tr>
<td>TCE (111 Trichloroethane)</td>
<td>30 days</td>
<td>45 days</td>
<td>-</td>
<td>60 days</td>
</tr>
<tr>
<td>Acetone</td>
<td>30 days</td>
<td>45 days</td>
<td>-</td>
<td>60 days</td>
</tr>
<tr>
<td>Diborane</td>
<td>30 days</td>
<td>45 days</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phosphene</td>
<td>30 days</td>
<td>45 days</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Arsene</td>
<td>30 days</td>
<td>45 days</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Blood Test and Exam
3. FACILITY EMISSION CONTROL REQUIREMENTS
FED
EMISSION CONTROL REQUIREMENTS

A SPECIAL TASK STUDY
For
NASA

By
INTEGRATED CIRCUIT ENGINEERING CORPORATION
SCOTTSDALE, ARIZONA
JUNE 1978
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1.

BACKGROUND
1. **BACKGROUND**

The following is an initial report on the emission control requirements for the FED operation, which is located at the NASA facility in Huntsville, Alabama. This work was requested by Mr. Ralph Grubb, and is part of Contract No. NAS8-32812. This study and initial report involves the determination of the safety of the present exhaust gas system of the laboratory, and other equipment would be required to meet acceptable industry and OSHA standards. The following report presents the detailed calculations and ICE's recommendations.

To provide more flexibility in the use of the data, the laboratory was divided into four sections, as shown on the attached chart. Calculations for each section were made individually, in addition calculations are made on the combined results to allow for any unique chemical combinations which might occur during exhaust gas mixing. These areas are as follows:

(a) Diffusion and CVD  
(b) Etch Stations (Chemical Hoods)  
(c) Photoresist  
(d) Epi

The specific assumptions and backgrounds are given under each section.
2.
SUMMARY
2. SUMMARY

Based upon the chemical and air-flow data, as supplied by NASA, the present exhaust system, which includes the CVD/diffusion, etch stations, and photoresist operations, will exceed OSHA limits for three different materials and be near the OSHA limit for one other, as shown in Figure 2.

Calculations were based both on normal operations and worst case conditions. As shown in Figure 3, under worst case conditions the hydrochloric acid from the CVD/diffusion area will exceed OSHA limits. Under normal operations the acetone and trichlorethylene from the etch station area will exceed OSHA limits. Thus, ICE would recommend the insulation of a gas scrubber to handle this exhaust system. This facility would then be compatible, with semiconductor practices with regard to safety and pollution control.

When the individual operations are considered with their normal exhaust gas flow, other chemicals also will exceed the OSHA limits in those branch lines. Figure 4 indicates that the exhaust, directly from the CVD/diffusion area at 900 cubic feet per minute (25 m³/min), will exceed OSHA limits for hydrogen chloride, ammonium chloride, and diborane. It should be noted however, that this will be further diluted in the total exhaust system, and the ammonium chloride and diborane will fall within safe limits. Figure 5 shows that the exhaust directly from the etch facility also exceeds OSHA limits for acetone and TCE. The exhaust from the photoresist area of approximately 1280 cubic feet per minute (36 m³/min), is sufficient and none of the chemicals will exceed OSHA limits.

Figure 6 is a summary of the total combined reacted exhaust from the system.

The epitaxial area was treated separately because it did have a separate exhaust system. Figure 7 shows that six chemicals in the epitaxial area will exceed OSHA limits. These are ammonia, hydrogen chloride, nitrous oxide, diborane, phosphine, and arsine. This confirms the requirement of the scrubber for that system which has already been ordered and is now being installed. Additional studies also show that the epitaxial exhaust will need a hydrogen burn-off.
CRITICAL MATERIALS

1. OVER OSHA LIMITS
   (a) HYDROCHLORIC ACID
   (b) ACETONE
   (c) TRICHLOROETHYLENE

2. NEAR OSHA LIMITS
   (a) SULFURIC ACID
3
ASSUMPTIONS
## Figure 3

### Critical Areas

**Total Facility (Etch, Photoresist, CVD/Diffusion)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Normal Operation</th>
<th>Worse Case Operation</th>
<th>OSHA Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Hydrochloric Acid</td>
<td>3.89</td>
<td>9.07</td>
<td>7</td>
</tr>
<tr>
<td>2. Acetone</td>
<td>2953</td>
<td>-</td>
<td>2400</td>
</tr>
<tr>
<td>3. Trichlorethylene</td>
<td>2338</td>
<td>-</td>
<td>535</td>
</tr>
</tbody>
</table>
### Figure 4

**Critical Areas**

**CVD/Diffusion Emissions, mg/m³**

<table>
<thead>
<tr>
<th>Material</th>
<th>Normal Output</th>
<th>Worse Case* Output</th>
<th>OSHA Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Chloride</td>
<td>28.8</td>
<td>67.2</td>
<td>7</td>
</tr>
<tr>
<td>Ammonium Chloride</td>
<td>7.53</td>
<td>15.1</td>
<td>5</td>
</tr>
<tr>
<td>Diborane</td>
<td>0.101</td>
<td>0.202</td>
<td>0.1</td>
</tr>
</tbody>
</table>
**Figure 5**

**Critical Areas**  
**Etch Facility**

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>NORMAL OPERATION</th>
<th>OSHA LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Acetone</td>
<td>2953</td>
<td>2400</td>
</tr>
<tr>
<td>2. TCE</td>
<td>2338</td>
<td>535</td>
</tr>
</tbody>
</table>
# COMBINED TOTAL EMISSIONS FROM ETCH STATIONS, DIFFUSION AND CVD STATIONS, AND PHOTORESIST STATIONS

## ETCH FACILITY

<table>
<thead>
<tr>
<th>Normal Case</th>
<th>ppm</th>
<th>g/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrofluoric Acid (HF)</td>
<td>0.69</td>
<td>0.79</td>
</tr>
<tr>
<td>Hydrochloric Acid (HCl)</td>
<td>0.002</td>
<td>0.004</td>
</tr>
<tr>
<td>Nitric Acid (HNO₃)</td>
<td>0.510</td>
<td>1.74</td>
</tr>
<tr>
<td>Sulfuric Acid (H₂SO₄)</td>
<td>0.055</td>
<td>0.785</td>
</tr>
<tr>
<td>Phosphoric Acid (H₃PO₄)</td>
<td>0.009</td>
<td>0.037</td>
</tr>
<tr>
<td>Acetic Acid (CH₃COOH)</td>
<td>2.8</td>
<td>7.6</td>
</tr>
<tr>
<td>Acetone</td>
<td>1139</td>
<td>2953</td>
</tr>
<tr>
<td>Ethylene</td>
<td>399</td>
<td>2338</td>
</tr>
<tr>
<td>Propanol</td>
<td>45.4</td>
<td>122</td>
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</table>

## DIFFUSION FACILITY

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<th>ppm</th>
<th>g/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrofluoric Acid (HF)</td>
<td>2.39</td>
<td>1054</td>
</tr>
<tr>
<td>Hydrochloric Acid (HCl)</td>
<td>3.89</td>
<td></td>
</tr>
<tr>
<td>Nitric Acid (HNO₃)</td>
<td>5.66</td>
<td></td>
</tr>
<tr>
<td>Sulfuric Acid (H₂SO₄)</td>
<td>5.07</td>
<td></td>
</tr>
<tr>
<td>Phosphoric Acid (H₃PO₄)</td>
<td>2459</td>
<td></td>
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</table>

## PHOTORESIST FACILITY

<table>
<thead>
<tr>
<th>Normal Case</th>
<th>ppm</th>
<th>g/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrofluoric Acid (HF)</td>
<td>0.056</td>
<td>0.044</td>
</tr>
<tr>
<td>Hydrochloric Acid (HCl)</td>
<td>0.020</td>
<td>0.006</td>
</tr>
<tr>
<td>Nitric Acid (HNO₃)</td>
<td>0.06</td>
<td>0.016</td>
</tr>
<tr>
<td>Sulfuric Acid (H₂SO₄)</td>
<td>0.134</td>
<td>0.016</td>
</tr>
<tr>
<td>Phosphoric Acid (H₃PO₄)</td>
<td>31</td>
<td>14.8</td>
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</tbody>
</table>

## TOTAL FACILITY EXHAUST

<table>
<thead>
<tr>
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<th>ppm</th>
<th>g/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrofluoric Acid (HF)</td>
<td>0.69</td>
<td>1.35</td>
</tr>
<tr>
<td>Hydrochloric Acid (HCl)</td>
<td>2.39</td>
<td>2.45</td>
</tr>
<tr>
<td>Nitric Acid (HNO₃)</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Sulfuric Acid (H₂SO₄)</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Phosphoric Acid (H₃PO₄)</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Acetic Acid (CH₃COOH)</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Acetone</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Ethylene</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Propanol</td>
<td>25(Tent)</td>
<td></td>
</tr>
</tbody>
</table>

## OSHA LIMITS

<table>
<thead>
<tr>
<th>ppm</th>
<th>g/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
</tr>
</tbody>
</table>

Problem Areas

- *
**Figure 7**

**Critical Areas**

**Epitaxy Operations**

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>Emissions, mg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Worse Case</td>
</tr>
<tr>
<td>Ammonia</td>
<td>500,000</td>
</tr>
<tr>
<td>Hydrogen Chloride</td>
<td>750,000</td>
</tr>
<tr>
<td>Nitrous Oxide</td>
<td>25,300</td>
</tr>
<tr>
<td>Diborane</td>
<td>1.29</td>
</tr>
<tr>
<td>Phosphine</td>
<td>1.29</td>
</tr>
<tr>
<td>Arsine</td>
<td>1.29</td>
</tr>
</tbody>
</table>
3. ASSUMPTIONS

The conclusions and recommendations of this report are based upon raw data supplied by NASA with regard to typical and maximum gas flows on normal equipment usage. This data has not been confirmed or check by ICE. ICE's calculations are based upon both typical and worse case conditions. Detailed assumptions as to gas flow and usage are given in the individual sections.
4

DIFFUSION
AND
CVD
4. **CVD AND DIFFUSION**

Because of the venting arrangements these two operations were considered as one group, in terms of exhaust gas requirements. Included in this group are the diffusion furnaces consisting of six tubes, and the CVD system consisting of two chambers. The basic assumptions are given in Figure 8. It is assumed that the total vent flow from this area is 25.5 cubic meters per minute. Normal operation assumes that one tube is operating for each type of dopant. Worst case conditions assumes two tubes. Normal conditions for HCl cleaning assumes two tubes. The worst case condition assumes all six tubes. For the CVD operation the normal operation assumes that one chamber is operating. The worst case condition assumes both chambers. The various chemicals used for both systems is listed in the following calculations. Figure 9 is the summary of the chemical outputs from this particular system. It should be noted that OSHA limits are exceeded at the output of this system for hydrogen chloride, ammoniumchloride, and diborane, however the OSHA limits are exceeded only for hydrogen chloride when this system is fully diluted at the exhaust output.

During the inspection of this facility it was noted that the output of the CVD reactor was not protected with ventilation or a hood. If the glass chamber would break, during the reactor operation the chemicals could quickly disperse into the room. It is, thus, recommended that that end of the CVD reactor be included in a vent or hood arrangement.
FIGURE 8

DIFFUSION OPERATION ASSUMPTIONS

2 Tubes Phosphine, 1% PH₃ in Argon (Nitrogen)
87cc/min Diluted with 11.2 l/min of Inert Gas

2 Tubes Diborane, 0.1% B₂H₆ in argon (Nitrogen)
87cc/Min Diluted with 5 l/min of Inert Gas

2 Oxidation Tubes
HCl Gas for Tube Cleaning - 15% in O₂ 99.999% HCl
HCl Gas Flow is 500 cc/min
Assume Normal 2, maximum of 6 tubes cleaned at one time.

Total Vent Flow 25.5 m³/min - No Dilution with CVD
Average Clean 300cc/min

Final Dilution with Total Exhaust
\[
\frac{25.5 \text{ m}^3/\text{min}}{188.7 \text{ m}^3/\text{min}} = .135 \text{ Diffusion and CVD Dilution Factor}
\]
## CVD and Diffusion Operation Emissions

<table>
<thead>
<tr>
<th>Substance (NH₃)</th>
<th>CVD Operation</th>
<th>Diffusion Operation</th>
<th>Gross Unreacted Total Output</th>
<th>Net Combined Output</th>
<th>Net Output with Total Exhaust Dilution</th>
<th>OSHA Problem Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm, Normal Case</td>
<td>3.14</td>
<td>3.14</td>
<td>3.14</td>
<td>3.14</td>
<td>.424</td>
<td>0</td>
</tr>
<tr>
<td>ppm, Worst Case</td>
<td>6.28</td>
<td>6.28</td>
<td>6.28</td>
<td>6.28</td>
<td>.948</td>
<td>0</td>
</tr>
<tr>
<td>mg/m³, Normal Case</td>
<td>2.39</td>
<td>2.39</td>
<td>2.39</td>
<td>2.39</td>
<td>.323</td>
<td>0</td>
</tr>
<tr>
<td>mg/m³, Worst Case</td>
<td>4.78</td>
<td>4.78</td>
<td>4.78</td>
<td>4.78</td>
<td>.645</td>
<td>0</td>
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<td>g/day, Normal Case</td>
<td>87.8</td>
<td>87.8</td>
<td>87.8</td>
<td>176</td>
<td>176</td>
<td>0</td>
</tr>
<tr>
<td>g/day, Worst Case</td>
<td>176</td>
<td>176</td>
<td>176</td>
<td>176</td>
<td>176</td>
<td>0</td>
</tr>
</tbody>
</table>

### Hydrogen Chloride

<table>
<thead>
<tr>
<th>Substance (HCl)</th>
<th>Run</th>
<th>Clean</th>
<th>Run</th>
<th>Clean</th>
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</thead>
<tbody>
<tr>
<td>ppm, Normal Case</td>
<td>3.14</td>
<td>11.8</td>
<td>3.14</td>
<td>17.7</td>
</tr>
<tr>
<td>ppm, Worst Case</td>
<td>6.40</td>
<td>20.5</td>
<td>6.40</td>
<td>18.6</td>
</tr>
<tr>
<td>mg/m³, Normal Case</td>
<td>9.1</td>
<td>19.2</td>
<td>9.1</td>
<td>20.3</td>
</tr>
<tr>
<td>mg/m³, Worst Case</td>
<td>10.2</td>
<td>35.4</td>
<td>10.2</td>
<td>37.3</td>
</tr>
<tr>
<td>g/day, Normal Case</td>
<td>167</td>
<td>603</td>
<td>167</td>
<td>603</td>
</tr>
<tr>
<td>g/day, Worst Case</td>
<td>374</td>
<td>1406</td>
<td>374</td>
<td>1406</td>
</tr>
</tbody>
</table>

### Ammonium Chloride

<table>
<thead>
<tr>
<th>Substance (NH₄Cl)</th>
<th>ppm, Normal Case</th>
<th>ppm, Worst Case</th>
<th>mg/m³, Normal Case</th>
<th>mg/m³, Worst Case</th>
<th>g/day, Normal Case</th>
<th>g/day, Worst Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm, Normal Case</td>
<td>3.92</td>
<td>7.65</td>
<td>7.65</td>
<td>7.65</td>
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<td>0</td>
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<td>ppm, Worst Case</td>
<td>0</td>
<td>6.62</td>
<td>6.62</td>
<td>6.62</td>
<td>0</td>
<td>0</td>
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<tr>
<td>mg/m³, Normal Case</td>
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<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
<td>0</td>
<td>0</td>
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<tr>
<td>mg/m³, Worst Case</td>
<td>0</td>
<td>276</td>
<td>276</td>
<td>276</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>g/day, Normal Case</td>
<td>1053</td>
<td>1406</td>
<td>1053</td>
<td>1406</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>g/day, Worst Case</td>
<td>374</td>
<td>554</td>
<td>374</td>
<td>554</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Nitrous Oxide (N₂O)

<table>
<thead>
<tr>
<th>Substance (N₂O)</th>
<th>ppm, Normal Case</th>
<th>ppm, Worst Case</th>
<th>mg/m³, Normal Case</th>
<th>mg/m³, Worst Case</th>
<th>g/day, Normal Case</th>
<th>g/day, Worst Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm, Normal Case</td>
<td>3.92</td>
<td>7.65</td>
<td>7.65</td>
<td>7.65</td>
<td>0</td>
<td>0</td>
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<tr>
<td>ppm, Worst Case</td>
<td>0</td>
<td>6.62</td>
<td>6.62</td>
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<tr>
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<td>15.1</td>
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<tr>
<td>mg/m³, Worst Case</td>
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<td>276</td>
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<td>g/day, Normal Case</td>
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<tr>
<td>g/day, Worst Case</td>
<td>374</td>
<td>554</td>
<td>374</td>
<td>554</td>
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### Dibromine (Br₂)

<table>
<thead>
<tr>
<th>Substance (Br₂)</th>
<th>ppm, Normal Case</th>
<th>ppm, Worst Case</th>
<th>mg/m³, Normal Case</th>
<th>mg/m³, Worst Case</th>
<th>g/day, Normal Case</th>
<th>g/day, Worst Case</th>
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</thead>
<tbody>
<tr>
<td>ppm, Normal Case</td>
<td>0.078</td>
<td>0.097</td>
<td>0.097</td>
<td>0.097</td>
<td>0.011</td>
<td>0.011</td>
</tr>
<tr>
<td>ppm, Worst Case</td>
<td>0.156</td>
<td>0.238</td>
<td>0.238</td>
<td>0.238</td>
<td>0.021</td>
<td>0.021</td>
</tr>
<tr>
<td>mg/m³, Normal Case</td>
<td>0.004</td>
<td>0.008</td>
<td>0.008</td>
<td>0.008</td>
<td>0.003</td>
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<tr>
<td>mg/m³, Worst Case</td>
<td>0.414</td>
<td>0.414</td>
<td>0.414</td>
<td>0.414</td>
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<td>279</td>
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### Phosphine (PH₃)

<table>
<thead>
<tr>
<th>Substance (PH₃)</th>
<th>ppm, Normal Case</th>
<th>ppm, Worst Case</th>
<th>mg/m³, Normal Case</th>
<th>mg/m³, Worst Case</th>
<th>g/day, Normal Case</th>
<th>g/day, Worst Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm, Normal Case</td>
<td>0.078</td>
<td>0.156</td>
<td>0.156</td>
<td>0.156</td>
<td>0.011</td>
<td>0.011</td>
</tr>
<tr>
<td>ppm, Worst Case</td>
<td>0.034</td>
<td>0.068</td>
<td>0.068</td>
<td>0.068</td>
<td>0.021</td>
<td>0.021</td>
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<tr>
<td>mg/m³, Normal Case</td>
<td>0.002</td>
<td>0.004</td>
<td>0.004</td>
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<td>0.003</td>
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<tr>
<td>mg/m³, Worst Case</td>
<td>0.194</td>
<td>0.382</td>
<td>0.382</td>
<td>0.382</td>
<td>0.026</td>
<td>0.026</td>
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<tr>
<td>g/day, Normal Case</td>
<td>171</td>
<td>173</td>
<td>173</td>
<td>173</td>
<td>173</td>
<td>173</td>
</tr>
<tr>
<td>g/day, Worst Case</td>
<td>343</td>
<td>347</td>
<td>347</td>
<td>347</td>
<td>347</td>
<td>347</td>
</tr>
</tbody>
</table>
DIFFUSION OPERATION CALCULATIONS

PHOSPHINE DOPANT GAS

Assume 1 tube with 1% PH₃ (in argon or nitrogen) at 87 cc/min diluted with 11.2 l/min of (argon or nitrogen). Assume worst case of 2 tubes run continuously for 24 hr/day with no dilute gas:

\[
\frac{87 \text{ cc/min} \times 0.01}{22.4 \text{ l/mol}} \times 34 \text{ g/mol} = 0.00132 \text{ g/min PH}_3 = 1.32 \text{ mg/min PH}_3
\]

One Tube in Operation

\[
\frac{1.32 \text{ mg/min}}{900 \text{ cfm} \times 0.0283 \text{ m}^3/\text{cf}} = 0.052 \text{ mg/m}^3 \text{ PH}_3 \text{ in Total Exhaust}
\]

Two Tubes in Operation

\[
0.052 \times 2 = 0.104 \text{ mg/m}^3 \text{ PH}_3 \text{ in Total Exhaust}
\]

OSHA Limit is 0.4 mg/m³

Total Daily Maximum Emission:

\[
1.32 \text{ mg/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 1.9 \text{ g/day PH}_3 \text{ One Tube}
\]

Two Tubes = 3.8 g/day PH₃

With Total Exhaust Dilution

Normal Case

\[
0.052 \text{ mg/m}^3 \times 0.135 = 0.007 \text{ mg/m}^3 \text{ PH}_3
\]

Worst Case

\[
0.104 \text{ mg/m}^3 \times 0.135 = 0.014 \text{ mg/m}^3 \text{ PH}_3
\]
DIFFUSION OPERATION

PHOSPHINE GAS

Assume normal operations of 1 tube and maximum of 2 tubes operates at one time with 87cc/min of 1% PH₃ (in argon or nitrogen) diluted with 11.2 l/M of argon or nitrogen

**Normal Case**

\[
\text{87cc/min x .01 = .87 cc/min PH}_3
\]

\[
\frac{.87 \text{ cc/min}}{(900 \text{ CFM} + 11.2 \text{ l/M}) \times 28317 \text{ cc/cf}} = .034 \text{ ppm PH}_3 \text{ Gas}
\]

**Worst Case** of 2 Tubes = .068 ppm PH₃ Gas

OSHA Limit is 0.3 ppm

**With Total Exhaust Dilution**

**Normal Case**

\[
.034 \text{ ppm x .135 = .005 ppm PH}_3
\]

**Worst Case**

\[
.068 \text{ ppm x .135 = .009 ppm PH}_3
\]
DIFFUSION OPERATION

DIBORANE DOPANT GAS

Assume 1 tube with 0.1% $\text{B}_2\text{H}_6$ (in argon or nitrogen) at 87 cc/min 5 l/min of argon or nitrogen. Assume worst case of 2 tubes run continuously for 24 hr/day with no dilute gas:

$$87 \text{ cc/min} \times .001 = .087 \text{ cc/min B}_2\text{H}_6$$

$$\frac{.000087 \text{ l} \times 27.67 \text{ g/mol}}{22.4 \text{ l/mol}} = .00010 \text{ g/min B}_2\text{H}_6 = .10 \text{ mg/min B}_2\text{H}_6$$

One Tube

$$\frac{.10 \text{ mg/min}}{900 \text{ CFM} \times .0283 \text{ m}^3/\text{cf}} = .0039 \text{ mg/m}^3 \text{ B}_2\text{H}_6$$

Two Tubes

$$\frac{.0039 \text{ mg/m}^3 \times 2}{.0078 \text{ mg/m}^3 \text{ B}_2\text{H}_6 \text{ in Total Exhaust}}$$

OSHA Limit is 0.1 mg/m$^3$

Total Daily Maximum Emission

$$\frac{.10 \text{ mg/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day}}{.0078 \text{ mg/m}^3 \text{ B}_2\text{H}_6 \text{ in Total Exhaust}} = 0.14 \text{ g/day B}_2\text{H}_6$$

Two Tubes = 0.28 g/day $\text{B}_2\text{H}_6$

With Total Exhaust Dilution

Normal Case

$$\frac{.0039 \text{ mg/m}^3 \times .135}{.0005 \text{ mg/m}^3 \text{ B}_2\text{H}_6}$$

Worst Case

$$\frac{.0078 \text{ mg/m}^3 \times .135}{.0010 \text{ mg/m}^3 \text{ B}_2\text{H}_6}$$
DIFFUSION OPERATION

DIBORANE GAS

Assume normal operation of 1 tube and maximum of 2 tubes operated at one time with 87 cc/min of 0.1% $B_2H_6$ (in argon or nitrogen) diluted with 5 l/min of argon or nitrogen.

Normal Case

\[
\frac{87 \text{ cc/min} \times 0.001 = 0.087 \text{ cc/min } B_2H_6}{(900 \text{ CFM + 5 l/min}) \times 28317 \text{ cc/l} = 0.0034 \text{ ppm } B_2H_6}
\]

Worst Case of 2 Tubes = 0.0068 ppm $B_2H_6$

OSHA Limit is 0.1 ppm

With Total Exhaust Dilution

Normal Case

\[
0.0034 \text{ ppm } \times 0.135 = 0.0005 \text{ ppm } B_2H_6
\]

Worst Case

\[
0.0068 \text{ ppm } \times 0.135 = 0.0009 \text{ ppm } B_2H_6
\]
DIFFUSION OPERATION

HCl TUBE CLEANING

Assume normal operations of 2 tubes or maximum of 6 tubes cleaned at one time using 15% HCl in O2 at gas flow of 500 cc/min/tube for 24 hr/day

Two Tubes (Normal)

500 cc/min x 2 x .15 = 150 cc/min HCl

\[ \frac{.150 \text{ mol}}{22.4 \text{ mol/L}} \times 36.46 \text{ g/mol} = .244 \text{ g/min} = 244 \text{ mg/min HCl} \]

\[ \frac{244 \text{ mg/min}}{900 \text{ CFM} \times .0283} = 9.59 \text{ mg/m}^3 \text{ HCl} \]

OSHA Limit is 7 mg/m³

Total Daily Maximum Emission

244 mg/min x 60 min/hr x 24 hr/day = 351 g/day HCl

Six Tubes (Maximum)

9.59 mg/m³ x 3 = 28.8 mg/m³ HCl

OSHA Limit is 7 mg/m³ HCl

Total Daily Maximum Emission

351 g/day x 3 = 1.053 kg/day

With Total Exhaust Dilution

Normal Case

9.59 mg/m³ x .135 = 1.29 mg/m³ HCl

Worst Case

28.8 mg/m³ x .135 = 3.88 mg/m³ HCl
DIFFUSION OPERATION

HCl TUBE CLEANING

Assume normal operations of 2 tubes or maximum of 6 tubes cleaned at one time using gas flow of 500 cc/min/tube of 15% HCl in O₂

Normal Case 2 Tubes

\[
\frac{500 \text{ cc} \times 2 \times 0.15}{900 \text{ cfm}} = \frac{150 \text{ cc/min}}{28317 \text{ cc/cf}} = 5.89 \text{ ppm HCl}
\]

Worst Case 6 Tubes = 17.7 ppm HCl Gas

OSHA Limit is 5 ppm

With Total Exhaust Dilution

Normal Case

\[
5.89 \text{ ppm} \times 0.135 = 0.796 \text{ ppm HCl}
\]

Worst Case

\[
17.66 \text{ ppm} \times 0.135 = 1.59 \text{ ppm HCl}
\]
CVD OPERATION

Ammonia, NH$_3$

Flow: 80 cc/min
Concentration: 100%

HCl Hydrogen Chloride

Flow: 300 cc/min in clean cycle
Concentration: 99.99%

Dichlorosilane, SiH$_2$Cl$_2$

Flow: 40 cc/min Vapor Product
Concentration: 100%

Nitrous Oxide, N$_2$O

Flow: 100 cc/min
Concentration: 100%

Diborane, B$_2$H$_6$

Flow: 100 cc/min
Concentration: 10% in Argon

Phosphine, PH$_3$

Flow: 20 cc/min
Concentration: 10% in Argon
CVD Vent Flow = 25.5 m$^3$/min

Final Dilution with Total Exhaust

\[
\frac{25.5 \text{ m}^3/\text{min}}{188.7 \text{ m}^3/\text{min}} = 0.135
\]
CVD OPERATION

DICHLOROSILANE GAS

Assume 40 cc/min of 100% SiH₂Cl₂ in one chamber.

\[
\text{SiH}_2\text{Cl}_2 + \text{Si} + 2\text{HCl}
\]

40 cc/min \(\text{SiH}_2\text{Cl}_2\) \(
\rightarrow
\)
80 cc/min HCl

\[
\frac{80 \text{ cc/min}}{900 \text{ cfm } \times 28317 \text{ cc/ft}^3} = 0.314 \text{ ppm HCl}
\]

Worst Case 2 Chambers = 6.28 ppm HCl

OSHA Limit is 5 ppm

With Total Exhaust Dilution

Normal Case

3.14 ppm \times 0.135 = 0.424 ppm HCl

Worst Case

6.28 ppm \times 0.135 = 0.848 ppm HCl

PHOSPHINE GAS

Assume 20 cc/min of 10% PH₃ in argon in one chamber

20 cc/min \times 0.1 = 2 cc/min PH₃

\[
\frac{2 \text{ cc/min}}{900 \text{ cfm } \times 28317 \text{ cc/ft}^3} = 0.078 \text{ ppm PH₃}
\]

Worst Case 2 Chambers = 0.156 ppm PH₃

OSHA Limit is 0.3 ppm

With Total Exhaust Dilution

Normal Case

0.078 ppm \times 0.135 = 0.011 ppm PH₃

Worst Case

0.156 ppm \times 0.135 = 0.021 ppm PH₃
C V D OPERATION

PHOSPHINE GAS
Assume 20 cc/min of 10% PH₃ in argon in one chamber.

\[
\frac{0.002 \text{ L/min}}{22.4 \text{ L/mol}} \times 34 \text{ g/mol} = 0.00304 \text{ g/min PH}_3 = 3.04 \text{ mg/min PH}_3
\]

One Chamber Operation

\[
\frac{3.04 \text{ mg/min}}{900 \text{ cfm} \times 0.0283 \text{ m}^3/\text{cf}} = 0.119 \text{ mg/m}^3 \text{ PH}_3 \text{ in Total Exhaust}
\]

Two Chamber Operation

0.119 mg/m³ x 2 = 0.238 mg/m³ PH₃

2 Chamber = 342.7 mg/day

With Total Exhaust Dilution

Normal Case

0.119 mg/m³ x 0.135 = 0.016 mg/m³ PH₃

Worst Case

0.238 mg/m³ x 0.135 = 0.032 mg/m³ PH₃
C V D OPERATION

DIBORANE GAS
Assume 20 cc/min of 10% B₂H₆ in argon in one chamber.

\[
\frac{2 \text{ cc/min}}{900 \text{ cfm} \times 28317 \text{ cc/ft}^3} = 0.078 \text{ ppm B}_2\text{H}_6 \text{ Gas}
\]

Worst Case: 2 Chambers = 0.156 ppm B₂H₆

OSHA Limit is 0.10 ppm

With Total Exhaust Dilution

Normal Case

\[
0.078 \text{ ppm} \times 0.135 = 0.0105 \text{ ppm B}_2\text{H}_6
\]

Worst Case

\[
0.156 \text{ ppm} \times 0.135 = 0.021 \text{ ppm B}_2\text{H}_6
\]

NITROUS OXIDE GAS
Assume 100 cc/min of 100 N₂O gas in one chamber.

\[
\frac{100}{900 \text{ cfm} \times 28317} = 3.92 \text{ ppm N}_2\text{O}
\]

Worst Case: 2 Chambers = 7.85 ppm

OSHA Limit is 25 ppm (Proposed)

With Total Exhaust Dilution

Normal Case

\[
3.92 \text{ ppm} \times 0.135 = 0.529 \text{ ppm N}_2\text{O}
\]

Worst Case

\[
7.85 \text{ ppm} \times 0.135 = 1.06 \text{ ppm N}_2\text{O}
\]
AMMONIA GAS

Assume 80 cc/min of 100% NH₃ gas in one chamber.

\[
\frac{80 \text{ cc/min}}{900 \text{ cfm} \times 28317 \text{ cc/cf}} = 7.14 \text{ ppm NH}_3
\]

Worst Case 2 Chambers = 6.28 ppm NH₃

OSHA Limit is 50 ppm

With Total Exhaust Dilution

Normal Case

\[11.77 \text{ ppm} \times .135 = 1.59 \text{ ppm HCl}\]

Worst Case

\[23.54 \text{ ppm} \times .135 = 3.18 \text{ ppm HCl}\]

HYDROGEN CHLORIDE GAS

Assume 300 cc/min of 99.99% HCl Gas in one Chamber.

\[
\frac{300 \text{ cc/min}}{900 \text{ cfm} \times 28317 \text{ cc/cf}} = 11.8 \text{ ppm HCl}
\]

Worst Case 2 Chambers = 23.5 ppm HCl

OSHA Limit is 5 ppm

With Total Exhaust Dilution

Normal Case

\[3.14 \text{ ppm} \times .135 = .424 \text{ ppm NH}_3\]

Worst Case

\[6.28 \text{ ppm} \times .135 = .848 \text{ ppm NH}_3\]
C V D OPERATION

N$_2$O GAS

Assume 100 cc/min of 100% N$_2$O gas in one chamber.

\[
\frac{100 \text{ L/min}}{22.4 \text{ L/mol}} \times 44.01 \text{ g/mol} = 1.96 \text{ g/min} = 196 \text{ mg/min} \text{ N}_2\text{O}
\]

\[
\frac{196 \text{ mg/min}}{900 \text{ cfm} \times 0.0283 \text{ m}^3/\text{cf}} = 7.7 \text{ mg/m}^3 \text{ N}_2\text{O}
\]

Worst Case 2 chambers 15.4 mg/m$^3$

OSHA Limit is 25 PPM (Proposed)

Total Daily Emission with Continuous Flow.

\[
196 \text{ mg/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 282 \text{ g/day}
\]

Worst Case 2 chambers 564 g/day

With Total Exhaust Dilution

Normal Case

\[
7.7 \text{ mg/m}^3 \times 0.135 = 1.04 \text{ mg/m}^3 \text{ N}_2\text{O}
\]

Worst Case

\[
15.4 \text{ mg/m}^3 \times 0.135 = 2.08 \text{ mg/m}^3 \text{ N}_2\text{O}
\]
CVD OPERATION

DIBORANE GAS

Assume 20 cc/min of 10% B\textsubscript{2}H\textsubscript{6} in argon in one chamber.

\[ 20 \text{ cc/min} \times 0.1 = 2 \text{ cc/min B}_{2}\text{H}_{6} \]

One Chamber Operation

\[ \frac{0.002 \text{l/min}}{22.4 \text{l/mol}} \times 27.67 \text{ g/mol} = 0.00247 \text{ g/min B}_{2}\text{H}_{6} = 2.47 \text{ mg/min B}_{2}\text{H}_{6} \]

\[ \frac{2.47 \text{ mg/min}}{900 \text{ cfm} \times 0.0283 \text{ m}^3/\text{cf}^2} = 0.097 \text{ mg/m}^3 \text{ B}_{2}\text{H}_{6} \text{ in Total Exhaust} \]

Two Chamber Operation

\[ 0.097 \text{ mg/m}^3 \times 2 = 0.194 \text{ mg/m}^3 \text{ B}_{2}\text{H}_{6} \]

Total Daily Maximum Emission

\[ 0.097 \text{ mg/m}^3 \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 139.7 \text{ mg/day} \]

2 Chamber = 279.4 mg/day

With Total Exhaust Dilution

Normal Case

\[ 0.097 \text{ mg/m}^3 \times 0.135 = 0.013 \text{ mg/m}^3 \text{ B}_{2}\text{H}_{6} \]

Worst Case

\[ 0.194 \text{ mg/m}^3 \times 0.135 = 0.026 \text{ mg/m}^3 \text{ B}_{2}\text{H}_{6} \]
CVD OPERATION

DICHLOROSILANE GAS

Assume 40 cc/min flow of 100% gas.

\[ \frac{0.040 \text{ l/min}}{22.4 \text{ l/mol}} \times 101.01 \text{ g/mol} = 0.180 \text{ g/min} = 180 \text{ mg/min SiH}_2\text{Cl}_2 \]

\[ \text{SiH}_2\text{Cl}_2 \rightarrow \text{Si} + 2\text{HCl} \]

\[ 180 \text{ mg/min} \times \frac{72.92 \text{ g}}{101.01 \text{ g}} = 129.9 \text{ mg/min HCl} \]

40 cc/min SiH\textsubscript{2}Cl\textsubscript{2} → 80 cc/min HCl

In One Chamber

\[ \frac{129.9 \text{ mg/min}}{900 \text{ cfm}} \times 0.0283 \text{ m}^3/\text{cf} = 5.1 \text{ mg/m}^3 \text{ HCl} \]

Worst Case = 2 chambers = 10.2 mg/m\textsuperscript{3} of HCl

OSHA Limit is 7 mg/m\textsuperscript{3}

Total Daily Emission with Continuous Flow

\[ 129.9 \text{ mg/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 187 \text{ g/day} \]

Worst Case = 2 chambers = 374 g/day HCl

With Total Exhaust Dilution

Normal Case

\[ 5.1 \text{ mg/m}^3 \times 0.135 = 0.689 \text{ mg/m}^3 \text{ HCl} \]

Worst Case

\[ 10.2 \text{ mg/m}^3 \times 0.135 = 1.38 \text{ mg/m}^3 \text{ HCl} \]
CV&D OPERATION

NH₃ Gas

Assume 80 cc/min of 100% NH₃ Gas.

\[
\frac{0.080}{22.4} \text{ l/min} \times 17.03 \text{ g/mol} = 0.061 \text{ g/min} = 61 \text{ mg/min NH}_3
\]

In One Chamber

\[
\frac{61 \text{ mg/min}}{900 \text{ cfm} \times 0.0283 \text{ m}^3/\text{cfm}} = 2.39 \text{ mg/m}^3 \text{ NH}_3
\]

Worst Case = 2 Chambers = 4.78 mg/m³ NH₃

OSHA Limit is 35 mg/m³

Total Daily Emission with Continuous Flow.

61 mg/min x 60 min/hr x 24 hr/day = 87.8 g/day

Worst Case = 2 Chambers = 175.7 g/day

With Total Exhaust Dilution

Normal Case

2.39 mg/m³ x 0.135 = 0.323 mg/m³ NH₃

Worst Case

4.78 mg/m³ x 0.135 = 0.645 mg/m³ NH₃
C V D OPERATION

HCl GAS IN CLEAN CYCLE

Assume 300 cc/min of 99.99% HCl Gas.

\[
\text{\( \frac{300 \text{ l/min}}{22.4 \text{ l/mol}} \times 36.46 \text{ g/mol} = 0.488 \text{ g} = 488 \text{ mg/min HCl} \)}
\]

One Chamber

\[
\text{\( \frac{488 \text{ mg/min}}{900 \text{ cfm} \times 0.0283 \text{ m}^3/\text{cf} = 19.2 \text{ mg/m}^3 \text{ HCl} \)}
\]

Worst Case = 2 Chambers = 38.4 mg/m³ HCl

OSHA Limit is 7 mg/m³

Total Daily Emission with Continuous Flow.

\[
488 \text{ mg/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 703 \text{ g/day}
\]

Worst Case = 2 Chambers = 1.4 kg/day

With Total Exhaust Dilution

Normal Case

\[
9.2 \text{ mg/m}^3 \times 0.135 = 1.24 \text{ mg/m}^3 \text{ HCl}
\]

Worst Case

\[
18.4 \text{ mg/m}^3 \times 0.135 = 2.48 \text{ mg/m}^3 \text{ HCl}
\]
NH₄Cl REACTION PRODUCT

NH₃ + HCl → NH₄Cl

\[
\begin{align*}
\text{NH}_3 + \text{HCl} & \rightarrow \text{NH}_4\text{Cl} \\
276,000 \text{ mg/day} & \quad \frac{60 \text{ min/hr} \times 24 \text{ hr/day} \times 900 \text{ cfm} \times 0.0283 \text{ m}^3/\text{cf}} = 7.53 \text{ mg/m}^3 \text{ NH}_4\text{Cl} \\
554,000 \text{ mg/day} & \quad \frac{60 \text{ min/hr} \times 24 \text{ hr/day} \times 900 \text{ cfm} \times 0.0283 \text{ m}^3/\text{cf}} = 15.1 \text{ mg/m}^3 \text{ NH}_4\text{Cl} \\
276 \text{ g/day} & \quad \frac{53.49 \text{ g/mol}}{22.4 \text{ l/mol}} = 115.6 \text{ l/day NH}_4\text{Cl} \\
115,600 \text{ cc/day} & \quad \frac{60 \text{ min/hr} \times 24 \text{ hr/day} \times 900 \text{ cfm} \times 28317 \text{ cc/ cf}} = 3.15 \text{ ppm NH}_4\text{Cl} \\
554 \text{ g/day} & \quad \frac{53.49 \text{ g/mol}}{22.4 \text{ l/mol}} = 231/9 \text{ l/day NH}_4\text{Cl} \\
231,000 \text{ cc/day} & \quad \frac{60 \text{ min/hr} \times 24 \text{ hr/day} \times 900 \text{ cfm} \times 28317 \text{ cc/ cf}} = 6.32 \text{ ppm NH}_4\text{Cl} \\
\end{align*}
\]

With Total Exhaust Dilution

Normal Case

\[
\begin{align*}
7.53 \text{ mg/m}^3 & \times 0.135 = 1.02 \text{ mg/m}^3 \text{ NH}_4\text{Cl} \\
3.15 \text{ ppm} & \times 0.135 = 0.425 \text{ ppm NH}_4\text{Cl}
\end{align*}
\]

Worst Case

\[
\begin{align*}
15.1 \text{ mg/m}^3 & \times 0.135 = 2.04 \text{ mg/m}^3 \text{ NH}_4\text{Cl} \\
6.32 \text{ ppm} & \times 0.135 = 0.853 \text{ ppm NH}_4\text{Cl}
\end{align*}
\]
COMBINED EXHAUST FROM DIFFUSION AND CVD

NORMAL CLEAN CASE

\[
\frac{87.8 \text{ g} \times 36.46 \text{ g}}{17.03} = 188 \text{ g of HCl Need to react with NH}_3 \text{ available}
\]

\[351 \text{ g} - 188 \text{ g} = 163 \text{ g Excess HCl}\]

\[
\frac{188 \text{ g} \times 53.49 \text{ g}}{36.46 \text{ g}} = 276 \text{ g NH}_4\text{Cl Produced}
\]

WORST CLEAN CASE

\[
\frac{176 \text{ g} \times 36.46 \text{ g}}{17.03 \text{ g}} = 377 \text{ g pf HCl Needed}
\]

\[1053 \text{ g} - 377 \text{ g} = 676 \text{ g Excess HCl}\]

\[
\frac{377 \times 53.49 \text{ g}}{36.46 \text{ g}} = 554 \text{ g NH}_4\text{Cl Produced}
\]
5

ETCH STATIONS
COMBINED EXHAUST FROM DIFFUSION AND CVD

REACTION OF HYDROGEN CHLORIDE AND AMMONIA

\[ \text{HCl} + \text{NH}_3 \rightarrow \text{NH}_4\text{Cl} \]

UNREACTED HCl

Normal Case

\[
\frac{163,000 \text{ mg/day}}{60 \text{ min/hr} \times 24 \text{ hr/day} \times 900 \text{ cfm} \times 0.0283 \text{ m}^3/\text{cf} } = 4.44 \text{ mg/m}^3 \text{ HCl}
\]

Worst Case

\[
\frac{676,000 \text{ mg/day}}{60 \text{ min/hr} \times 24 \text{ hr/day} \times 900 \text{ cfm} \times 0.0283 \text{ m}^3/\text{cf} } = 18.4 \text{ mg/m}^3 \text{ HCl}
\]

\[
\frac{163 \text{ g/day}}{36.46 \text{ g/mol} \times 22.4 \text{ l/mol} = 100 \text{ l/day}}
\]

\[
\frac{100,000 \text{ cc/day}}{60 \text{ min/hr} \times 24 \text{ hr/day} \times 900 \text{ cfm} \times 28317 \text{ cc/cf} } = 2.72 \text{ ppm HCl}
\]

\[
\frac{676 \text{ g/day}}{36.46 \text{ g/mol} \times 22.4 \text{ l/mol} = 415 \text{ l/day}}
\]

\[
\frac{415,000 \text{ cc/day}}{60 \text{ min/hr} \times 24 \text{ hr/day} \times 900 \text{ cfm} \times 28317 \text{ cc/cf} } = 11.3 \text{ ppm HCl}
\]

With Total Exhaust Dilution

Normal Case

\[4.44 \text{ mg/m}^3 \times 0.135 = 0.599 \text{ mg/m}^3 \text{ HCl}\]

\[2.72 \text{ ppm} \times 0.135 = 0.367 \text{ ppm HCl}\]

Worst Case

\[18.4 \text{ mg/m}^3 \times 0.135 = 2.48 \text{ mg/m}^3 \text{ HCl}\]

\[11.3 \text{ ppm} \times 0.135 = 1.53 \text{ ppm HCl}\]
5. ETCH STATIONS

The 18 etch stations and the associated vent system was treated as a separate exhaust system, and calculations were made as to maximum emissions of the various chemicals used. Figure 10 shows the basic layout of the etch station and a partial list of the chemicals involved. Figure 11 has a more complete list showing the etch station solution requirements, and the predicted amount of usage. ICE based their calculations upon these values. Figure 12 shows the basic assumptions on vent air flow made for etch stations. Figure 13 is a summary of the total maximum emissions from the etch station facilities. It should be noted that two chemicals, acetone and TCE exceed OSHA limits, and must be treated. The third chemical H_2SO_4 is very close to the OSHA limits and calculations should be made after stations are in operation to determine more accurately the actual values.

It should be noted that it would be possible to substitute for TCE, 111 trichlorethane, which would reduce that particular emission problem. However, the acetone still would exceed the OSHA limits, and scrubbing or some other treatment would still be required.
<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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<tbody>
<tr>
<td>1</td>
<td>Buffer H₂O₄</td>
<td>D.I. H₂O</td>
<td>Jacob Etch</td>
<td>Photo Strip</td>
<td>D.I. H₂O</td>
<td>Aluminum Etch</td>
<td>H₃PO₄</td>
<td>HNO₃</td>
<td>Initial Clean</td>
<td>H₂SO₄</td>
</tr>
<tr>
<td>2</td>
<td>10:1 HF</td>
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<td></td>
<td></td>
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<td></td>
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<table>
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<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
</tr>
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<tbody>
<tr>
<td>11</td>
<td>D.I. H₂O</td>
<td>PRE Metal</td>
<td>D.I. H₂O</td>
<td>PR. Micro Strip</td>
<td>D.I. H₂O</td>
<td>H₃PO₄</td>
<td>BOE 50°C</td>
</tr>
<tr>
<td>12</td>
<td>10:1 H₂O:HF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Si Etch</td>
<td>Alcohol</td>
<td>D.I. H₂O</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>H₂O</td>
<td>KOH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 10**
<table>
<thead>
<tr>
<th>Sta. No.</th>
<th>Etch Station Solution Requirements</th>
<th>Must Be Covered</th>
<th>Requires Mixing Prior To Use</th>
<th>Predicted Amount Of Usage</th>
<th>Required Change Frequency</th>
<th>Used Once &amp; Discarded</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BOE (RT)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H₂O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NH₄F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>BOE (50°C)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>10:1 (H₂O:HF)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Metal Etch</td>
<td>X</td>
<td>X</td>
<td>1-2 times/ process</td>
<td>200 wafers</td>
<td>8 hours</td>
</tr>
<tr>
<td></td>
<td>Aluminum Etch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H₃PO₄-HNO₃-HAC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Silicon Etch</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alcohol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H₂O KOH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Passivation Etch</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Jacobson's Etch</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phosphoric Acid</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>13</td>
<td>Photo Resist Strip (Microstrip)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>7</td>
<td>Sulphuric-Nitric Acid Solution</td>
<td>X</td>
<td>X</td>
<td>2-3 times/ process</td>
<td>1 day</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Acetone</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Trichloroethylene</td>
<td>X</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

HAC, Acetic Acid
KOH, Potassium Hydroxide
H₃PO₄, Phosphoric Acid
NH₄F, Ammonium Floride
HNO₃, Nitric Acid
Alcohol, Isopropyl Alcohol (Propanol)
Assume Each Etch Station has 8cf Vapor Space (2 x 2 x 2 ft.)

\[ 8 \text{ cf} = 0.23 \text{ m}^3 \]

\[ 4500 \text{ cfm} \div 18 \text{ Stations} = 250 \text{ cfm/Station} = 7.08 \text{ m}^3/\text{min/Station} \]

\[ \frac{7.08 \text{ m}^3/\text{min}}{0.23 \text{ m}^3} = 30.8 \text{ m}^3/\text{m}^3/\text{min} \text{ Space Velocity} \]

Assume only 20% of maximum equilibrium concentration results in vent air moving at 30.8 space velocity.

\[ \frac{30.8}{2} = 154 \text{ Hood Dilution Factor (Space velocity and non-equilibrium)} \]

Add Outside Air

\[ \frac{188.7 \text{ m}^3/\text{min}}{127 \text{ m}^3/\text{min}} = 1.5 \text{ Vent Dilution Factor} \]

**Figure 12**
## Total Maximum Emissions from Etch Facility

<table>
<thead>
<tr>
<th></th>
<th>HF</th>
<th>HCl</th>
<th>HNO₃</th>
<th>H₂SO₄</th>
<th>H₃PO₄</th>
<th>CH₃COOH</th>
<th>Acetone</th>
<th>Trichloroethene</th>
<th>Propanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 10:1 HF BRT</td>
<td>0.26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. DI H₂O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Jacobson Etch BRT</td>
<td>0.0002</td>
<td>0.004</td>
<td>0.005</td>
<td>0.13</td>
<td>0.002</td>
<td>0.001</td>
<td></td>
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<tr>
<td>4. P.R. Strip</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>5. DI H₂O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Aluminum Etch BRT</td>
<td>0.005</td>
<td>0.013</td>
<td></td>
<td></td>
<td>0.003</td>
<td>0.160</td>
<td>0.014</td>
<td>0.62</td>
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<tr>
<td>7. H₂SO₄-HNO₃ Clean BRT</td>
<td>0.5</td>
<td>1.60</td>
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<tr>
<td>8. DI H₂O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Acetone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1139</td>
<td>2953</td>
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<td>10. TCE</td>
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<tr>
<td>11. Silicon Etch</td>
<td></td>
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<tr>
<td>12. DI H₂O</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>13. H₃PO₄ BRT</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>0.006</td>
<td>0.025</td>
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<td>14. 10:1 HF BRT</td>
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<tr>
<td>15. DI H₂O</td>
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<tr>
<td>16. P.R. Strip</td>
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<td></td>
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<td></td>
<td>0.02</td>
<td>0.082</td>
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<td>17. DI H₂O</td>
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<td></td>
<td></td>
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<tr>
<td>18. BOE @ 50°C</td>
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<td></td>
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<tr>
<td>TOTAL FACILITY</td>
<td>0.37</td>
<td>0.33</td>
<td>0.0002</td>
<td>0.004</td>
<td>0.010</td>
<td>1.743</td>
<td>0.056</td>
<td>0.765</td>
<td>0.009</td>
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<tr>
<td>OSHA Human Exposure Limits (For 8 Hours)</td>
<td>3.0</td>
<td>2.0</td>
<td>5.0</td>
<td>7.0</td>
<td>2.0</td>
<td>5.0</td>
<td>-</td>
<td>1.0</td>
<td>-</td>
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</table>

*Possible Substitute is 1,1,1-Trichloroethane - OSHA Limit

**EPA**

<table>
<thead>
<tr>
<th>HNO₃ Emissions in mg/m³/hr</th>
<th>Maximum Hourly Average 24 Hourly (From HNO₃ Etching)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.47</td>
<td>0.10</td>
</tr>
</tbody>
</table>
Etch Station No. 1

10:1 HF = 4.9% HF, Estimated Partial Vapor Pressure @ 20°C ≈ .0006 tor

Equilibrium Concentration

\[ \frac{.0006 \text{ tor}}{760 \text{ tor}} \times 20.01 \text{ g/mol} \times 44.64 \frac{\text{mol}}{\text{m}^3} \times 1000 \text{ mg/g} = 54 \text{ mg/m}^3 \]

Maximum Concentration from Station No. 1

\[ \frac{54 \text{ mg/m}^3}{154} = .35 \text{ mg/m}^3 \text{ HF} \]

With Vent Dilution

\[ \frac{.35 \text{ mg/m}^3}{1.5} = .23 \text{ mg/m}^3 \text{ HF} \]

Etch Station No. 2

No Emission

Etch Station No. 3

5% HCl, Estimated Partial Vapor Pressure @ 20°C ≈ .005 tor
10% HNO₃, Estimated Partial Vapor Pressure @ 20°C ≈ .008 tor
3% H₂SO₄, Estimated Partial Vapor Pressure @ 20°C ≈ .0004 tor

HCl Equilibrium Concentration

\[ \frac{.0005 \text{ tor}}{760 \text{ tor}} \times 36.46 \text{ g/mol} \times 44.64 \frac{\text{mol}}{\text{m}^3} \times 1000 \text{ mg/g} = .97 \text{ mg/m}^3 \]

Maximum Concentration from Station No. 3

\[ \frac{.97 \text{ mg/m}^3}{154} = .006 \text{ mg/m}^3 \text{ HCl} \]

With Vent Dilution

\[ \frac{.006 \text{ mg/m}^3}{1.5} = .004 \text{ mg/m}^3 \text{ HCl} \]
\[ \text{HNO}_3 \text{ Equilibrium Concentration} \]
\[ \frac{0.008 \text{ tor}}{760 \text{ tor}} \times 63.01 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 29.5 \text{ mg/m}^3 \]

Maximum Concentration from Station No. 3
\[ \frac{29.5 \text{ mg/m}^3}{154} = 0.19 \text{ mg/m}^3 \text{ HNO}_3 \]

With Vent Dilution
\[ \frac{0.19 \text{ mg/m}^3}{1.5} = 0.13 \text{ mg/m}^3 \text{ HNO}_3 \]

\[ \text{H}_2\text{SO}_4 \text{ Equilibrium Concentration} \]
\[ \frac{0.00004 \text{ tor}}{760 \text{ tor}} \times 98.08 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 0.23 \text{ mg/m}^3 \]

Maximum Concentration from Station No. 3
\[ \frac{0.23 \text{ mg/m}^3}{154} = 0.0015 \text{ mg/m}^3 \text{ H}_2\text{SO}_4 \]

With Vent Dilution
\[ \frac{0.0015 \text{ mg/m}^3}{1.5} = 0.001 \text{ mg/m}^3 \text{ H}_2\text{SO}_4 \]

Etch Station No. 4

Emissions same as Etch Station No. 16

Etch Station No. 5

No Emission
Etch Station No. 6

63% H$_3$PO$_4$, Estimated Partial Vapor Pressure @ 20°C $\approx$ 0.0005 tor
16% CH$_3$COOH, Estimated Partial Vapor Pressure @ 20°C $\approx$ 0.50 tor
2% HNO$_3$, Estimated Partial Vapor Pressure @ 20°C $\approx$ 0.0008 tor

H$_3$PO$_4$ Equilibrium Concentration

$$\frac{0.0005\ \text{tor}}{760\ \text{tor}} \times 98.00 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 2.87 \text{ mg/m}^3$$

Maximum Concentration from Station No. 6

$$\frac{2.87 \text{ mg/m}^3}{154} = 0.018 \text{ mg/m}^3 \text{ H}_3\text{PO}_4$$

With Vent Dilution

$$\frac{0.018 \text{ mg/m}^3}{1.5} = 0.012 \text{ mg/m}^3 \text{ H}_3\text{PO}_4$$

CH$_3$COOH Equilibrium Concentration

$$\frac{0.5\ \text{tor}}{760\ \text{tor}} \times 60.05 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 1763 \text{ mg/m}^3$$

Maximum Concentration from Station No. 6

$$\frac{1763 \text{ mg/m}^3}{154} = 11.45 \text{ mg/m}^3 \text{ CH}_3\text{COOH}$$

With Vent Dilution

$$\frac{11.45 \text{ mg/m}^3}{1.5} = 7.6 \text{ mg/m}^3 \text{ CH}_3\text{COOH}$$

HNO$_3$ Equilibrium Concentration

$$\frac{0.0008\ \text{tor}}{760\ \text{tor}} \times 63.01 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 2.96 \text{ mg/m}^3$$

Maximum Concentration from Station No. 6

$$\frac{2.96 \text{ mg/m}^3}{154} = 0.019 \text{ mg/m}^3 \text{ HNO}_3$$

With Vent Dilution

$$\frac{0.019 \text{ mg/m}^3}{1.5} = 0.013 \text{ mg/m}^3 \text{ HNO}_3$$
Etch Station No. 7

65% H₂SO₄, Estimated Partial Vapor Pressure @ 50°C ≈ 0.0025 tor
23% HNO₃, Estimated Partial Vapor Pressure @ 50°C ≈ 1.00 tor

H₂SO₄ Equilibrium Concentration

\[
\frac{0.0025 \text{ tor}}{760 \text{ tor}} \times 98.08 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 14.4 \text{ mg/m}^3
\]

Maximum Concentration from Station No. 7

\[
\frac{14.4 \text{ mg/m}^3}{154} = 0.094 \text{ mg/m}^3 \text{ H}_2\text{SO}_4
\]

With Vent Dilution

\[
\frac{0.094 \text{ mg/m}^3}{1.5} = 0.062 \text{ mg/m}^3 \text{ H}_2\text{SO}_4
\]

HNO₃ Equilibrium Concentration

\[
\frac{1.00 \text{ tor}}{760 \text{ tor}} \times 63.01 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 369.9 \text{ mg/m}^3
\]

Maximum Concentration from Station No. 7

\[
\frac{369.9 \text{ mg/m}^3}{154} = 2.40 \text{ mg/m}^3 \text{ HNO}_3
\]

With Vent Dilution

\[
\frac{2.4 \text{ mg/m}^3}{1.5} = 1.60 \text{ mg/m}^3 \text{ HNO}_3
\]

Etch Station No. 8

No Emissions

Etch Station No. 9

100% Acetone, Estimated Partial Vapor Pressure @ 20°C ≈ 200 tor

\[
\frac{200 \text{ tor}}{760 \text{ tor}} \times 58.08 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 682,287 \text{ mg/m}^3
\]

Maximum Concentration from Station No. 9

\[
\frac{682,287 \text{ mg/m}^3}{154} = 4430 \text{ mg/m}^3 \text{ Acetone}
\]

With Vent Dilution

\[
\frac{4430 \text{ mg/m}^3}{1.5} = 2953 \text{ mg/m}^3 \text{ Acetone}
\]
Etch Station No. 10

100% Trichlorethylene, Estimated Partial Vapor Pressure @ 20°C ≈ 70 tor

Equilibrium Concentration of Trichlorethylene

\[
\frac{70 \text{ tor}}{760 \text{ tor}} \times 131.4 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 540,261 \text{ mg/m}^3
\]

Maximum Concentration from Station No. 10

\[
\frac{540,261 \text{ mg/m}^3}{154} = 3508 \text{ mg/m}^3 \text{ Trichlorethylene}
\]

With Vent Dilution

\[
\frac{3508 \text{ mg/m}^3}{1.5} = 2338 \text{ mg/m}^3 \text{ Trichlorethylene}
\]

Etch Station No. 11

29% Propanol, Estimated Partial Vapor Pressure @ 20°C ≈ 8 tor

Equilibrium Concentration of Propanol

\[
\frac{8 \text{ tor}}{760 \text{ tor}} \times 60.11 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 28,182 \text{ mg/m}^3
\]

Maximum Concentration from Station No. 11

\[
\frac{28,182 \text{ mg/m}^3}{154} = 183 \text{ mg/m}^3 \text{ Propanol}
\]

With Vent Dilution

\[
\frac{183 \text{ mg/m}^3}{1.5} = 122 \text{ mg/m}^3 \text{ Propanol}
\]

Etch Station No. 12

No Emissions
Etch Station No. 13
85% H₃PO₄, Estimated Partial Vapor Pressure @ 20°C ≈ 0.0010 tor

Equilibrium Concentration of H₃PO₄

\[
\frac{0.001 \text{ tor}}{760 \text{ tor}} \times 98.00 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 5.74 \text{ mg/m}^3
\]

Maximum Concentration from Station No. 13

\[
\frac{5.74 \text{ mg/m}^3}{154} = 0.037 \text{ mg/m}^3 \text{ H}_3\text{PO}_4
\]

With Vent Dilution

\[
\frac{0.037 \text{ mg/m}^3}{1.5} = 0.025 \text{ mg/m}^3 \text{ H}_3\text{PO}_4
\]

Etch Station No. 14
Same As From Station No. 1

Etch Station No. 15
No Emission

Etch Station No. 16
98% H₂SO₄, Estimated Partial Vapor Pressure @ 20°C ≈ 0.0033 tor

Equilibrium Concentration of H₂SO₄

\[
\frac{0.0033 \text{ tor}}{760 \text{ tor}} \times 98.08 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 18.97 \text{ mg/m}^3
\]

Maximum Concentration from Station No. 16 or No. 4

\[
\frac{18.97 \text{ mg/m}^3}{154} = 0.123 \text{ mg/m}^3 \text{ H}_2\text{SO}_4
\]

With Vent Dilution

\[
\frac{0.123 \text{ mg/m}^3}{1.5} = 0.082 \text{ mg/m}^3 \text{ H}_2\text{SO}_4
\]

Etch Station No. 17
No Emission
Etch Station No. 18

9.8% HF, Estimated Partial Vapor Pressure @ 50°C ≈ 0.065 tor

Equilibrium Concentration of HF

\[ \frac{0.065 \text{ tor}}{760 \text{ tor}} \times 20.01 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 76.2 \text{ mg/m}^3 \]

Maximum Concentration from Station No. 18

\[ \frac{76.2 \text{ mg/m}^3}{154} = 0.49 \text{ mg/m}^3 \text{ HF} \]

With Vent Dilution

\[ \frac{0.49 \text{ mg/m}^3}{1.5} = 0.33 \text{ mg/m}^3 \text{ HF} \]
DAILY TOTAL MASS EMISSIONS PRODUCED BY DILUTION OF ETCH STATION EXHAUST
(FROM FIGURE 13) WITH TOTAL FACILITY EXHAUST

127 m³/min x 60 min/hr x 24 hr/day = 182880 Mass Flow Conversion Factor

HF Total Output

\[ 0.79 \text{ mg/m}^3 \times 182880 = 145 \text{ g/day} \]

HCl Total Output

\[ 0.004 \text{ mg/m}^3 \times 182880 = 0.732 \text{ g/day} \]

HNO₃ Total Output

\[ 1.74 \text{ mg/m}^3 \times 182880 = 318 \text{ g/day} \]

H₂SO₄ Total Output

\[ 0.785 \text{ mg/m}^3 \times 182880 = 144 \text{ g/day} \]

H₃PO₄ Total Output

\[ 0.037 \text{ mg/m}^3 \times 182880 = 6.77 \text{ g/day} \]

Acetic Acid Total Output

\[ 7.6 \text{ mg/m}^3 \times 182880 = 1390 \text{ g/day} \]

Acetone Total Output

\[ 2953 \text{ mg/m}^3 \times 182880 = 540 \text{ Kg/day} \]

Trichlorethylene Total Output

\[ 2338 \text{ mg/m}^3 \times 182880 = 428 \text{ Kg/day} \]

Propanol Total Output

\[ 122 \text{ mg/m}^3 \times 182880 = 22 \text{ Kg/day} \]
6. PHOTORESIST

The following assumptions were made in calculating emissions from the photoresist area:

(a) A throughput of 25 wafers per day was assumed.

(b) The Hunt Waycoat photoresist was assumed with the usage of 5 drops per wafer. The vent flow of 1,280 cubic feet per minute was assumed.

As indicated in the summary chart, the emissions from the Waycoat material principally Xylene is well within the OSHA limits.
## PHOTORESIST OPERATION

<table>
<thead>
<tr>
<th>XYLENE EMISSIONS (From Waycoat #3 Photoresist)</th>
<th>PHOTORESIST</th>
<th>OSHA LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm</td>
<td>0.3</td>
<td>100</td>
</tr>
<tr>
<td>mg/m³</td>
<td>1.88</td>
<td>433</td>
</tr>
<tr>
<td>g/day</td>
<td>97.9</td>
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</tbody>
</table>
# PHOTORESIST OPERATION EMISSIONS

## PHOTORESIST APPLICATION (Spin & Bake)

<table>
<thead>
<tr>
<th></th>
<th>XYLENE</th>
<th>STODDARD</th>
<th>N-BUTYL ACETATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm, Average</td>
<td>.056</td>
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<td></td>
</tr>
<tr>
<td>mg/m³, Average</td>
<td>.361</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g/day, Average</td>
<td>97.9</td>
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<td></td>
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</tbody>
</table>

## PHOTORESIST DEVELOPMENT (Develop & Bake)

<table>
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<th>XYLENE</th>
<th>STODDARD</th>
<th>N-BUTYL ACETATE</th>
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</thead>
<tbody>
<tr>
<td>ppm, Average</td>
<td>.044</td>
<td>.020</td>
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<tr>
<td>ppm, Peak</td>
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<td>14.8</td>
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<tr>
<td>mg/m³, Average</td>
<td>.186</td>
<td>.134</td>
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<tr>
<td>mg/m³, Peak</td>
<td>130</td>
<td>92.2</td>
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</tr>
<tr>
<td>g/day</td>
<td>50.6</td>
<td>36.3</td>
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</tbody>
</table>

## OSHA LIMIT

<p>| | | | |</p>
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<thead>
<tr>
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<tbody>
<tr>
<td>ppm</td>
<td>100</td>
<td>200</td>
<td>150</td>
</tr>
<tr>
<td>mg/m³</td>
<td>435</td>
<td>1150</td>
<td>710</td>
</tr>
</tbody>
</table>
PHOTORESIST APPLICATION, SPIN AND BAKE

25 wafer/day Using 5 drops/wafer
5 drops x 1 cc/drop x 25 wafer/day = 125 cc/day

Hunt Waycoat #3 @ 45 Centipoise

87 wt% Xylene
13 wt% Solids
.90 SP GR (Water = 1.0)

125 cc/day x .90 SPGR x .87 = 97.9 g/day Xylene Total Emission

Vent Flow 1280 cfm

1280 cfm x .0283 m³/cf x 60 min/hr x 24 hr/day = 52,162 m³/day

\[
\frac{97.9 \text{ g/day} \times 1000 \text{ mg/g}}{52.162 \text{ m}^3/\text{day}} = 1.88 \text{ mg/m}^3 \text{ Xylene in Hood Exhaust}
\]

OSHA Limit is 435 mg/m³

Xylene Emissions

\[
\frac{97.9 \text{ g/day}}{106.17 \text{ g/mol}} \times 22.4 \text{ l/mol} = 20.7 \text{ l/day Xylene}
\]

\[
\frac{20.7 \text{ l/day}}{52,162,000 \text{ l/day (vent flow)}} = .3 \text{ ppm Xylene}
\]

With Total Exhaust Dilution

\[
\frac{1.88 \text{ mg/m}^3 \times 36.1 \text{ m}^3/\text{min}}{188.7 \text{ m}^3/\text{min}} = .361 \text{ mg/m}^3 \text{ Xylene}
\]

\[
\frac{.3 \text{ ppm} \times 36.1 \text{ m}^3/\text{min}}{188.7 \text{ m}^3/\text{min}} = .056 \text{ ppm Xylene}
\]

Daily Total Mass Emission

\[
.361 \text{ mg/m}^3 \times 188.7 \text{ m}^3/\text{min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 97.9 \text{ g/day}
\]
PHOTORESIST DEVELOP AND BAKE

Assume 25 cc of Stoddard Solvent sprayed in 5 sec and 25 cc of N-Butyl acetate sprayed in 5 sec for each wafer developed. Assume 25 wafers/day processed.

<table>
<thead>
<tr>
<th>Estimated Vapor Press @ 20°C</th>
<th>Plane Surface</th>
<th>Spray Drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stoddard Solvent</td>
<td>45 ton</td>
<td>90 ton</td>
</tr>
<tr>
<td>N-Butyl Acetate</td>
<td>25 ton</td>
<td>50 ton</td>
</tr>
</tbody>
</table>

Total Liquid Spray Volume

| Stoddard Solvent | 625cc/Day |
| N-Butyl Acetate  | 625cc/Day |

Photoresist Develop,

Stoddard Solvent, Total Exhaust Dilution, Average Emission

\[
\frac{90}{ton} \times \frac{760}{ton} \times 625 \text{ cc} = 74 \text{ cc/day Liquid Vaporized}
\]

Liquid volume to vapor volume factor is 162.6

\[
74 \text{ cc/day} \times 162.6 = 12,026 \text{ cc/day Vapor Volume}
\]

\[
\frac{12,026 \text{ cc/day}}{188.7 \text{ m}^3/\text{min} \times 1,000,000 \text{ cc/m}^3 \times 60 \text{ min/hr} \times 24 \text{ hr/day}} = .044 \text{ pm Daily Average}
\]

200 ppm OSHA Limit

\[
74 \text{ cc/day} \times .6849/\text{cc} = 50.6 \text{ g/day Total Stoddard Solvent}
\]

\[
\frac{50,600 \text{ mg/day}}{188.7 \text{ m}^3/\text{m} \times 60 \text{ min/hr} \times 24 \text{ hr/day}} = .186 \text{ mg/m}^3 \text{ Daily Average}
\]

OSHA Limit 1150 mg/m³
STODDARD SOLVENT, TOTAL EXHAUST, PEAK EMISSION

\[
\frac{90 \text{ tor}}{760 \text{ tor}} \times 25 \text{ cc} = 3.0 \text{ cc/5 sec Liquid Vaporized}
\]

Liquid Volume to Vapor Volume Factor is 162.6

\[
3.0 \text{ cc/5 sec} \times 162.6 = 488 \text{ ml/5 sec Vapor Volume}
\]

\[
488 \times 12 \text{ spray periods/min}
\]

\[
\frac{188.7 \text{ m}^3/\text{min} \times 1,000,000 \text{ cc/m}}{} = 31 \text{ ppm Peak Emission}
\]

OSHA Limit 200 ppm

\[
3.0 \text{ ml/5 sec} \times .684 \text{ g/cc} = 2.05 \text{ g/5 sec}
\]

\[
2050 \text{ mg/5 sec} \times 12 \text{ spray periods/min}
\]

\[
\frac{188.7 \text{ m}^3/\text{min}}{} = 130 \text{ mg/m}^3 \text{ Peak Emission}
\]

OSHA Limit 1150 mg/m³

**Photoresist Develop**

N-Butyl Acetate, Total Exhaust Dilution, Average Emission

\[
\frac{50 \text{ tor}}{760 \text{ tor}} \times 625 \text{ cc} = 41.1 \text{ cc/day Liquid Vaporized}
\]

Liquid Volume to Vapor Volume Factor is 142.1

\[
41.1 \text{ cc} \times 142.1 = 5841 \text{ cc/day Vapor Volume}
\]

\[
\frac{5841 \text{ cc/day}}{188.7 \text{ m}^3/\text{min} \times 1,000,000 \text{ cc/m}^3 \times 60 \text{ min/hr} \times 24 \text{ hr/day}} = .02 \text{ ppm Daily Average}
\]

OSHA Limit 150 ppm

\[
41.1 \text{ cc/day} \times .883 \text{ g/cc} = 36.3 \text{ g/day}
\]

\[
\frac{36,300 \text{ mg/day}}{188.7 \text{ m}^3/\text{min} \times 60 \text{ min/hr} \times 24 \text{ hr/day}} = .134 \text{ mg/m}^3 \text{ Daily Average}
\]

OSHA Limit 710 mg/m³
N-BUTYL ACETATE, TOTAL EXHAUST, PEAK EMISSION

\[
\frac{50 \text{ tor}}{760 \text{ tor}} \times 25 \text{ cc} = 1.64/5 \text{ sec} \quad \text{Liquid Vaporized}
\]

Liquid Volume to Vapor Volume Factor is 142.1

\[
1.64 \text{ cc} \times 142.1 = 233 \text{ cc/5 sec} \quad \text{Vapor Volume}
\]

\[
\frac{233 \times 12 \text{ sprays/5 sec}}{188.7 \text{ m}^3/\text{min} \times 1,000,000 \text{ cc/m}^3} = 14.8 \text{ ppm} \quad \text{Peak Emission}
\]

OSHA Limit 150 ppm

\[
1.64 \text{ cc/5 sec} \times .883 = 1.45 \text{ g/5 sec}
\]

\[
\frac{1450 \text{ mg/5 sec} \times 12 \text{ sprays/5 sec}}{188.7 \text{ m}^3/\text{min}} = 92.2 \text{ mg/m}^3 \quad \text{Peak Emission}
\]

OSHA Limit 710 mg/m^3

Photoresist Bake

Stoddard Solvent, N-Butyl Acetate, Total Exhaust Dilution, Average Emission

Assume photoresist film thickness of 1 and 25% absorption of solvent.

\[
\frac{(3 \times 2.54)^2 \text{cm} \times \pi \times 1 \times 10^{-4} \text{cm}}{2} = .0015 \text{ cc/wafer} \quad \text{Photoresist Volume}
\]

\[
.0015 \text{ cc} \times 25\% = .0004 \text{ cc} \quad \text{Solvent/Wafer}
\]

\[
.004 \text{ cc} \times 25 \text{ wafer/day} = .0015 \text{ cc/day} \quad \text{Solvent Liquid Volume}
\]

Liquid Volume to Vapor Volume Factor is 149.6

\[
.0015 \text{ cc/day} \times 149.6 = .224 \text{ cc/day} \quad \text{Vapor Volume from Bake Out}
\]

\[
\frac{.224 \text{ cc/day}}{188.7 \text{ m}^3/\text{min} \times 1,000,000 \text{ cc/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day}} = .0000008 \text{ ppm Daily Average}
\]

Contribution from bake is negligible
7

EXPITAXIAL
OPERATION
7. EPITAXIAL OPERATION

As indicated on the master plan this particular operation has a separate exhaust system and will utilize a gas scrubbing operation.

There are four major concerns with the epi system.

(a) Use of hydrogen and its concentration. Provisions must be made for hydrogen burn-off or maintaining the hydrogen concentration within a noncombustible ratio.

(b) The disposal of the amount of the various dopant gases is a critical safety problem

(c) With the scrubber in use the acidic content of the water and its drainage becomes a consideration.

(d) Although not a safety problem, the RF generator does require a registration and a license. A typical form is attached.

Assumptions

For the problems of hydrogen gas and flammability conditions a normal flow of five liters per minute was assumed, and a maximum potential flow of 110 liters per minute was assumed from one chamber. Reviewing the calculations in Figure A it can be seen that a percent of hydrogen and air must be kept less than 4 percent or greater than 75 percent to be safe. Because of potential variable amounts hydrogen used, ranging from five liters per minute to maximum possible of a 110 liters per minute, more than 330 liters per minute of air would have to be added to assure that the hydrogen would stay in a safe area. (See Figure B) Thus, ICE would recommend a burn-off procedure to handle the hydrogen prior to the scrubber.

Other assumptions made for the epitaxial reactor assumed a normal case of 1 chamber operating and a worse case of 2 chambers operating. Figure C shows the potential amount of various materials which will be omitted from the eptaxial reactor for normal or worse case conditions. It should be noted that in almost every case this value exceeds OSHA limits, thus, a scrubber is absolutely necessary.
**PART I**

CERTIFICATION REGARDING OPERATION

In charge for the operation of the ISM equipment listed on page 2 of this form at the following location:

- **FLOOR OF BLDG. OR OTHER LOCATION**
- **STREET AND NUMBER**
- **CITY, COUNTY, AND STATE**

I HEREBY CERTIFY THAT:

I am familiar with Part 18 of the FCC Rules pertaining to the operation of the equipment listed on page 2 of this form; and

I have assured myself that this installation does not cause harmful interference. If harmful interference arises, I will take prompt steps to eliminate the harmful interference; and

If this equipment is prototype certification for this equipment has been filed with the FCC, I have had the equipment installed in exact accordance with the instructions furnished by the manufacturer; and

If this equipment is prototype certification for this equipment has NOT been filed with the FCC, I have attached the report of measurements of the RF energy emitted by the equipment. I have read this report and confirm that the data contained therein are true, correct, and complete. I, myself, except for such data as were obtained from measurements or observations made by other persons to which I am not informed but believe the same to be true; and if the measurements were made at a location other than the site of operation listed above, I have had the equipment installed in exact accordance with the instructions furnished by the manufacturer.

Dated this .......... day of ........................................, 19..........

**NAME OF FIRM**

**Firm's Signature**

**BUSINESS ADDRESS**

**STREET**

**NUMBER**

**CITY**

**STATE**

**ZIP CODE**

**PART II**

CERTIFICATION BY CORPORATION CONCERNING SIGNATURE OF EMPLOYEE

I HEREBY CERTIFY THAT:

The person who signed Part I of this Certificate and who is named below is in the employ of the corporation named below and has supervisory responsibility for the operation of the equipment named in this Certificate; and that the corporation named below accepts full responsibility for his action.

Dated this .......... day of ........................................, 19..........

**NAME OF AUTHORIZED EMPLOYEE**

**Firm's Signature**

**NAME OF CORPORATION**

**MAIL ADDRESS OF CORPORATION**

**WARNING**

FALSE STATEMENTS ON THIS FORM ARE PUNISHABLE BY IMPRISONMENT FOR NOT MORE THAN FIVE YEARS AND A FINE OF NOT MORE THAN $10,000. TITLE 18, U.S. CODE, SECTION 1001.
EPI OPERATIONS

EPI Operations, Hydrogen Gas Disposal

Assume normal flow of 5 l/min and maximum flow of 110 l/min in one chamber. Determine minimum air dilution to stay below 4% flammability limit and maximum air dilution to stay above the 75% flammability limit. (Assume burnoff not in use)

At 5 l/min

\[
\frac{5 \text{ l/min}}{0.75} - 5 \text{ l/min} = 1.67 \text{ l/min} \quad \text{Maximum Air Addition to Exhaust Gas to Stay Above Upper Explosive Limit}
\]

\[
\frac{5 \text{ l/min}}{0.04} - 5 \text{ l/min} = 120 \text{ l/min} \quad \text{Minimum Air Addition to Exhaust Gas to Stay Below Lower Explosive Limit}
\]

At 110 l/min

\[
\frac{110 \text{ l/min}}{0.75} - 110 \text{ l/min} = 36.7 \text{ l/min} \quad \text{Maximum Air Addition to Exhaust Gas to Stay Above Upper Explosive Limit}
\]

\[
\frac{110 \text{ l/min}}{0.04} - 110 \text{ l/min} = 2640 \text{ l/min} \quad \text{Minimum Air Addition to Exhaust Gas to Stay Below Lower Explosive Limit}
\]

Conclusion

Burning is safer than dilution exhausting
FIGURE B

AIR ADDITION REQUIRED FOR NON-EXPLOSIVE,
DILUTION DISPOSAL, OF HYDROGEN GAS EXHAUST

ORIGINAL PAGE IS
OF POOR QUALITY
## EPITAXY OPERATION EMISSIONS

<table>
<thead>
<tr>
<th></th>
<th>Silicon Growth with SiCl₄ Source</th>
<th>Silicon Growth with SiH₄ Source</th>
<th>Ammonia/ Nitrous Oxide</th>
<th>HCl Cleaning</th>
<th>HCl Etching</th>
<th>OSHA Limits</th>
<th>Problem Areas</th>
<th>H₂O Solubility CC/CH₃OH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AMMONIA (NH₃)</strong></td>
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<td><strong>HYDROGEN CHLORIDE (HCl)</strong></td>
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<td>mg/m³</td>
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<td><strong>ARSENE (AsH₃)</strong></td>
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</tbody>
</table>
EPI OPERATING CONDITIONS

Hydrogen:
Flow: 110 l/min (Maximum)
Concentration: 100%

Ammonia NH₃:
Flow: 5 l/min, 1 Hour Maximum
Concentration: 100%

Hydrogen Chloride HCl:
Flow: Etch 1.25 l/min 2 min 2 Batch/Day
Clean 15 l/min 15 min 2 Cleans/Day
Concentration: 99.9%

Silicon Tetrachloride SiCl₄
Flow: 6 g/min 100% HCl Vapor Product
Concentration: 100%

Silane SiH₄
Flow: 160 cc/min
Concentration: 100%

Arsene AsH₃
Flow: 130 cc/min
Concentration: 50 ppm in H₂

Diborane B₂H₆
Flow: 130 cc/min
Concentration: 50 ppm in H₂

Phosphine PH₃
Flow: 130 cc/min
Concentration: 50 ppm in H₂

Nitrous Acid N₂O
Flow: 130 cc/min
Concentration: 50 ppm in H₂
CALCULATIONS

EPI OPERATIONS

EPI Operations, Silicon Tetrachloride

Assume normal epi growth using one chamber with 6 g/min of 100% SiCl₄ diluted with 5 l/min of hydrogen.

\[
\text{SiCl}_4 + 2\text{H}_2 \rightarrow \text{Si} + 4\text{HCl}
\]

\[
\frac{6 \text{ g/min} \times 36.46 \text{ g/mol} \times 4 \text{ mol}}{169.9 \text{ g/mol}} = 5.15 \text{ g/min HCl}
\]

\[
\frac{5.15 \text{ g/min}}{36.46 \text{ g/mol} \times 22.4 \text{ l/mol}} = 3.16 \text{ l/min HCl}
\]

\[
\frac{3.16 \text{ l/min}}{5 \text{ l/min} + 3.16 \text{ l/min}} = 387.255 \text{ ppm HCl}
\]

OSHA Limit is 5 ppm

One Tube

\[
\frac{5150 \text{ mg/min}}{.00816 \text{ m}^3/\text{min}} = 631.127 \text{ mg/m}^3
\]

Total Daily Maximum Emissions (24 hr/day)

\[
5.15 \text{ g/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 7.416 \text{ kg/day One Tube}
\]

Two Tubes = 14.83 kg/day
EPI OPERATIONS

EPI Operations, Diborane Doping

Assume normal conditions of silicon growth using silane with one chamber using 130 cc/min of 50 ppm B₂H₆ in hydrogen diluted with normal flow of H₂ at rate of 1 l/min for maximum of one hour.

130 cc/min x .000050 = .0065 cc/min B₂H₆ input Dopant Gas

\[
\frac{.0065 \text{ cc/min}}{5000 \text{ cc/min} + .160 \text{ cc/min} + .0065 \text{ cc/min}} = 1.29 \text{ ppm B₂H₆ in Exit Gas From One Chamber}
\]

OSHA Limit is 0.1 ppm

\[
\frac{.0000065 \text{ l/min}}{22.4 \text{ l/mol}} \times 27.67 \text{ g/mol} = .00802 \text{ mg.min B₂H₆}
\]

One Tube

\[
\frac{.00802 \text{ mg/min}}{.00517 \text{ m}^3/\text{min}} = 1.55 \text{ mg/m}^3 \text{ B₂H₆}
\]

Total Daily Maximum Emission (1 hour maximum run)

\[
.00802 \text{ mg/min} \times 120 \text{ min} = .48/\text{mg}
\]

Two Tubes = .96 mg
EPI OPERATIONS

EPI Operations, Arsine Doping

Assume normal conditions of silicon growth using silane with one chamber using 130 cc/min of 50 ppm AsH₃ in hydrogen diluted with normal flow of H₂ at a flow of 5 l/min for maximum of 1 hour.

130 cc/min x .000050 = .0065 cc/min AsH₃ input Dopant Gas

\[
\frac{.0065 \text{ cc/min}}{5000 \text{ cc/min} + .160 \text{ cc/min} + .0065 \text{ cc/min}} = 1.29 \text{ ppm AsH}_3 \text{ in Exit Gas in One Chamber}
\]

OSHA Limit is 0.05 ppm

\[
\frac{.0000065 \text{ l/min}}{22.4 \text{ l/mol}} \times 77.91 \text{ g/mol} = .023 \text{ mg/min AsH}_3
\]

One Tube

\[
\frac{.023 \text{ mg/min}}{.00517 \text{ m}^3/\text{min}} = 4.37 \text{ mg/m}^3 \text{ AsH}_3
\]

Total Daily Maximum Emission (1 hour maximum run)

\[
.023 \text{ mg/min} \times 60 \text{ min/hr} = 1.38 \text{ mg}
\]

Two Tubes = 2.76 mg
EPI OPERATIONS

EPI Operations, Phosphine Doping

Assume normal conditions of silicon growth using silane with one chamber using 130 cc/min of 50 ppm \( \text{PH}_3 \) in hydrogen diluted with normal flow of \( \text{H}_2 \) at rate of 5 l/min for maximum of 1 hour.

\[
130 \text{ cc/min} \times 0.000050 = 0.0065 \text{ cc/min} \ \text{PH}_3 \ \text{input Dopant Gas}
\]

\[
\frac{0.0065 \text{ cc/min}}{5000 \text{ cc/min} + 0.160 \text{ cc/min} + 0.0065 \text{ cc/min}} = 1.29 \text{ ppm} \ \text{PH}_3 \ \text{in Exit Gas From One Chamber}
\]

OSHA Limit is 0.3 ppm

\[
0.000065 \text{ l/min} \times 34 = 0.0099 \text{ mg/min} \ \text{PH}_3
\]

One Tube

\[
0.0099 \text{ mg/min} = 1.9 \text{ mg/m}^3 \ \text{PH}_3
\]

Total Daily Maximum Emission (1 Hour Maximum Run)

\[
0.0099 \text{ mg/min} \times 60 \text{ min} = 0.594 \text{ mg}
\]

Two Tubes = 1.19 mg
EPI OPERATION

EPI Operation, Ammonia Gas

Assume normal operations of 1 chamber and maximum of 2 chambers with 5 l/min of 100% NH₃ gas diluted with 5 l/min hydrogen for a time period of 1 hour maximum.

\[
\frac{5 \text{ l/min}}{5 \text{ l/min} + 5 \text{ l/min}} = 500,000 \text{ ppm of NH}_3 \text{ in Exit Gas}
\]

OSHA Limit is 50 ppm

\[
\frac{5 \text{ l/min}}{22.4 \text{ l/mol}} \times 17.03 \text{ g/mol} = 3.80 \text{ g/min NH}_3
\]

One Tube

\[
3800 \text{ mg/min} = 380 \text{ mg/m}^3 \text{ NH}_3
\]

Total Daily Maximum Emission (1 Hour Maximum Run)

\[
3.80 \text{ g/min} \times 60 \text{ min} = 228 \text{ g}
\]

Two Tubes = 456 g
EPI OPERATION

EPI Operation, Nitrous Oxide Gas

Assume normal operation of 1 chamber suing 130 cc/min of 100% N₂O diluted with 5 l.min of H₂ for maximum of 1 hour.

\[
\frac{130 \text{ cc/min}}{5000 \text{ l/min} + 130 \text{ cc/min}} = 25,341 \text{ ppm N}_2\text{O in Exit Gas From One Chamber}
\]

OSHA Limit is 25 ppm (Tentative)

\[
\frac{130 \text{ l/min}}{22.4 \text{ l/mol}} \times 44.01 \text{ g/mol} = .255 \text{ g/min N}_2\text{O}
\]

One Tube

\[
\frac{225 \text{ mg/min}}{.00517 \text{ m}^3/\text{min}} = 49,707 \text{ mg/m}^3 \text{ NH}_3
\]

Total Daily Emission (1 Hour Maximum Run)

\[
.255 \text{ g/min} \times 60 \text{ min} = 15.3 \text{ g}
\]

Two Tubes = 30.6 g
EPI OPERATION

EPI Operation, Hydrogen Chloride Gas

Assume normal etching operations of 1 chamber, with 2 batches/day of 1.25 1/min of 99.99 HCl for a time period of 2 min. diluted with a hydrogen flow of 5 1/min.

\[
\frac{1.25 \text{ l/min}}{5 \text{ l/min} + 1.25 \text{ l/min}} = 200,000 \text{ ppm HCl in Exit Gas During Each Batch}
\]

Assume normal cleaning operations of 1 chamber with 2 cleans/day of 15 l/min of 99.99 HCl for a time period of 15 min. diluted with 5 l/min flow of hydrogen.

Normal Cleaning

\[
\frac{15 \text{ l/min}}{5 \text{ l/min} + 15 \text{ l/min}} = 750,000 \text{ ppm HCl in Exit Gas During Each Batch}
\]

OSHA Limit is 5 ppm
EPI OPERATION

EPI Operation, Hydrogen Chlorine Gas

Etching

\[
\frac{1.25 \text{ l/min}}{22.4 \text{ l/mol}} \times 36.46 \text{ g/mol} = 2.03 \text{ g/min HCl}
\]

One Tube

\[
\frac{2030 \text{ mg/min}}{0.00625 \text{ m}^3/\text{min}} = 324,800 \text{ mg/m}^3 \text{ HCl}
\]

Total Daily Emission

2 Batches/day for 2 min duration (1 tube)

\[
2.03 \text{ g/min} \times 4 \text{ min} = 8.12 \text{ g HCl}
\]

Two Tubes (2 Batch for 2 Min.)

\[
8.12 \text{ g} \times 2 = 16.24 \text{ g HCl}
\]
EPI OPERATION

EPI Operation, Hydrogen Chloride Gas

Cleaning
\[
\frac{15 \text{ L/min}}{22.4 \text{ L/mol}} \times 36.46 \text{ g mol} = 24.42 \text{ g/min HCl}
\]

One Tube
\[
\frac{24.442 \text{ mg/min}}{0.02 \text{ m}^3/\text{min}} = 1,221,000 \text{ mg/m}^3 \text{ HCl}
\]

Total Daily Emission

2 Cleans/day for 15 min. duration (1 Tube)
\[
24.42 \text{ g/min} \times 30 \text{ min} = 732.6 \text{ g HCl}
\]

Two Tubes
\[
732.6 \text{ g} \times 2 = 1.465 \text{ kg HCl}
\]
8

SCRUBBER
8. SCRUBBERS

Based upon the system requirements for a scrubber at the exhaust gas outlet, ICE performed the calculations to determine the requirements for the scrubber, considering the total air flow and the various chemicals involved. As shown in Figure D, a total of 188 cubic meters per minute of air flow will go in the scrubbers. Typical industry requirements has suggested the use of three DFC0623 scrubber modules or equivalent to provide a sufficient handling capability for this exhaust gas flow. In addition a total of 15 gallons per minute of water will be required.

Because of various gases and chemicals entering the scrubbers, the pH of the liquid effluent is a factor. A particular requirement will be to neutralize the various acids, including hydrochloric acid which is above the OSHA limit. A limestone bed will be required. As indicated by the calculations, for normal case daily usage a total of 15 pounds of limestone per day would be utilized and under worse case conditions a total of 22 pounds per day.
**FIGURE D**

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>m³/min INERT GAS</th>
<th>m³/min AIR</th>
<th>m³/min H₂</th>
<th>m³/min TOTAL</th>
<th>cfm TOTAL</th>
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<td>-</td>
<td>127</td>
<td>4500</td>
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<tr>
<td>Diffusion</td>
<td>.06</td>
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<td>-</td>
<td>25.5</td>
<td>900</td>
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<tr>
<td>CVD</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Photoresist</td>
<td>-</td>
<td>36.2</td>
<td>-</td>
<td>36.2</td>
<td>1280</td>
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<tr>
<td>TOTAL</td>
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<td>188.7</td>
<td>0</td>
<td>188.7</td>
<td>6680</td>
</tr>
</tbody>
</table>

Use 3 - DSE U623 Scrubber modules

2300 cfm x 3 = 6900 cfm Exhaust

5 cfm x 3 = 15 gmp Water

15 gpm x 3785 cc/gal = 56,775 cc/min
CHEMICAL REMOVAL IN SCRUBBER

COMBINED EXHAUST FROM DIFFUSION, CVD, PHOTORESIST AND ETCH STATIONS.

AMMONIA

\[ \text{NH}_3 \text{ solubility} = 89.9 \text{ g/100 cc} = .899 \text{ g/cc at ambient temperature} \]

\[ .899 \text{ g/cc} \times 56,775 \text{ cc/min} = 51,040 \text{ g/min NH}_3 \text{ maximum solubility rate achievable} \]

\[ \text{NH}_3 \text{ Production, assume total daily effluent is charged to scrubber in 30 min. run.} \]

Normal Case = 87.8 g/day = 87.8 g/30 min. = 2.93 g/min.

51,040 g/min > 2.93 g/min. = complete removal

Worst Case = 176 g/day = 176 g/30 min. = 5.87 g/min.

51,000 g/min > 5.87 g/min. = complete removal

Thus no significant level of \( \text{NH}_3 \) in scrubber exit gas. All \( \text{NH}_3 \) in scrubber liquid.

In either case scrubber liquid effluent pH will go up slightly because of resulting \( \text{NH}_4\text{OH} \) production.

HYDROGEN CHLORIDE

\[ \text{HCl Solubility} = 80 \text{ g/100cc} = .80 \text{ g/cc at ambient temperature} \]

\[ .80 \text{ g/cc} \times 56,775 \text{ cc/min} = 45,420 \text{ g/min maximum solubility rate achievable} \]

\[ \text{HCl Production, assume total daily effluent is charged to scrubber in 30 min. run.} \]

Normal Case = 1054 g/day = 1054 g/30 min. = 35.13 g/min.

45,420 g/min > 35.13 g/min. = complete removal

Worst Case = 2459 g/day = 2459 g/30 min. = 82 g/min.

45,520 g/min > 82 g/min. = complete removal

Thus no significant level of HCl in scrubber exit gas. All HCl in scrubber liquid.
HYDROGEN CHLORIDE NEUTRALIZATION

HCl reactivity with limestone bed is as follows:

\[ 2 \text{HCl} + \text{CaCO}_3 \rightarrow \text{CaCl}_2 + \text{CO}_2 + \text{H}_2\text{O} \]

**Normal Case** = 1054 g/day HCl

\[
\frac{1054 \text{ g/day} \times 100.09 \text{ g/mol}}{2(36.46) \text{ g/mol}} = 1446 \text{ g/day}
\]

\[
\frac{1446 \text{ g/day}}{454 \text{ g/lb}} = 3.19 \text{ lb/day Limestone}
\]

Assume 50% reagent efficiency (based on surface of pebble bed)

3.19 lb/day x 2 = 6.38 lb/day Limestone required for HCl neutralization

**Worst Case** = 2459 g/day HCl

\[
\frac{2459 \text{ g/day} \times 100.09 \text{ g/mol}}{2(36.46) \text{ g/mol}} = 3080 \text{ g/day}
\]

\[
\frac{3080 \text{ g/day}}{454 \text{ g/lb}} = 6.79 \text{ lb/day Limestone}
\]

Assume 50% reagent efficiency

6.79 lb/day x 2 = 13.6 lb/day Limestone required for HCl neutralization
NITROUS OXIDE

$N_2O$ Solubility = 0.12 g/cc at ambient temperature

$0.12 \text{ g/cc} \times 56,775 \text{ cc/min} = 6813 \text{ g/min.}$ $N_2O$ maximum solubility rate achievable

$N_2O$ Production. Assume total daily effluent is charged to scrubber in 30 min. run.

**Normal Case** = 282 g/day = 564 g/30 min. = 9.4 g/min.

$6813 \text{ g/min} > 9.4 \text{ g/min.} = \text{Complete Removal}$

**Worst Case** = 564 g/day = 564 g/30 min = 18.8 g/min.

$6813 \text{ g/min} > 18.4 \text{ g/min} = \text{Complete Removal}$

Thus no significant level of $N_2O$ in scrubber exit gas. All $N_2O$ in scrubber liquid.

DIBORANE

$B_2H_6$ is slightly soluble in ambient temperature. When it dissolves in water it reacts as follows:

$$B_2H_6 + 6H_2O \rightarrow 2H_3BO_3 + 6H_2$$

(Boric Acid)

With this slight solubility, production of boric acid and the subsequent reaction of boric acid with limestone it can be assumed that negligible amounts of diborane will exist in the scrubber exit gas.
PHOSPHINE

PH$_3$ Solubility = 26 cc gas/100 cc water at ambient temperature

\[ \frac{0.026 \text{ l}}{22.4 \text{ l/mol}} \times 77.95 \text{ g/mol} = 0.090 \text{ PH}_3 \text{ Gas in 100 cc water} \]

\[ 0.090 \text{ g/100 cc} = 0.0009 \text{ g/cc} \]

\[ 0.0009 \text{ g/cc} \times 56,775 \text{ cc/min} = 51.1 \text{ g/min PH}_3 \text{ Maximum solubility rate achievable} \]

PH$_3$ Production. Assume total daily effluent is charged to scrubber in 30 min. run.

**Normal Case** = 173 g/day = 173 g/30 min. = 5.77 g/min.

\[ 51.1 \text{ g/min} > 5.77 \text{ g/min} = \text{complete removal} \]

**Worst Case** = 347 g/day = 347 g/30 min. = 11.6 g/min.

\[ 51.1 \text{ g/min.} > 11.6 \text{ g/min} = \text{complete removal} \]

Thus no significant level of PH$_3$ exists in scrubber exit gas. All PH$_3$ in scrubber liquid.

HYDROFLUORIC ACID

HF is infinitely soluble in scrubber water under normal conditions, therefore no vapor HF emission is assumed in scrubber exit gas.

HF will react with limestone bed as follows:

\[ 2\text{HF} + \text{CaCO}_3 \rightarrow \text{CaF}_2 + \text{CO}_2 + \text{H}_2\text{O} \]

**Normal Case** = 144 g/day HF

\[ \frac{144 \text{ g/day} \times 100.09 \text{ g/mol}}{2(20.01) \text{ g/mol}} = 361 \text{ g/day} + 454 = 0.8 \text{ lb/day Limestone} \]

Assume 50% reagent reactivity efficiency

\[ 0.8 \text{ lb/day} \times 2 = 1.6 \text{ lb/day Limestone required for HF neutralization.} \]
NITRIC ACID

HNO₃ is infinitely soluble in scrubber water under normal conditions, therefore no vapor HNO₃ emission is assumed on scrubber exit gas.

HNO₃ will react with limestone bed as follows:

\[ 2\text{HNO}_3 + \text{CaCO}_3 \rightarrow \text{Ca(NO}_3)_2 + \text{CO}_2 + \text{H}_2\text{O} \]

Normal Case = 318 g/day HNO₃

\[ 318 \text{ g/day} \times \frac{100.09 \text{ g/mol}}{2(63.01 \text{ g/mol})} = 253 \text{ g/day} = 0.6 \text{ lb/day Limestone} \]

Assume 50% reagent reactivity efficiency

0.6 lb/day \times 2 = 1.2 lb/day Limestone required to neutralize HNO₃

SULFURIC ACID

H₂SO₄ is infinitely soluble in scrubber water under normal conditions, therefore no vapor H₂SO₄ emission is assumed in scrubber exit gas.

H₂SO₄ will react with limestone bed as follows:

\[ \text{H}_2\text{SO}_4 + \text{CaCO}_3 \rightarrow \text{CaSO}_4 + \text{CO}_2 + \text{H}_2\text{O} \]

Normal Case = 144 g/day H₂SO₄

\[ 144 \text{ g/day} \times \frac{100.09 \text{ g/mol}}{98.08 \text{ g/mol}} = 147 \text{ g/day} = 0.3 \text{ lb/day Limestone} \]

Assume 50% reagent reactivity efficiency

0.3 lb/day \times 2 = 0.6 lb/day Limestone required to neutralize H₂SO₄
PHOSPHORIC ACID

$\text{H}_3\text{PO}_4$ is very soluble in scrubber water under normal conditions, therefore $\text{H}_3\text{PO}_4$ emission is assumed in scrubber exit gas.

$\text{H}_3\text{PO}_4$ will react with limestone bed as follows:

$$2\text{H}_3\text{PO}_4 + 3 \text{CaCO}_3 \rightarrow \text{Ca}_3(\text{PO}_4)_2 + 3 \text{CO}_2 + 3\text{H}_2\text{O}$$

Normal Case = 6.8 g/day $\text{H}_3\text{PO}_4$

$$6.8 \text{ g/day} \times \frac{3(100.09) \text{ g/mol}}{2(98) \text{ g/mol}} = 10.4 \text{ g/day} + 454 = 0.02 \text{ lb/day Limestone}$$

Assume 50% reagent reactivity efficiency

$$0.02 \text{ lb/day} \times 2 = 0.04 \text{ lb/day Limestone required to neutralize } \text{H}_3\text{PO}_4$$

ACETIC ACID

$\text{CH}_3\text{COOH}$ is very soluble in scrubber water under normal conditions, therefore no vapor $\text{CH}_3\text{COOH}$ emission is assumed in scrubber exit gas.

$\text{CH}_3\text{COOH}$ will react with limestone bed as follows:

$$2\text{CH}_3\text{COOH} + \text{CaCO}_3 \rightarrow \text{Ca}_2(\text{CH}_3\text{O}_2)_2 + \text{CO}_2 + \text{H}_2\text{O}$$

Normal Case = 1390 g/day $\text{CH}_3\text{COOH}$

$$1390 \text{ g/day} \times \frac{100.09 \text{ g/mol}}{2(60.05) \text{ g/mol}} = 1158 \text{ g/day} + 454 = 2.6 \text{ lb/day Limestone}$$

Assume 50% reagent reactivity efficiency

$$2.6 \text{ lb/day} \times 2 = 5.2 \text{ lb/day Limestone required to neutralize } \text{CH}_3\text{COOH}$$
ACETONE

CH₂COCH₃ is infinitely soluble in scrubber water under normal conditions, therefore CH₂COCH₃ emission is assumed in scrubber exit gas.

TRICHLOROETHYLENE

Trichlorethylene is only very slightly soluble in scrubber water under normal conditions, therefore it is assumed that all trichlorethylene emission is present in the scrubber exit gas.

PROPANOL

Propanol is infinitely soluble in scrubber water under normal conditions, therefore no vapor emission of propanol is assumed to exist in scrubber exit gas.

STODDARD SOLVENT

This petroleum solvent is essentially insoluble in the scrubber water under normal conditions, therefore it is assumed the total emission is present in the scrubber exit gas.

XYLENE

This aromatic hydrocarbon is essentially insoluble in the scrubber water under normal conditions. Therefore, it is assumed that the total emission is present in the scrubber exit gas.
BUTYL ACETATE

This organic ester is only very slightly soluble in the scrubber water under normal conditions. Therefore, it is assumed that the total emission is present in the scrubber exit gas.

SCRUBBER LIMESTONE CONSUMPTION

<table>
<thead>
<tr>
<th>REACTANT</th>
<th>NORMAL CASE DAILY USAGE, lb</th>
<th>WORST CASE DAILY USAGE, lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCl</td>
<td>6.38</td>
<td>13.6</td>
</tr>
<tr>
<td>HF</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>HNO₃</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>H₂SO₄</td>
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<td>0.6</td>
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<td>H₃PO₄</td>
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<td>CH₃COOH</td>
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<tr>
<td></td>
<td>15.02</td>
<td>22.24</td>
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</tbody>
</table>

When any ammonia is present in the scrubber water it will react with these six acids to reduce the consumption of limestone. Any ammonium salts (e.g. NH₄Cl, NH₄F, NH₄NO₃ etc.) produced in this neutralization will be soluble in the scrubber water, thus, they will not be present in the scrubber exit gas.
9

RECOMMENDATIONS
9. **RECOMMENDATIONS**

Based upon the data received by NASA, ICE calculated the potential emissions from the exhaust system. As a result of these calculations, it was determined that the OSHA limits would be exceeded under worst case operating conditions by the HCl gas, and under normal operating conditions by acetone and trichlorethylene. Thus, ICE recommends that an exhaust gas scrubber be installed.

Based upon the air flow requirements, ICE recommends that three DFC023 scrubber modules or equivalent be utilized to handle the typical exhaust volume. These three scrubber modules will require a total of 15 gallons per minute (56,775 milliliters per minute of water).

In addition, ICE recommends that a hydrogen burn-off be installed on the present epitaxy reactor system. Calculations elsewhere in this report show that the scrubber is absolutely needed for epitaxial reactor, however, no provisions have been made to take an account of the hydrogen gas flow.

ICE also recommends that exhaust hoods or vent hoods be placed over the end of the CVD reactor to protect the room of unwanted gas flow during possible tube breakage.

It should be noted that the above calculations and recommendations are based on the planned conditions, as provided by NASA. These conclusions do not take into account added processing steps or new chemicals which might be added at a later date. It should be noted that some chemicals such as H2SO4 are close to the limits now, and any change in the rate can cause these materials to exceed OSHA limits.

If an exhaust gas scrubber is not used, ICE strongly recommends that the present exhaust vent be modified to a vertical position to release the gases above the roof line. In addition, the outlet should be at least six feet from any possible air intakes. Vents should also have some type of covering or traps, so heavy rain water will not wash down the stack, and create possible corrosive problems in the duct work.
It should be noted that in some areas the EPA requires measurements of contaminants at the exhaust stack. For example, semiconductor plants in Austin, Texas must measure pollutants at the exhaust stack outlet, thus, scrubbers would be necessary to meet EPA requirements. Other locations, such as Phoenix, Arizona are allowed to measure contaminants at the plant boundary, which does allow adequate dilution.

In reviewing this particular requirement, ICE found that there is no source of information in the industry regarding vapor pressures of mixed chemicals. This is necessary to provide and obtain accurate calculations of potential hazards. ICE made several assumptions in arriving at the necessary vapor pressures for the calculations listed in this report. It would be desirable to have experimental and calculated data confirmed, so that these vapor pressure values might be available to others in the industry as well as reinforcing our calculations.
Several chemical solutions used in the processing of polysilicon-gate CMOS/SOS deep depletion circuits require that they be mixed by the processor. Some solutions cannot be readily found in the mixed form while others should be mixed immediately prior to use. All chemicals used in processing should be reagent grade or equivalent to prevent contamination of the wafers.

**Sulfuric Acid-Nitric Acid Solution**

- 2ml $\text{H}_2\text{SO}_4$ Sulfuric Acid (-98%)
- 1ml $\text{HNO}_3$ Nitric Acid (-70%)

**Buffered Oxide Etchant**

- 5g $\text{NH}_4\text{F}$ Ammonium Flouride-Crystal
- 2ml $\text{HF}$ Hydroflururic Acid (-49%)
- 8ml $\text{H}_2\text{O}$ Water

**Hydroflouric Acid Solution**

- 1ml $\text{HF}$ Hydroflouric Acid (-49%)
- 10ml $\text{H}_2\text{O}$ Water

**Jacobson's Etchant**

- 25ml $\text{H}_2\text{O}$ Water
- 5ml $\text{HCl}$ Hydrocholoric Acid (-37%)
- 5ml $\text{HNO}_3$ Nitric Acid (-70%)
- 1ml $\text{H}_2\text{SO}_4$ Sulfuric Acid (-98%)
APPENDIX A (concluded)

**Aluminum Etchant**

<table>
<thead>
<tr>
<th>Volume</th>
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<tr>
<td>25ml</td>
<td>H₃PO₄</td>
<td>Phosphoric Acid (~85%)</td>
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<td>5ml</td>
<td>CH₃COOH</td>
<td>Acetic Acid - Glacial (~100%)</td>
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<tr>
<td>1ml</td>
<td>HNO₃</td>
<td>Nitric Acid (~70%)</td>
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**Aluminum Compatible Photo Resist Remover**

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<td>Sulfuric Acid (~93%)</td>
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<td>1g</td>
<td>CrO₃</td>
<td>Chromic Acid Anhydride-Crystal</td>
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**Silicon Etchant**

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<td>KOH</td>
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<td>1-Propanol</td>
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<td>H₂O</td>
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**Azeotropic Mixture for Gate Oxidation**

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## APPENDIX B

### ABBREVIATIONS

#### VOLUME

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<td>cf</td>
<td>Cubic Feet</td>
</tr>
<tr>
<td>cc</td>
<td>Cubic Centimeters</td>
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<tr>
<td>l</td>
<td>Liters</td>
</tr>
<tr>
<td>gal</td>
<td>Gallons</td>
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<tr>
<td>m³</td>
<td>Cubic Meters</td>
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#### FLOW

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<tr>
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<td>Cubic Centimeters Per Minute</td>
</tr>
<tr>
<td>l/min</td>
<td>Liters Per Minute</td>
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<tr>
<td>m³/min</td>
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<tr>
<td>gpm</td>
<td>Gallons Per Minute</td>
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<tr>
<td>lb/day</td>
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<tr>
<td>g/min</td>
<td>Grams Per Minute</td>
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<tr>
<td>g/day</td>
<td>Grams Per Day</td>
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#### CONCENTRATION

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<tr>
<td>ppm</td>
<td>Parts Per Million (volume basis)</td>
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<tr>
<td>mg/m³</td>
<td>Miligrams Per Cubic Meter</td>
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#### MASS

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<th>Description</th>
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</thead>
<tbody>
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<td>Grams</td>
</tr>
<tr>
<td>mg</td>
<td>Miligrams</td>
</tr>
<tr>
<td>lb</td>
<td>Pounds</td>
</tr>
<tr>
<td>kg</td>
<td>Kilograms</td>
</tr>
<tr>
<td>mol</td>
<td>One Gram Molecular Weight</td>
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#### PRESSURE

<table>
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<tr>
<td>tor</td>
<td>Milimeters of Mercury at 20°C</td>
</tr>
<tr>
<td>atm</td>
<td>Atmospheres (1 atm = 760 tor)</td>
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</table>

#### DENSITY

<table>
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<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>g/cc</td>
<td>Grams Per Cubic Centimeter</td>
</tr>
</tbody>
</table>
APPENDIX C
CONSTANTS AND CONVERSION FACTORS

22.4 Volume of 1 gram molecular weight of gas (1 mol volume)
44.64 Mol volumes per cubic meter
162.6 Stoddard solvent, liquid volume to vapor volume conversion
142.1 Xylene solvent, liquid volume to vapor volume conversion
0.0283 Cubic meters per cubic feet
28317 Cubic centimeters per cubic foot
0.135 Diffusion and CVD exhaust dilution factor
154 Etch hood dilution factor
1.5 Total vent dilution factor
454 Grams per pound
0.90 Specific gravity of xylene
0.684 Specific gravity of stoddard solvent
0.883 Specific gravity of n-butylacetate
760 Standard conditions atmospheric pressure in tor
# MOLECULAR WEIGHT OF CHEMICALS

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Symbol</th>
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<td>Diborane</td>
<td>B₂H₆</td>
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<td>Hydrogen Chloride</td>
<td>HCl</td>
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<td>Dichlorosilane</td>
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<tr>
<td>Nitrous Oxide</td>
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<td>Hydrogen Fluoride</td>
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<td>Xylene</td>
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<td>Stoddard Solvent</td>
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# Epitaxy Operation Emissions

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<th>Silicon Growth with SiCl₄ Source</th>
<th>Silicon Growth with SiH₄ Source</th>
<th>Ammonia/ Nitrous Oxide</th>
<th>HCl Cleaning</th>
<th>HCl Etching</th>
<th>OSHA Limits</th>
<th>Problem Areas</th>
<th>H₂O Solubility (CC/CM₄₂O)</th>
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<td><strong>Ammonia (NH₃)</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td>CVD Operation</td>
<td>Diffusion Operation</td>
<td>Gross Unreacted Total Output</td>
<td>Net Combined Output</td>
<td>Net Output with Total Exhaust Dilution</td>
<td>OSHA OSHA Limits</td>
<td>Problem Areas</td>
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<td>---------------------</td>
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<tr>
<td><strong>AMMONIA (NH₃)</strong></td>
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<td>g/day, Worst Case</td>
<td>176</td>
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<tr>
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#### COMBINED TOTAL EMISSIONS FROM

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**ORIGINAL PAGE 18**
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**OSHA Human Exposure Limits**
(For 8 Hours)

- **HF:** 3.0 ppm
- **HCl:** 2.0 ppm
- **HNO₃:** 5.0 ppm
- **H₂SO₄:** 7.0 ppm
- **H₃PO₄:** - ppm
- **CH₃COO:** 1.0 ppm
- **CH₃COOH:** 10 ppm
- **Total Facility:** 25 ppm

**EPA NO₂ Emissions**

- **Maximum Hourly:** 350 ppm
- **Average 24 hr:** 1900 ppm

*Possible Substitute is 1,1,1-Trichloroethane
**OSHA Limit**

**EPA NO₂ Emissions in**

- **Maximum Hourly:** 0.47
- **Average 24 hr:** 0.10
ORIGINAL PAGE IS
OF POOR QUALITY

Fed Air Flow System

H₂O (10 Gallons/minute ± 4)

110L/minute

maximum

Scrubber

EPI

Chemical Hoods

Photoresist

900 CPM

(225.5 m³/min)

4500 CPM

(127 m³/min)

6688 CFM

(336.1 m³/min)

Diffusion
OPERATIONS AND SAFETY CHECKLIST
GENERAL FACILITIES

THIS INCLUDES CONSIDERATIONS FOR THE FOLLOWING AREAS:
A. DI WATER, COOLING WATER AND WASTE WATER SYSTEMS.
B. COMPRESS GAS STORAGE, GAS AND VACUUM DISTRIBUTION SYSTEMS.
C. VENT GAS SYSTEM.
D. CHEMICAL STORAGE AND HANDLING, CHEMICAL ANALYSIS
E. GLASSWARE CLEANING.
F. ELECTRICAL AND PROCESS TESTING.

I-PRECONDITION/CALIBRATION STEPS

1. Check or calibrate resistivity meters and indicators.
2. Check or calibrate system pressure gauges, flow indicators and flow meters.
3. Check operations of biological suppression system.
4. Check for proper operation of solenoid valves, control valves and pressure relief devices. Check for corrosion or scale that can interface with proper operation. (Ref. 1)
5. Check operations of chemical waste sewer operation. Check neutralization and pH monitor system.
6. Check water quality from pre-treatment system. (Particulates, organics, dissolved gasses)
7. Check resin regeneration reagent reservoir. Replenish as needed.

CAUTION: Eye, limb and body protection required when handling or exposed to strong acids and bases. (Ref. 2, P. 11-14, P. 165-166)

8. Check operations of automatic regeneration cycle. (Ref. 1; Ref. 3)
9. Check operations polisher tanks. (Ref. 1)
10. Check operations of storage tank level control and circulating system. (Ref. 1)
11. Check distribution system for leaks.
B. Compressed Gas Storage, Gas and Vacuum Distribution System

1. Make sure gas cylinders are properly identified and mechanically secured in bulk storage and in manifold and on-site use. (Ref. 2, P. 10-42).

2. Install cylinders in supply manifold. Inspect fittings and over-pressure relief. Check for leaks in fittings and manifold.

3. Check operations of vacuum pump and vacuum distribution system.

4. Check for leaks in total gas or vacuum system.

5. Check operations of hazardous gas monitors. (Ref. 4).

6. Check operations of combustible gas detectors. (Ref. 5).

7. Check operations and readiness of Survivair self-contained breathing equipment. Replenish air supply as needed. (Ref. 2, P. 32-36).

C. Vent Gas System

1. Check flow volume and draft pressure at various inlet stations. Balance system as needed.

2. Check for structural integrity and loose joints in duct system. Check for leaks.

3. Check for condensation in horizontal runs or natural traps. Drain if possible.

   CAUTION: Eye and hand protection required when handling or exposed to fluids that can be acidic. (Ref. 2, P. 11-14).

4. Check structural integrity of blowers and motors.

5. Check proper operations of vent gas scrubbers. Replenish limestone beds as needed.
D. Chemical Storage and Handling

1. Make sure that the safe amounts of chemicals are in internal and external storage. (Ref. 2, P. 94-106).

2. Make sure that solvents, acids, bases and oxidizers are all stored and handled separately.

3. Check for venting or leaking containers. Remove or correct as needed. (Ref. 2, P. 11-14).

   CAUTION: Face and hand protection required when handling or exposed to acids, bases or solvents. (Ref. 2, P. 11-14).

4. Use care in dispensing, mixing or diluting chemicals. Avoid spills, contaminations, toxic vapors or inflammable vapors. (Ref. 2, P. 11-14, 94-106).

   CAUTION: Eye, face, and hand protection required when working with strong acids or bases. Extreme care is required in handling HF. Absolute integrity of hand protection is essential. (Ref. 2, P. 11-14, 159-160, 213-216). In case of acid splash or spill use safety shower or eye wash as needed. Neutralize and absorb spills to eliminate liquid hazard. Ventilate room to eliminate vapor hazard.

5. Always dilute acids by adding the required amount of DI water to the acid while stirring. Never add acid to water. Be alert for a temperature rise due to the possible heat of solution.

6. Keep chemical container properly sealed as much as possible to avoid contamination.

E. Glassware Cleaning

1. Check for proper operations of reactor tube, cleaning hood, exhaust vent, DI water flow, and waste water drain.

2. Store dirty reactor tubes so as to avoid breakage and possible toxic vapor emissions.
3. Use care in dispensing, using, and draining acid etches and cleaners. 
   CAUTION: Eye, face, body and limb protection required when exposed to or working with HF/HNO₃ mixtures. (Ref. 2, P. 159-160, 213-216). Absolute integrity of hand protection is essential when exposed to HF.

4. Always handle dirty lab glassware as if it were contaminated with hazardous or toxic chemicals.

5. Store cleaned glassware to avoid possible gaseous or particulate contamination.

6. Check for chips or cracks. Repair and stress relieve as needed. Reclean and then properly store.

F. Electrical and Process Test

1. Check main electric power supply. Check voltage regulation, ripple and proper phasing. Check operations of breakers. (Ref. 2, P. 79-81, 82-93).

2. Check electric power supply at each piece of major equipment. Check conduit, outlets and breakers.
   CAUTION: Make sure all equipment is properly grounded. (Ref. 2, P. 82-93).

3. Check for proper operations of electrical test equipment. Verify integrity of grounding and shielding where needed. (Ref. 6).

4. Check for proper probe operations. Replace probe points as needed. (Ref. 6).

5. Calibrate electrical test equipment as needed. (Ref. 6).

6. Check and calibrate power supplies used for electrical testing. (Ref. 2, 79-81).

2-OPERATING/PROCESS STEPS

Operations of these general facilities can be done in the manual mode. The water systems, gas systems, vent systems, and test systems are normally operated in the automatic mode.
3-NORMAL SHUT DOWN STEPS


1. Shut down automatic regeneration system. ..............................................
2. Switch off instrumentation and controls. .............................................
3. Continue circulation system. ..............................................................

If long term shut down (several weeks or more) is anticipated then these additional steps are needed.

4. If continued circulation with the biological suppression system operating cannot be maintained, then the total system (including resin bed, but excluding pretreater) should be filled with a 1% formaldehyde in DI water solution to prevent biological fouling of lines, equipment, and resin. .............................................................
5. Remove regenerating reagents. Return to bulk storage. ........................
6. Switch off main electric power supply. .............................................
7. Shut down waste water treatment system. ..........................................

B. Compressed Gas Storage, Gas and Vacuum Distribution System.

1. Close cylinder valves on supply manifold. ...........................................
2. Switch off hazardous gas monitors. (Ref. 4). .....................................
3. Switch off combustible gas detectors. (Ref. 5). .................................
4. Shut down vacuum system. ...............................................................

If long term shut down (several days or more) is anticipated, then these additional steps are needed.

5. Vent hazardous or toxic gas systems. Purge with N₂. ..........................
6. Vent N₂ gas system. .................................................................

C. Vent Gas System

1. Make sure all sources of toxic, hazardous, or flammable vapors have been removed from the various processing systems. .........................
2. Shut down vent gas system blowers. ................................................
3. Shut down vent gas scrubbers. ......................................................
F. Electrical and Process Test

1. Switch off individual test modules. ........................................... □

2. Check for electrical equipment defects such as shorts, insulation breaks, proper grounds. (Ref. 2, P. 79-93). ........................... □

Normal maintenance and preventative maintenance is done on equipment after normal shut down. (Ref. 3, Ref. 5, Ref. 6).
4-EMERGENCY SHUT DOWN STEPS


This can be caused by chemical problems, (reagent spills) electrical/mechanical problems (power outage, loss of water pressure, or pump, valve or solenoid failure) or fire in an adjacent area.

1. Activate fire extinguisher system if needed.  
2. Switch off main electrical power supply.  
3. Turn off circulation system.  
4. Drain and dispose of regeneration reagents.  
5. Shut down cooling water system.  
6. Shut down waste water neutralizing and monitoring system.  
7. Inventory extent of damage.  

B. Compressed Gas Storage, Gas and Vacuum Distribution Systems.

This can be caused by toxic, hazardous or flammable gas leak, fire, over temperature or over pressure conditions or electrical/mechanical problems.

1. Activate fire extinguisher system if needed.  
2. Close valves on leaking cylinders or leaking manifold and fittings. (Ref. 2, P. 37-42).

   CAUTION: If vent gas system is shut-down and process gas cannot be safely turned off, then enter room only with self-contained breathing equipment to extinguish fire or close valves. (Ref. 2, P. 32-36, Ref. 7).

3. Shut down vent gas system.  
4. Shut down N₂ gas system.
5. Shut down vacuum systems. ..........................................
6. Switch off main AC electric power. .................................
7. Force ventilate room. Test for toxic or flammable gasses. (Ref. 4, Ref. 5). ..........................................
8. Inventory extent of damage. ........................................

C. Vent Gas System
This can be caused by fire or electrical/mechanical problems. ........
1. Shut down vent system when any fire occurs. An operating vent system can drain flames into an unaccessible and thus uncontrollable area. ..........................................
2. Shut down or dispose of sources of hazardous, toxic or flammable vapors. ........................................

CAUTION: When vent gas system is shut down and process gasses cannot be safely turned off, then enter rooms only with self-contained breathing equipment. (Ref. 2, P. 32-36, Ref. 7).

3. Shut down vent gas scrubber. ........................................
4. Shut down N₂ gas system. ........................................
5. Switch off main AC electric power. .................................
6. Force ventilate rooms. Test for toxic or flammable gasses. ....
7. Inventory extent of damage. ........................................

D. Chemical Storage and Handling, Chemical Analysis.
This can be caused by a fire or damaged, leaking, or venting containers.
1. Activate fire extinguisher system if needed. ........................
2. Remove and dispose of source of venting or leaking chemicals, acids, bases or solvents. .................................

CAUTION: Eye, face and hand protection required when handling or exposed to strong acids and bases or solvents. (Ref. 2, P. 11-14, 94-106.)
3. Check for toxic or hazardous gasses produced by thermal decomposition of chemicals exposed to a fire.

4. Check for toxic or hazardous gasses produced by interaction of chemical or solvent from broken containers.

5. Force ventilate room. Test for toxic or flammable gasses. (Ref. 4, Ref. 5).

6. Inventory extent of damage.

E. Glassware Cleaning

This can be caused by fire in adjacent area, major acid spill or mechanical problem.

1. Drain or dispose of acid etch solutions and cleaners.

   CAUTION: Eye, face, body, and limb protection required when handling or exposed to HF/HNO₃ mixtures. (Ref. 2, P. 159-160, 213-216).

2. Be careful for acid splash or broken glassware.

3. Switch off main AC electric power.

4. Over temperature of acid etches can cause production of toxic vapors. If this occurs then force ventilate room and remove source.

   CAUTION: If vent gas system is shut down and toxic gasses are present, then enter room only with self-contained breathing equipment. (Ref. 2, P. 32-36, Ref. 7).

5. Neutralize and absorb spills to eliminate liquid hazards.

6. Inventory extent of damage.

F. Electrical and Process Testing.

This can be caused by power outages, shorts, and mechanical/electrical problems with switches, relays, power supplies.

1. Switch off individual equipment modules.
CAUTION: Make sure all electrical equipment is properly de-energized. Faulty switches or breakers can fail to switch off. (Ref. 2, P. 79-81).

2. Turn off $N_2$ or vacuum supply to test modules.

3. Inventory extent of damage.
5-EMERGENCY SHUT DOWN, CLEAN UP, INSPECTION AND REPAIR STEPS

Most of these steps are applicable to all of the General Facilities Areas.

1. Make sure main AC electrical power is switched off. (Ref. 2, P. 79-81).

2. Clean up any fire extinguisher, chemical splash or fire damage on equipment.

   **CAUTION:** Eye and hand protection required when cleaning splashes of unknown origin. Handle as if it were a strong acid base or solvent. (Ref. 2, P. 11-14).

3. Inspect/test and repair any electric cable or insulation damage...

   **CAUTION:** Make sure all equipment is properly grounded. Make sure there are no electrical shorts. (Ref. 2, 79-93).

4. Selectively switch on electric power to each piece of equipment. Check for proper reaction.

5. Inspect, test and repair as needed the total vent system and vent gas scrubber.

6. Inspect and test operations of toxic gas monitor and combustible gas detector. (Ref. 4, Ref. 5).

7. Check for broken glassware. Discard or repair and clean as required.

8. Repair damage to fitting and relief devices on gas cylinder and manifolds. Pressure test as needed. (Ref. 2, P. 37-46).

9. Do required maintenance on each piece of equipment. (Ref. 3, Ref. 6).

10. When system check and required maintenance is completed, then either go to normal shut down or to Precondition/Calibration steps as needed.
6-REFERENCES


2. Safety and Environmental Health Standards, MM 1700. 4B, MSFC, October 15, 1974.


OPERATION AND SAFETY CHECKLIST
VENT GAS SCRUBBER

EMERGENCY SHUTDOWN PROCEDURE

1. Activate fire extinguisher system if needed

2. Evacuate work area if excessive toxic, corrosive or flammable gas is detected (Ref. 2, P. 720)

3. Shut-down process gas sources (EPI, Diffusion, CVD Etch)

4. Turn off electric power to scrubber

5. Turn off water supply to scrubber

Clean Up After Emergency Shut-Down

1. Clean work area to assure that any toxic, corrosive or explosive gas residue is below safe limits. If excessive residue is indicated; continue venting area until safe levels are reached before starting clean up. (Ref. 2, P. 720)

2. Make sure final drain is working properly

3. If limestone bed is plugged or depleted then drain water and replenish reagent

4. Drain scrubber water into limestone bed

Caution: Water may contain acid residue. Use gloves, face mask, and lab coat. Neutralize and dilute any spills to drain. (Ref. 1, P.3; Ref 2, P. 11 & 12)

5. Check integrity of vent duct system by leak testing

6. Check integrity of scrubber module for liquid and gas leaks
OPERATION

Preconditioning Steps

1. Switch on electric supply .........................................................

2. Turn on water supply, set pressure regulator to 20 PSI.
   (Ref. 1, P.2) .............................................................................

3. Remove 2 scrubber lids. ..............................................................

   Caution: Possible acid water residue.
   Use gloves, face mask and lab coat. (Ref 2, P. 11 & 12.)

4. Check for proper operation of spray heads (Ref. 1, P. 2). ...........

5. Check that demister is not plugged. .............................................

6. Replace scrubber lids. Check for seal integrity. ...........................

7. Turn on blower. Check for correct rotation, speed and volume flow.
   Check mechanical integrity. (Belts, pulleys, mounts, motor arching
   or overheating). .................................................................

8. Check liquid level and presence of agitation thru view ports.
   (Ref. 1, P. 2 & 3) .................................................................

9. Check for lid seal leaks, vent duct leaks, and liquid leaks .........

10. Check for proper flow from scrubber into limestone bed and from bed
    to final drain ........................................................................

11. Check limestone bed level. Replenish if necessary. .................

12. Check for proper air flow into final vent .................................

13. Establish equilibrium air and water flow for 45 minutes before
    introducing vent gasses. (Ref. 1, P. 3) ..............................
OPERATION

Operating Steps

1. Make sure precondition steps and condition have been achieved.

2. Check for 10 seal and ducts for gas leaks and scrubber unit and piping for liquid leaks.
   a. Small or non-hazardous leaks should be noted for repair and maintenance. (Ref. 1, P. 3)
   b. Large or catastrophic leaks should be handled emergency shut down.

   CAUTION: All gas leaks should be treated as toxic and all liquid leaks as acid.

3. Check for plugged spray heads (Ref. 1, P. 3)

4. Make sure demister is not plugged (Ref. 1, P. 3)

5. Check for plugged drain to sanitary sewer

6. Maintain appropriate level in limestone bed

7. Test gas effluent for acceptable level of toxic gases (Ref. 3, P. 720)

8. Test liquid effluent for pH from 6.0 to 9.0. Also check for As, B, F, concentration (Ref. 4, P. 1 & 2)

Normal Shut-Down


2. Maintain air and water flow for 15 minutes to purge remaining gas and liquid contaminants.

3. Shut off blower and water supply

4. Drain scrubber and limestone bed

5. Turn off electric supply
Emergency Shut-Down

There are three categories of problems that can require emergency shut-down. They are:

1. Ducting Problem. Leak or rupture (H₂ explosion) in vent duct to scrubber.

2. Scrubber Problem. Abnormal high vent gas flow, loss of blower, loss of water, massive leak or loss of scrubber seal, ruptured scrubber, plugged nozzles or plugged drain.

3. Limestone Bed and Drain Problems. Plugged (overflowing) or channeling (no neutralizing) bed, depleted bed, plugged final drain.
APPENDIX

References

1. Instruction Manual, No. IS20-78, Ducon Fumatron Scrubber

2. Safety and Environmental Health Standards, Marshal Manual MM 1700. 4B, July 1, 1976


Chemical Problem Shut-Down

This can be caused by reactive gas explosion or fire, large gas system leaks, gas flow from process tube (flange leak, crack, rupture), or vent system failure.

1. Activate fire extinguisher system if needed.

2. Close valves on reactive gas cylinder.

CAUTION: If vent system is not working and reactive gas cylinder valves cannot be closed, then enter room only with self-contained air breathing equipment to extinguish fire or close valves. (Ref 8).

3. Shut off CVD main electric supply at C180 Distribution Panel (Ref 1).

4. Shut off N2 supply to equipment (Ref. 1, Sec. 2.4, 6.4).

5. Force ventilate room, test for toxic gas residue.

6. Switch off individual pieces of equipment. (Ref. 1, Sec. 1.3 P 2 & 3; Ref. 5).

7. Inventory extent of damage.

Electrical Problem Shut-Down

This can be caused by power outage, voltage excursions, shorts, damage to wire and insulation, and defects in electrical equipment (motors, solenoids, etc.).

1. Isolate and switch off vacuum module. (Ref. 1, Sec. 1.3 P. 3; 6.2 P 20; Ref 5).

2. Isolate and switch off furnace. (Ref. 1, Sec. 1.3 P. 2 & 3; Ref. 5).

3. Isolate and switch off gas system. (Ref. 1, Sec. 1.3 P 2 & 3; Ref. 5).
4. Shut down load station  
(Ref. 1, Sec. 1.3, P 2; Ref. 5)  

5. Shut down up-stream computer  
(Ref. 1, Sec. 1.3, P. 3; Ref. 5).  

6. Shut down monitrol (Ref. 1, Sec. 1.3, P. 2; Ref. 5)  

7. Check equipment for possible electric shock  

**Mechanical Problem Shut-Down**  

This can be caused by malfunctions on mechanical equipment, handling mechanisms, instruments and meters, control valves and pressure regulators.  

1. Shut-down reactive gas system  
(Ref. 1, Sec. 5.2, P. 17, Fig. 6 & 7).  

2. Shut-down vacuum module system  
(Ref. 1, Sec. 1.3, P. 3; 6.2, P. 20; Ref. 5).  

3. Shut-down furnace (Ref. 1, Sec. 1.3, P. 2 & 3; Ref. 5)  

4. Shut-down load station  
(Ref. 1, Sec. 1.3, P. 2; Ref. 5).  

5. Shut-down up-stream computer  
(Ref. 1, Sec. 1.3, P. 3; Ref. 5).  

6. Shut-down monitrol (Ref. 1, Sec. 1.3, P. 2; Ref. 5).  

7. Inspect for equipment defects.  

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**EMERGENCY SHUT-DOWN - CLEAN-UP, INSPECTION AND REPAIR STEPS**  

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**Resulting from chemical problems**  

1. Make sure electrical power is turned off  
(Ref. 7, Position 24).  

2. Vacuum-up dry extinguisher power, mop up liquid.  

3. Wipe equipment, gages, meter faces with detergent water (Ref. 4, Sec. IV, P. 8).  

4. Inspect/test and repair electrical wiring and insulating damage. Make sure all equipment is properly grounded.  

5. Selectively switch on all equipment electric power for testing. (Ref. 1, Sec. 1.3, P 2 & 3; Ref. 5).  

6. Clean vent system, test for correct flow.
1 - PRECONDITIONING/CALIBRATION STEPS

Utilities and Gasses

1. Turn on N₂, set pressure regulator at 80 PSIG, and set flow rate to wafer track, load station and vacuum module (Ref. 1, Sec. 2.4, P 10, S. 4, P, 22) .

2. Process reactive gas lines hooked up to panel. Purge gas lines and manifold with N₂ (Ref. 1, Sec. 5.1, P. 16, 5.2, P. 16) (Limit pressure to <50 PSIG) .

3. Electric power lines plugged into proper outlets. Caution: Make sure all equipment is properly grounded.

Equipment Check

1. Check proper operation of total vent gas system (Ref. 1, Sec. 6.2, P. 20; Fig. 6 & 7) .

2. Check proper operation of total vacuum module system. (Ref. 1, Sec. 6.2, P. 20; Fig. 8) .

3. Check oil level in vacuum pump, add if needed (Ref. 2, Sec. 2.2) .

4. Check and replace as needed filters on N₂ lines .

5. Pressure test process gas system when leak is suspected. After test, vent pressure and open individual gas cylinders. (Ref. 1, Sec. 5.1, P. 16) .

6. Check operations of pressure regulators, solenoid and control valves on gas system, wafer handling system and vacuum system (Ref. 1, Sec. 5.7, 5.8, P. 18; 6.2, 6.4, P. 22; Fig. 4,6 & 7). .

7. Calibrate thermocouple circuits, and vacuum gages (Ref. 1, Sec. 6.2, 6.3, Ref. 4, Sec. III, P,7) .

8. Check/set temperature, pressure, pressure limits flow/conditions required for process. Pages 17 & 18) .

9. Purge vacuum pump to exhaust with N₂ (Ref. 1, Sec. 6.4 E. P. 23).

10. Turn Vacuum Pump on. (Ref. 1, Sec. 6.2 P. 20).

11. Pump down vacuum system. Check for acceptable leak rate of rise. Repressure with N₂. (Ref. 1, Sec. 6.2, P. 20 & 21; Sec. 6.4 E, P. 23).
Initializing System

1. Establish initial conditions (Ref. 1, Sec. 1.2, P.1, Ref. 5)
2. Start up wafer track (Ref. 5)
3. Switch on monitor. Load system, control point table and process tapes. Select manual/auto mode (Ref. 1, Sec. 1.3 A, P.2; Ref. 5)
4. Switch on load station. Select manual/auto mode (Ref. 1, Sec. 1-3 B, P.2; Ref. 5).
5. Switch on vacuum pump. Select manual/auto mode (Ref. 1, Sec. 6.2 P. 20; Ref. 5).
6. Carefully load wafers into empty carrier on BT-1

2 - OPERATING/PROCESS STEPS

Operations of the system are done in either the automatic or manual mode.

1. Check to make sure initializing conditions have been set. (Ref. 1, Sec. 1.2, P. 1; Ref. 5).
2. Start up-stream computer (Ref. 1, Sec. 1.3A, 4.0, P. 14).
3. Start monitor computer (Ref. 1, Sec. 1.3, P. 3; P. 2).
4. Automatic Mode
   Operate total system in remote/auto mode (Ref. 1, Sec. 1.3, B, P.2).
5. Manual Mode
   Operate wafer loading system in local/manual mode (Ref. 1, Sec. 3.1, P. 13; Ref 2.0, P. 11 & 3.0 P. 11).
6. Operate vacuum module system in local/manual mode (Ref. 1, Sec. 6.1, P. 20).
7. Clean and check operation of reactive gas regulators; solenoid valves and flow meters. 
Purge lines and manifold (Ref. 1, Sec. 5-2, P. 16 & 17; Ref. 5).

8. Pressure/leak test gas system (Ref. 1, Sec. 5.1, P. 17).

9. Clean vacuum pump, check oil level and contamination, and check operations. (Ref. 1, Sec. 6.3, P. 20; Ref. 2, Sec. 3.1, 3.2, P. 6; Ref 5).

10. Remove, clean and reinstall process tubes. Repair/replace damaged components (Ref. 1, Sec. 7.1, 7.2, P. 24).

11. Leak test process tube/vacuum system (Ref. 1, Sec. 7.3, P. 25).

12. Check operation of safety interlock on vacuum module. (Ref. 1, Sec. 6.4, P. 22).

13. Check furnace heat-up and control. (Ref. 5).

14. Check operations of boat puller/pusher (Ref. 1, Sec. 2.3, P. 9; Ref. 6).

15. Check operations of load station through a complete cycle (Ref. 1, Sec. 2.0, P. 4; Sec. 2.1, P. 5; Fig. 2; Ref. 6).

16. Check operations of up-stream controller (Ref. 1, Sec. 4.0, P. 14 & 15; Ref. 5).

17. Check operations of monitrol (Ref. 1, Sec. 3.0, P. 11 & 12; Ref. 5).

18. When system checks are complete, then either go to normal shut-down steps or to precondition/calibration steps as needed. (Ref. 5).
3 - NORMAL SHUT-DOWN STEPS

Operations of the system are completed in the automatic or manual mode. All wafers are removed from system.

1. Establish final conditions (deposition completed).
2. Purge vacuum pump to exhaust with N₂.
3. Switch off vacuum pump (Ref. 1, Sec. 6.2, P. 20; Sec. 6.4 B,C,D, P. 22).
4. Switch off up-stream computer.
5. Unload tapes (Ref. 1, Sec. 1.3, P. 2).
6. Switch off monitrol (Ref. 1, Sec. 1.3, 2.1, P. 2).
7. Close valves on reactive gas cylinders. Purge lines and manifold with N₂ (Ref. 1, Sec. 5.2, P. 16).
8. Turn off N₂ and dry air supply (Ref. 1, Sec. 2.4, P. 10).
9. Switch off main electric supply (Ref. 7, position 24).

The need for maintenance is determined by inspection after normal shut-down.

1. Check and clean process tube (Ref. 1, Sec. 7.1, 7.2, P. 24).
2. Switch on electric supply to equipment under test.
3. Leak test vacuum system (Ref. 1, Sec. 7.3, P. 25).
4. Check vacuum pump oil for level and contamination (Ref. 2, Sec. 3.1, 3.2).
5. Clean foreline trap. (Ref. 1, Fig. 8).
6. Replace gas filers as needed.
7. Check seals and lubricate vacuum gate valves (Ref. 3, Sec. 1., P. 1).
8. Clean and lubricate mechanical equipment as needed.
9. Check vent system equipment and flow. (Ref. 1, Fig. 8).
References

2. Primary Vacuum Rotary Pump, Instructions for Starting and Maintenance, CIT-Alcatel
3. SVB Series, High Vacuum Gate Valves Operation and Maintenance, Torr Vacuum Products.
4. Thermocouple Vacuum Gage Controller Operating Instruction, Varian Lexington Vacuum Division
5. CVD System Routine (CVD 9 & 10)
6. CVD Reactor Automatic Loading Station Sequence (CVD 7 & 8)
7. Photograph Of RM C-180 Power Distribution Panel
REFERENCE 5

CVD SYSTEM ROUTINE

1. Furnaces are energized by switches on controllers

2. Doping systems are turned on by switches on plug strips (1 per cabinet) at the bottom of the cabinets. Lights at top of cabinets have separate switches.

A. FURNACE (COMPUTER MONITROL)
   1. Turn on Plug Strips
   2. Turn Monitrol ON
   3. Sequence Control Switch to Manual Mode
   4. Verify Tube off lights lit (2 tubes)
   5. Verify all "VALVES OFF" Indicators ON.

B. LOAD STATION
   1. Turn on Load Station Breaker at end of station.
   2. Turn on Lamiter Flow Fan and Load Station Lights
   3. Turn on Load Station Power (under air track)
   4. Turn on Buffer - T Power Switches (4)
   5. Verify N2 Regulator set at 20 PSIG for Buffer T and TRAM track.
   6. Set TRAM TRACK N2 regulator at 6-7 PSIG.

C. VACUUM SYSTEM
   1. Verify power plug into vacuum Pump Frame
   2. Turn on Vacuum Pump Power Switches -2 on Monitrol & 2 on Pump Panel.
   4. Set pump and Vent Switches to closed position (Push Button Switch out).

D. FURNACE REACTOR
   UPPER TUBE - #1 LOWER TUBE - #2
   1. In Temperature Controller Drawer, Place Switches in "Manual Mode".
   2. Place Thumb Wheel Switches to desired temperature.
   3. Close Furnace Tube Main Element Breaker
   4. Set Deviation Indicator to desired tolerance points and energize.
   5. Verify station exhaust cooling Fan is ON.
   6. Temperature profile process tube.
   7. #1 (Upper) Tube used for SiN4 & Poly Si.
      #2 (Lower) Tube used for Doped & Undoped SiO2 (BzH6 + PH3)
      Monitrol Designation
      Tube #1 - Gold
      Tube #2 - Red
E. MONITROL

1. Verify all switches in Auto Mode (UP) on I/O Modules
2. Verify all output Lights for valves are off.
3. Open Ball values for each "Flow Loop" in source cabinet.
   ON, OFF

F. Furnace Ready for Loading and Processing when temperature is stabilized.
DIFFUSION FURNACE AND CVD REACTOR AUTOMATIC LOADING STATION SEQUENCE

A. Loading Sequence

1. Push BT (BOAT) request Switch (X) on Monitrol.
2. Horizontal (H) Boat Pusher (BP)
   Pulls paddle from tube. Out H-LIMIT SWITCH (LS) Actuated
   H-BP and Paddle stops.
3. Claw opens vertical (V) BP descends
4. SELECTED TUBE POSITION (STP) LS is Actuated
   CLAS POSITION Switch (CPS) is activated.
   VBP Stops
   Claw closes
   VBP and Boat Ascends
5. CPS - deactivated
   HBP moves toward tube
   CPS Activated again
   HBP stops
   VBP moving up
   Sequence 5 repeated until HBP actuates HORIZONTAL Middle Position
   Switch (HMPS).
6. HMPS function:
   increases VBP ACCENT RATE
   HBP keyed to a constant push rate toward tube.
7. VBP stops when upper LS is activated.
8. HBP stops when in LS is activated.
9. VBP descends
   Reaches Buffer T (BT) PS
   V RATE decreases
   Boat is placed in BT
   Boat handle activates claw LS
   VBP STOPS
10. The claw opens
    BT carriage and Boat descends
    Descends until bottom limit is reached
11. Wafers are transferred between BT’s
    After wafers are loaded. (BT Loaded Command)
12. Carriage and Boat has ascended to claw position
13. Claw closes
    claw and boat ascends to VBP UPPER LS
    claw and boat stop
14. HBP pulls paddle from tube
    HMPS activated stops paddle
15. VBP descends slow rate
    boat engages paddle
    CPS activated VBP stops
    HBP moves paddle out very slow rate
    CB5 deactivates VBP descends until CP5 activation again stop VBP
16. VBP action continues until either
    (1) HBP Activities out LS and STOPS
        Tube position switch
        CLS actuated
    (2) VBP activates VLS and stops
        HBP stops at the same time
17. Claw opens  
   VBP travels to top limit position  

18. HBP moves boat into tube process position  
   H in P5 actuated.  

B. Unloading Sequence  

1. Push Process End Switch (X) on Monitrol  
2. Sequence order and description  
   a. A2  
   b. A3  
   c. A4  
   d. A5  
   e. A6  
   f. A7  
   g. A8  
   h. A9  
   i. A10  

3. BT proximity sensor is activated by the wafer presence and sends  
   wafers out on exit air track on a 4 second time interval until boat  
   is empty and bottom limit is reached, and carriage ascends to top  
   position.  

4. a. 13  
   a. 14  
   a. 15  
   a. 16  
   a. 17  
   a. 18
OPERATION AND SAFETY CHECKLIST
EPITAXIAL DEPOSITION

I. PRECONDITIONING/CALIBRATION STEPS

Utilities and Gasses

1. Turn on AC electric power if needed (Ref 1, Sec 3.2, p 3-1; Ref 2, switch 1, 2, 3, 4 & 5) .................................................. ☐

   **CAUTION:** Make sure that AC power is connected to proper line voltage. Make sure that reactor module is properly grounded. Electric power should be normally left on for the reactor light, electronic components and RF chamber air blower (Ref 1, sec 7.8, p 2-14; Sec 3.2A, p 3-1).

2. Turn on exhaust system and exhaust scrubber. Check for clear lines and proper operation (Ref 1, sec 2.8, p 2-14, 2-15) ........................................................... ☐

3. Turn on raw water supply to RF generator heat exchanger. Check water quality, inlet temperature (55-60°F) and room dew point (Ref 1, sec 2.3, p 2-3, 2-4, 2-5; Ref 7, sec 2.3, p 13 & 14, sec 4.1, p 18) ..................................................... ☐

4. Turn on main N₂ valve at incoming gas control system panel if needed (Ref 1, sec 3.2B, p 3-1; Ref 3, valve Main N₂) ...... ☐

   **CAUTION:** The N₂ valve should remain on at all times (Ref 1, sec 3.2, p 3-1).

5. Set main N₂ gas pressure regulator at 20-30 psi (Ref 1, sec 3.2, p 3-1; Ref 3, valve Main N₂ and regulator Main N₂) .... ☐
6. Set N₂ purge gas pressure regulator at 10-15 psi (Ref 1, sec 2.6, p 2-8, 2-9; sec 3.2, p 3-3, 3-5; Ref 3, regulator Purge N₂).

7. Set fluidic interlock N₂ gas pressure regulator at 10 psi (Ref 1, sec 3.2, p 3-1; Ref 2, regulator Fluidic N₂).

8. Turn on hydrogen burn-off system.

9. Turn on main H₂ valve at incoming gas control system panel (Ref 1, sec 3.2D, p 3-5; Ref 3 valve Main H₂).

10. Set main H₂ gas pressure regulator at 20-30 psi (Ref 1, sec 3.2D, p 3-5; Ref 3 regulator Main H₂).

Equipment Check

1. Check reactor tube for structural integrity and cleanliness. Repair and/or replace and clean as needed (Ref 1, sec 4.3, p 4-2, 4-3, 4-4, 4-5)........................................

   CAUTION: Do not touch quartz tube with bare hands. Use gloves.
   Eye, face and hand protection are required when cleaning tube with HF/HNO₃ acid mixtures (Ref 1, sec 4.3, p 4-3).

2. Check reactor door gasket for gas-tight seal. (Ref 1, sec 3.1, p 3-1)........................................

3. Check that susceptors are clean and that build-up is not excessive. Clean as needed (Ref 1, sec 3.1, sec 4.2, p 4-1, 4-2)........................................

4. Check that pyrometers are aligned and clean (Ref 1, sec 4.15, p 4-11)........................................

5. Check operations of N₂ purge system. Flows should be 50-65 l/min. Graphic panel Purge N₂ and reactor control unit POST N₂ indicator lights on (Ref 4, switch LN and switch RN, Flowmeter A; Purge N₂; Ref 5, POST N₂ switch)........................................

6. Check operations of hazardous gas monitor (Ref 6)........................................

7. Purge process gas system with N₂ (Ref 1, sec 3.3, p 3-5; Ref 4, switch-on 2, 17 & 24, 14 & 24, 13/24)........................................

8. Leak test process gas system (Ref 1, sec 4.4, p 4-5, 4-6)........................................

9. Turn on process gas cylinders. Set pressure regulators at 30-100 psi (Ref 1, sec 2.7, p 2-11)........................................
CAUTION: SiH₄ is flammable in contact with air or O₂.
PH₃, AsH₃ and B₂H₆ are toxic.
PH₃ and B₂H₆ are flammable in contact with air or O₂.
NH₃ in an irritant, can be flammable with air or O₂, and reacts with chloride gasses (HCl, SiCl₄).
N₂O is toxic.
HCl is an irritant and reacts with NH₃. Ref 1, sec 2.7, p 2-11, 2-12, 2-13, 2-14.

9. Turn on process gas cylinders. Set pressure regulators at 30-100 psi (Ref 1, sec 2.7, p 2-11)........................

10. Check operations of process gas system by manual operations of graphic panel switches. (Ref 1, sec 3.3A, B, C, E, H, p 3-5, 3-6, 3-7, 3-8, sec 3.4A, B, C, p 3-8, 3-9; Ref 4, all graphic panel witches, all mass flow controllers, rotometers: Purge N₂, Purge H₂)..........................

11. Check back pressure gauges to verify correct operations of vent exhaust system (Ref 1, sec 2.8, p 2-14; Ref 10 right and left gauges)..........................

12. Load SiCl₄ source into bubbler if needed. (Ref 1, sec 3.3D, p 3-6)........................................

13. Check operation of HEPA filter. Check cleanliness of loading area (Ref 1, sec 1.8, p 1-5, sec 4.18, p 4-13)........

14. Check operations of wafer track and loading/unloading wafers on susceptor.

15. Check operations of RF chamber doors (Ref 1, sec 3.3G, p 3-7)........................................

16. Check operations of reactor tube loading doors (Ref 1, sec 1.8, p 1-6, sec 3.5C & G, p 3-9, 3-10; Ref 12 Tube Doors)................

17. Check operations of loading/unloading susceptor and holder into reactor tube..................

18. Check that required maintenance has been done (Ref 1, sec 4.1 through 4.18, p 4-1 through 4-13)................
19. Start-up the closed loop water recirculator on RF generator. Check DI water level and purity (Ref 7, sec 4.2, p 18 & 19; Ref 1, sec 3.2, p 2-3, 2-4; Ref 8, pump switch) 

20. Check that RF control indicates RF Off (Ref 5 switch RF Off; Ref 1, sec 3.3E, p 3-7) 

21. Check settings on RF generator (Ref 7, sec 4.3, p 19, sec 4.4, p 19, 20; Ref 8, Filament Switch; Ref 9, meters, switch, indicator lights) 

22. Start-up RF generator, check for proper functioning (Ref 9, Start-up switch; Ref 1, sec 3.3F & G, p 3-7) 

**CAUTION:** Personnel using heart pacemakers can be exposed to harmful radiation in the vicinity of RF equipment. The RF generator enclosure has a high-voltage exposure hazard and the load coil or load coil leads can cause RF burns if touched (Ref 7, sec 3, p 17 & 18). 

23. Check for proper operation of RF reactor automatic temperature controller (Ref 1, sec 1.6, p 1-4, 1-5; Ref 5 automatic temperature controller) 

24. Check and calibrate susceptor temperature (Ref 1, 3.7, p 3-14, 3-15)
Initializing System

1. Establish initial conditions for gas control system. Select Manual/Automatic operations (Ref 1, sec 3.3, p 3-5, 3-6, 3-7, 3-8, sec 3.4, p 3-8; Ref 4, Graphic panel switches and mass flow controllers).

2. Establish initial conditions for electronic system. Reactor control unit, select Local/Remote operations. Automatic temperature controller and real time programmer (Ref 1, sec 3.6, p 3-10, sec 3.8C, p 3-17, 3-18, sec 3.4C, p 3-9, sec 3.7A & B, p 3-12, 3-13; Ref 5, reactor control unit, automatic temperature controller, real time programmer).

3. Establish initial condition of RF generator. (Ref 1, sec 2.3, p 2-3, 2-4, 2-5; Ref 7, sec 4.3, p 19 & 20; Ref 8, Filament switch; Ref 9, meters, switches and indicator lights correct).

4. Start up wafer track and load station.

5. Susceptors and holders are stored in N2 purged reactor tube (Ref 1, sec 3.5, p 3-9).

6. Reactor control unit SAFE light is on and automatic temperature controller RF switch is off (Ref 1, sec 3.2C, p 3-3, 3-5, sec 3.3E, p 3-7).
II. OPERATING/PROCESSING STEPS

Operations of the system are done in either the automatic or manual mode.

1. Check to make sure that Preconditioning/Calibration and Initializing conditions have been met (Ref 1, sec 3.1, 3.2, 3.3, 3.4, p 3-1 to 3-9) ........................................

2. Bring wafers on air track up to loading station ........................................

3. Open door of one reactor tube (Ref 1, sec 3.5C, p 3-9; Ref 10, Door switch) ........................................

4. Unload susceptor from this reactor tube (Ref 1, sec 3.5, p 3-9, 3-10; Ref 11, Unload switch and indicators) ........................................

   CAUTION: Never use metal rod to retrieve or place susceptor and susceptor boat. Severe shock can result from RF coupling.

5. Load wafers on susceptor ........................................

6. Load susceptor into reactor tube and close door (Ref 1, sec 3.5, p 3-10; Ref 11, Load switch and indicators; Ref 10, Door switch) ........................................

7. Repeat Steps 3, 4, 5, & 6 above for the other reactor tube ........................................

8. Open gas pressure regulator panel valve to desired reactant gas source. Graphic panel switch set to vent (Ref 3, dopant gas valves) ........................................

   CAUTION: Never allow NH$_3$ to flow in any part of the system when chlorides (HCl, SiCl$_4$) are present. Purge before NH$_3$ use with Exhaust Purge and after NH$_3$ use with NH$_3$ Exhaust Purge valve (Ref 3, dopant gas valves, Exhaust Purge valve, NH$_3$ Exhaust Purge valve)
9. Activate PRE N₂ and PRE H₂ Purge (Ref 1, sec 3.6, p 3-10, 3-11; Ref 5, PRE N₂ and PRE H₂ Switches) ........................................

10. When STDBY Light comes on, then select tube for run. Ready light will come on (Ref 1, sec 3.6, p 3-11; Ref 5, Standby light, Reactor Tube Select switch and Ready light) .................................................

11. Automatic Mode, Graphic Panel switch in AUTO position. Activate AUTO OPER switch. (Ref 1, sec 3.8A, p 3-16; Ref 4, Manual/Auto switch; Ref 1, sec 3.8D, p 3-18; Ref 5, Auto Oper switch) ........................................................................

   CAUTION: Check to make sure that flowmeter rates are essentially the same to reactor as to vent. Reset Exhaust Purge Control valve if needed (Ref 1, sec 4.6, p 4-7)

12. Check susceptor temperature as needed (Ref 1, sec 3.7, p 3-14, 3-15) .................................................................................................

13. Manual mode, Graphic Panel switch in MANUAL position. (Ref 1, sec 3.7, p 3-12; Ref 4, Manual/Auto Switch) ..................................

14. Operate graphic panel switches to select gas flows into reactor tube. (Ref 1, sec 3.7, p 3-12; Ref 4, gas solenoid switches) ............................................................

   CAUTION: Check to make sure that flowmeter rates are essentially the same to reactor as to vent. Reset Exhaust Purge valve if needed. (Ref 1, sec 4.6, p 4-7).
CAUTION: Never allow NH₃ to flow in any part of the system when chlorides (HCl, SiCl₄) are present. Purge before NH₃ use with Exhaust Purge and after NH₃ use with NH₃ Exhaust Purge (Ref 3, Dopant Gas valve and NH₃ Exhaust Purge valve).

15. Check susceptor temperature as needed (Ref 1, sec 3.7, p 3-14, 3-15).

16. When run is completed, turn off RF source to RF coil (Ref 1, sec 3.7D, p 3-13; Ref 5, RF Off Switch).

17. Post purge reactor tube with H₂ and then N₂ (Ref 1, sec 3.7E, p 3-13; Ref 5, POST H₂ and POST N₂ switches).


19. When SAFE light is on the reactor doors are opened, the susceptors are unloaded, the wafers are unloaded from the susceptors and the wafers removed by the air track (Ref 1, sec 3.9, p 3-19; Ref 5, Safe Light; Ref 10, Door switch, Ref 11, Unload switch and indicators).

CAUTION: Never use metal rod to retrieve susceptor and susceptor boat. Severe shock can result from RF coupling.
III. NORMAL SHUT-DOWN STEPS

Operations of the system are completed in the automatic or manual mode. All wafers are removed from the reactor tubes.

Short-Term Shut-Down (1 - 10 days)

1. Establish final conditions. (Ref 1, sec 3.9, p 3-19) ..............

2. Close all valves on all process gas cylinders (Ref 1, sec 2.7, p 2-11, 2-12, 2-13, 2-14). ........................................

3. Close valve on H₂ at incoming gas control system panel (Ref 1, sec 3.2D, p 3-5; Ref 3, Main H₂ Valve). .......................

4. Close all process solenoid valves on graphic panel (Ref 1, sec 3.3, p 3-5; Ref 4, graphic panel switches) ...................

CAUTION: Maintain N₂ purge flow in reactor tube (Ref 1, sec 3.2B & C, p 3-1, 3-3, 3-5)

5. Close both reactor load doors (Ref 12, load doors) ..............

6. Turn off H₂ burn-off system........................................

7. Leave exhaust vent system on. Turn off exhaust scrubber (Ref 1, sec 2.8, p 2-14, 2-15) ........................................

8. Shut down wafer track and loading system ......................

9. Leave main AC power on (Ref 1, sec 3.2, p 3-1; Ref 2, Switches 1, 2, 3, 4, & 5) ........................................

10. Shut down RF generator (Ref 7, sec 4.6, p 25; Ref 9, RF Power switch; Ref 8, Filament, Pump and Generator switch) .......

11. Shut down raw water supply to RF generator heat exchanger (Ref 1, sec 2.3, p 2-3) ........................................
Long Term Shut-Down (> 10 Days)

1. Perform steps 1, 2, 3, 5, 8, 9, 10 & 11 as indicated above for Short-Term Shut-Down.

2. Relieve pressure in process gas system (Ref 1, sec 3.3, p 3-5, 3-6; Ref 4 Open solenoid switches).

3. Purge process gas system with N2 to vent (Ref 1, sec 3.3, p 3-5, 3-6; Ref 4, solenoid switches).


5. Turn off H2 burn-off system.

6. Turn off exhaust gas scrubber. Turn off exhaust vent system. (Ref 1, sec 2.8, p 2-14, 2-15).

7. Close valve on N2 at incoming gas control system panel (Ref 1, sec 3.2B, p 3-1; Ref 2, Main N2).

8. Turn off main AC power (Ref 1, sec 3.2, p 3-1; Ref 2, switches 1, 2, 3, 4, & 5).

The need for maintenance is determined by inspection after normal shutdown.

1. Check and clean reactor tube and door as needed (Ref 1, sec 4.3, p 4-2, 4-3, 4-4, 4-5, sec 4.7, p 4-7).

CAUTION: Do not touch quartz tube with bare hands. Use gloves. Eye, face and hand protection are required when cleaning tube with HF/HNO₃ acid mixture (Ref 1, sec 4.3, p 4-3).

2. Check and clean susceptor as needed. (Ref 1, sec 3.1, p 3-1, sec 4.2, p 4-1, 4-2).

CAUTION: Do not touch susceptor with bare hands. Use gloves.
3. Leak test reactor tube. (Ref 1, sec 4.4, p 4-5) .................

4. Check and clean gas rotometers as necessary. (Ref 1, sec 4.11, p 4-11) ................................................

5. Check, clean and leak test process gas system (Ref 1, sec 3.3A, B, C, D, p 3-5, 3-6; Ref 4, solenoid valve switches; Ref 1, sec 4.4, p 4-5, 4-6, sec 4.5, p 4-6, 4-7, sec 4.8, p 4-8, sec 4.9, p.4-8, sec 4.10, p 4-8, sec 4.16, p 4-11) ..............................................

6. Replace in-line gas filters as needed (Ref 1, sec 4.14, p 4-10) ................................................

7. Check exhaust vent system (Ref 1, sec 4.5, p 4-6, sec 4.6, p 4-7) ................................................

8. Clean and lubricate mechanical equipment (Ref 1, sec 4.13, p 4-11) ................................................

9. Clean and aim Pyrometer (Ref 1, sec 4.15, p 4-10) ..............

10. Profile RF coil (Ref 1, sec 4.19, p 4-13) ......................
IV. EMERGENCY SHUT-DOWN STEPS

Chemical Problem Shut-Down

This can be caused by reactive gas explosion or fire, large gas system leak(s), gas flow from reactor tube (door leak, crack or rupture) or exhaust vent system and scrubber failure.

1. Activate fire extinguisher system if needed.............................

2. If run can be safely and conveniently terminated, then override to start POST N₂ Purge (Ref 1, sec 3.11, p 3-20; Ref 5, POST N₂ Switches)........................................

3. Close valves on process gas cylinders (Ref 1, sec 2.7, p 2-11, 2-12, 2-13, 2-14)..........................................................

   CAUTION: If exhaust system is not working and process gas sources cannot be safely turned off, then enter room only with self-contained air breathing equipment to extinguish fire or close valves. (Ref 13)

4. Close valve on H₂ gas source at incoming gas control system Panel (Ref 1, sec 3.2D, p 3-5; Ref 3, Main H₂ Valve)..............

5. Switch off RF Generator (Ref 7, sec 4.6, p 25; Ref 9, RF Power switch; Ref 8, Filament, Pump and Generator switch)...............................

   CAUTION: The RF Generator enclosure has high-voltage exposure hazard. Proper grounding is necessary if enclosure is opened.

6. Switch off main AC power (Ref 1, sec 3.2, p 3-1; Ref 2, switches 1, 2, 3, 4, & 5).................................
7. Close valve on N₂ purge gas source at incoming gas control system panel (Ref 1, sec 3.2B, p 3-1, Ref 3, Main N₂ valve). .................................................................

8. Force ventilate the room. Test for toxic or flammable gas residue..............................................

9. Shut down exhaust gas scrubber, turn off exhaust vent system (Ref 1, sec 2.8, p 2-14, 2-15). ..................
Electrical or Mechanical Problem Shut-Down

This can be caused by power outages, voltage excursions, shorts, damage to wire and insulation, damage or defects in RF system, defects in electrical equipment (motors, solenoids, interlock circuits), malfunctions of mechanical equipment, handling equipment, instruments and meters, solenoid valves and pressure regulators.

1. If run can be safely and conveniently terminated, then override to start POST H₂ purge (Ref 1, sec 3.11, p 3-20; Ref 5, POST N₂ switches) ................................ 

2. Switch off RF generator (Ref 7, sec 4.6, p 25; Ref 9, RF power switch; Ref 8, Filament, Pump and Generator switch) .............................................

CAUTION: The RF generator enclosure has high-voltage exposure hazard. Proper grounding is necessary if enclosure is opened.

3. Close valves on process gas cylinders (Ref 1, sec 2.7, p 2-11, 2-12, 2-13 & 2-14) ................................

CAUTION: If exhaust system is not working and process gas cylinders cannot be safely turned off, then enter room only with self-contained air breathing equipment to close valves and shut down equipment. (Ref 13)

4. In a power failure, the normally open N₂ purge will continue to function (Ref 1, sec 3.2C, p 3-3, 3-5) ................

5. Close valve on H₂ gas source at incoming gas control system panel (Ref 1, sec 3.2D, p 3-5; Ref 3, Main H₂ valve) ........................................................................ 

6. Switch off main AC power (Ref 1, sec 3.2, p 3-1;
    Ref 2, switches 1, 2, 3, 4, & 5).......................................... □

7. Close valve on N₂ purge gas source at incoming
    gas control system panel (Ref 1, sec 3.2B, p 3-1;
    Ref 3, Main N₂ valve).................................................. □

8. Shut-down exhaust gas scrubber. Turn off exhaust vent
    system (Ref 1, sec 2.8, p 2-14, 2-15)............................. □
V. EMERGENCY SHUT-DOWN
CLEAN-UP, INSPECTION, AND REPAIR STEPS
Resulting from Chemical Problems

1. Make sure AC power is turned off (Ref 1, sec 3.2, p 3-1; Ref 2 switch 1, 2, 3, 4, & 5) ........................................

2. Vacuum up any dry extinguisher powder on cabinets, walls and floors ........................................

3. Vacuum and wipe with alcohol the internal cabinet areas (Ref 1, sec 4.12, p 4-11) ..................

4. Wipe external cabinets, gages, meters with detergent and water (Ref 12, module cabinet) ............

5. Wipe wafer loading area and wafer track with alcohol (Ref 1, sec 4.12. p 4-11; Ref 12, wafer loading area) ........................................

6. Re-vacuum and wet-mop floors ...................................

7. Check for fouling of HEPA filter. Replace as needed (Ref 1, sec 1.8, p 1-5, sec 4.18, p 4-13) ..............

8. Check for proper operations of hazardous gas monitor (Ref 6 ) ........................................
Resulting From Electrical or Mechanical Problems as Well as Chemical Problems

1. Make sure AC power is turned off (Ref 1, sec 3.2, p 3-1; Ref 2 switch 1, 2, 3, 4, & 5)........................................  

2. Inspect/test and repair electrical wiring and insulation damage.................................................................  

CAUTION: Make sure all equipment is properly grounded. Make sure RF generator high-voltage is discharged before inspection or repairs (Ref 2, sec 3, p 16).  

3. Selectively switch on all equipment AC power for testing (Ref 1, sec 3.2, p 3-1; Ref 2, switch 1, 2, 3, 4, & 5: Ref 7, sec 4.5, p 20 & 21; Ref 9 Start-Up button)........................................  

4. Clean, inspect and repair vent exhaust and scrubber system (Ref 1, sec 2.8, p 2-14, 2-15)............................  

5. Clean and check operations of N₂ and H₂ Gas regulators, solenoid valves, flowmeters and mass flowmeters. Set pressure regulators. (Ref 1, sec 3.2B & D, p 3-1, 3-5)....................................................  

6. Clean and check operations of process gas regulators, solenoid valves and switches, flowmeters, mass flow controllers and pressure relief valves. Purge all lines with N₂ (Ref 1, sec 4.8, 4.9, 4.10, p 4-8, 4-9, sec 4.16, p 4-11)........................................  

7. Pressure/leak test process gas system (Ref 1, sec 4.4, p 4-5, 4-6)...............................................................  

8. Clean and check reactor tube exhaust line and exhaust purge lines (Ref 1, sec 4.5, p 4-6, 4-7, sec 4.6, p 4-7)..........................
9. Clean and inspect reactor tube and door. Replace door gasket as needed. (Ref 1, sec 4.3. p 4-2, 4-3, 4-4, 4-5) .................................................................

10. Clean, inspect and adjust RF coils. Inspect and repair RF generator leads. (Ref 1, sec 4.19, p 4-13) .................................................................

11. Clean, inspect and check operations of RF Chamber forced air circulation system. (Ref 1, sec 1.7, p 1-15, sec 4.18, p 4-13) .................................................................

12. Clean, inspect and test hazardous gas monitor system (Ref 6) .................................................................

13. Clean, inspect and test operations of air track, wafer loading and furnace loading systems through a load/unload cycle .................................................................

14. When system checks are complete, then go to normal shut-down steps or to precondition/calibration steps as needed .................................................................
APPENDIX

References

1. Instruction Manual, Unipak Reactor System, August, 1974, Unicorp Inc.
2. Equipment Photo, Power Input and Fuse Panel.
3. Equipment Photo, Incoming Gas Pressure Regulator Panel.
8. Equipment Photo, RF System Generator Pump and Filament Switch.
9. Equipment Photo, RF System, Meters, Switch and Indicators.
10. Equipment Photo, Reactor Control Station.
11. Equipment Photo, Reactor Loader Control Panel.
OPERATIONS AND SAFETY CHECKLIST
ION IMPLANTER

1-PRECONDITION/CALIBRATION STEPS

Utilities and Gases

1. Turn-on N₂. Check pressure regulator setting. (Ref. 1; Ref. 2, Sec. VI B4, P.32).

2. Turn-on cooling water. Check for proper flow rate through each loop. (Ref. 1; Ref. 2, Sec. IV, P.7, Sec. VI B3, P. 32).

3. Turn-on machine AC electric power (Ref. 2, Sec. VI B1, P. 32).
   CAUTION: Make sure all equipment is properly grounded. (Ref. 8, P. 82-93).

4. Turn-on compressed air. Check pressure regulator setting (Ref. 1; Ref. 2, Sec. VI B5, P. 32).

Equipment Check

1. Check operations of vent gas exhaust system.

2. Check roughing pump oil level and operation at 3 stations.

3. Check oil level in diffusion pumps at 3 stations.

4. Check operation of LN₂, system and control panel. (Ref. 1, Sec. B 4, P. 1; Ref. 2, Sec. VI B 6, P. 32; Ref. 3, Ref. 8).
   CAUTION: Eye, face, and hand protection needed when manually handling or exposed to LN₂ (Ref. 8, P. 185-187).

5. Purge feed gas handling system. Check feed gas bottle connections and pressure regulator. (Ref. 2, Sec. V D 1).

6. Check operations of wafer track, buffer tees, wafer-matic and carousel.
Initializing System

1. Start-up at stations 1, 2, and 3 roughing pumps. Stabilize systems under low vacuum with isolation gate valves open. (Ref 1, A 1, P 1).

2. Start-up diffusion pump station no. 1. (Accelerator Column) (Ref. 1, Sec. B 1, 2 & 3, D 7 & 8, P. 1; Ref. 4).

3. Turn-on vacuum gauge (Ref. 1, Sec. D 9, P. 1; Ref. 4).

4. Start-up diffusion pump station No. 2 (Scanner Tee) (Ref. 1, Sec. D & G, P. 1; Ref. 2, Sec. V M P. 25).

5. Start-up diffusion pump station No. 3 (Target Chamber) (Ref. 1, Sec. C 5 & 6, E 10-16, P. 1).

CAUTION: Never shut-down diffusion pumps while system is under vacuum and isolation valve is open. Close valve and vent with N² to atmospheric before shut-down. High foreline pressure will cause automatic shut-down of diffusion pump.

6. Switch LN² controller to auto position for 3 locations (Ref. 1, Sec. B 4, P. 1; Ref. 3).

CAUTION: Lock terminal door and remove key.

7. Turn-on dopant gas sources in the high voltage terminal. (Ref. 1, Sec. F, P. 1; Ref. 2, Sec. V D, P. 12).

8. Turn-on wafer handling system. (Ref. 1, Sec. H).

9. Turn-on AC power at current integrator panel. (Ref. 1, Sec. I-23, P. 2; Ref. 4).

10. Turn-on magnet control power supply. (Ref. 1, Sec. I-24, P. 2; Ref. 5).

11. Turn-on ion source control with key. Turn-on terminal power. (Ref. 1, Sec. I-25 & 26, P. 2; Ref. 5).
CAUTION: Personnel who normally work in the area of the ion source should wear a radiation badge when this equipment is in operation. (Ref. 6).

12. Turn-on high voltage power supply (Ref. 1, Sec. I-26, P. 2; Ref. 5).

13. Turn-on and fine tune the ion beam (Ref. 1, Sec. I-28 & 29, P. 2; Ref. 5).

14. Turn-on deflector power supply adjust HV output. (Ref. 5; Ref. 6).

15. Turn-on quadripole power supply. Adjust 1 and 2 settings (Ref. 4).

16. Turn-on beam scanner and hybrid tracking control. (Ref. 3, Ref. 6).

17. If no interlocks have been located as indicated by absence of alarm, then system is ready to run. (Ref. 6).


2-OPERATING STEPS

OPERATION OF THE SYSTEM IS DONE IN THE COMPLETELY AUTOMATIC MODE.

1. Check to make sure initializing conditions have been met.

2. Load wafers (Ref. 1, Sec. J-31, P. 2; Ref. 6).

3. Start run (Ref. 1, Sec. J-32, P. 2; Ref. 6).

4. Run can continue and additional runs made as long as interlock conditions are met. (Ref. 2, Sec. IV).

3-NORMAL SHUT-DOWN STEPS

Operations of the system are completed in the automatic mode. All wafers are removed from the system.

1. Switch-off ion beam and high voltage power supply. (Ref. 1, Sec. K142, P. 2; Ref. 5).
2. Switch-off terminal power and switch-off ion source control with key. Remove key. (Ref. 1, Sec. K3 & 4, P. 2; Ref. 5).

3. Switch-off magnet control power supply. (Ref. 1, Sec. K5, P. 2; Ref. 5).

4. Switch-off beam scanner and hybrid tracking control. (Ref. 3; Ref. 6).

5. Switch-off quadripole power supply (Ref. 4).

6. Switch-off deflector power supply. (Ref. 5; Ref. 6).

7. Switch-off AC power at current integrator panel. (Ref. 1, Sec. K6, P. 2; Ref. 4).

8. Turn-off dopant gas sources in the high voltage terminal. (Ref. 1, K8, P. 2; Ref. 2, Sec. VD, P. 12).

9. Close isolation gate valves on diffusion pumps at 3 locations. (Ref. 1, Sec. L9 & M13, P. 2).

10. Switch-off diffusion pumps at 3 locations. (Ref. 1, Sec. L10 & M14, P. 2).

11. Switch-off vacuum gauge. (Ref. 1, Sec. K7, P. 2; Ref. 4).

12. Switch-off LN2 controller. (Ref. 1, Sec. M16, P. 2; Ref. 3).

System is now secured in normal pre-run condition. This condition can be maintained for several hours and additional runs made by proceeding through the initializing system steps 2 through 18. If shut-down is for a day or more, then the following additional steps are needed.

13. Open isolation gate valves at 3 locations.

14. Switch-off roughing pumps at 3 locations.

15. Vent purge total vacuum system with N2 up to atmospheric pressure.

16. Purge dopant gas system with N2 (Ref. 1, Sec. K8, P. 2; Ref. 2, Sec. VD, P. 12).
17. Turn-off cooling water in diffusion pump loops.
18. Turn-off buffer tees.
19. Turn-off wafer track.
20. Turn-off compressed air. (Ref. 2, Sec. B 5, p. 32).
21. Turn-off main AC power. (Ref. 2, Sec. VI B 1, P. 32).
23. Do routine maintenance and preventative maintenance after normal shut-down.

4-EMERGENCY SHUT-DOWN STEPS

Electrical or Mechanical Problem Shut-Down

This can be caused by power outages, shorts, damage to electrical wiring, and defects or malfunctions in electrical equipment and instrumentation systems. Violation of fail-safe or interlock systems will result in shut-down. (Ref. 2, Sec. IV, P 7 & 8). Any of these conditions will probably result in an aborted run.

1. Switch-off ion source control with key. (Ref. 1, Sec. N1, P. 2; Ref. 5).
2. Switch-off AC power at current integrator panel. (Ref. 1, Sec. N2, P. 2; Ref. 4).
3. Switch-off magnet control power supply. (Ref. 1, Sec. M3, P. 2; Ref. 5).

CAUTION: Make sure that equipment is properly grounded. Check for potential electrical shock. (Ref. 8, P. 82-93.)

4. Switch-off beam scanner and hybrid tracking control. (Ref. 3; Ref. 6).
5. Switch-off quadrupole power supply. (Ref. 4).
6. Switch-off deflector power supply (Ref. 5; Ref. 6).
7. Switch-off vacuum instrumentation. (Ref. 1, Sec. N4, M2, P2; Ref. 4).

8. Switch-off diffusion pumps at 3 locations. (Ref. 1, Sec. M1, P.2).

9. In event of power failure, all gate valves will close. Then vent high vacuum system with N₂ up to atmospheric pressure.

10. Switch-off LN₂ controllers at 3 locations. (Ref. 1, Sec. M3, P. 2; Ref. 3; Ref. 8, P. 185-187).

11. Turn-off dopant gas sources in the high voltage terminal. (Ref. 1, Sec. O1, P. 2; Ref. 2, Sec. V D, P. 12).

12. Turn-off wafer track and buffer tee loading system. (Ref. 1, Sec. N5, P. 2).


This level of shut-down is satisfactory for trouble-shooting and maintenance on most electrical or mechanical problems. If the problem is more severe, then the additional steps required for chemical or fire shut-down should be done.

Chemical or Fire Problem Shut-Down

This can be caused by small electrical fires, venting of dopants, gasses or major fires in adjacent areas.

1. Activate fire extinguisher system if needed.

2. Turn-off or isolate any leaking dopant gas bottles. (Ref. 1, Sec. O1, P. 2).

3. Evacuate room, return only if toxicity and flamability sources have been controlled.

4. In event of fire near the air header lines the fusible safety caps will close down the dopant gas flow by bleeding the air header. (Ref. 7).

5. Go through emergency shut-down steps listed above in steps 1 through 11.

6. Switch-off roughing pumps at 3 locations.
7. Vent purge total vacuum system with N₂ up to atmospheric pressure. Vacuum gate valves should be open.

8. Turn-off compressed air. (Ref. 2, Sec. VI, B5, P. 32)

9. Switch-off main AC electric power. (Ref. 2, Sec. VI B1, P. 32)

10. Turn-off cooling water. (Ref. 2, Sec. VI, B3, P. 32)

11. Turn-off N₂. (Ref. 2, Sec. VI B4, P. 32)


5-EMERGENCY SHUT-DOWN
CLEAN-UP, INSPECTION AND REPAIR STEPS

1. Make sure main electrical power is switched-off. (Ref. 2, Sec. VI, B1, P. 32)

2. Clean-up any fire extinguisher or fire damage.

3. Inspect/test and repair electrical wire and insulation damage.

   **CAUTION:** Make sure that all equipment is properly grounded. Make sure that there are no electrical shorts. (Ref. 8, P. 79-93)

4. Switch-on main AC electric power then selectively switch-on all electric powered equipment for operational testing.

5. Test mechanical equipment and make repairs as necessary.

6. Selectively test all vacuum system components, instruments, controllers and interlocks. Perform leak test on vacuum system.

7. Test and repair dopant gas system as needed.

8. Test and repair vent gas exhaust system as needed.

9. Test and repair high voltage terminal and ion source equipment, instruments and controllers as needed.

10. Check operations of wafer track and wafer loading system.
11. Check filters and operations of ultra-clean work/loading station.

12. When system checks are successfully completed then either go to normal shut-down stable condition or to the precondition/calibration steps for additional runs.
References

1. Ion Implanter System Routine.


3. Photo of instrumentation and control panel for hybrid tracking control, beam scanner, LN$_2$ controller and deflector power supply.

4. Photo of instrumentation and control panel for pump station No. 1, current integrator and quadripole controls.

5. Photo of instrumentation and control panel for H.V. power supply, magnet control and ion source control.


7. Fusible safety fittings, eutect melting points of 160, 255 and 281°F. Franklin Valve and Fitting Co.

OPERATIONS AND SAFETY CHECKLIST
ION IMPLANTER

SYSTEM ROUTINE
REFERENCE 1

A. SYSTEM PRECONDITION
1. System under low vacuum
2. Cooling water on.
3. LN2 on.
NOTE: If a malfunction occurs at any point isolate the problem, correct problem and continue.

B. OPERATIONAL PROCEDURE

Sequence
Pump Station no. 1 Panel
1. Check foreline pressure station no. 1 (5 microns or less reading on meter).
2. Turn Hi-vac value switch (pump sta. no. 1) to the manual closed position.
3. Turn (diffusion) pump on.
4. Turn LN2 (station no. 1 and 2) to the auto position (LN2 control panel to the left of pump sta. panel).

C. CHAMBER STATION PANEL
5. Turn Torr Gauge (power) on (located directly under the scan monitor panel).
6. Turn (diffusion) pump on.

D. PUMP STATION NO. 1
7. Check rough pressure station no. 1 (monitor meter 5 micron or less, Thermocouple Selector switch in roughing position).
8. Turn Hi-vac valve switch to the unprotected open position.

When the LN2 traps are full and the system chilled down (approx. 30 min.) continue.

9. Turn NRC 855 (Hi-vac) gauge power on (locate top panel of the control console).

E. CHAMBER STATION
10. Turn foreline valve switch to closed position.
11. Turn roughing valve switch to open position.
12. Monitor meter, when pressure is less than 50 microns close roughing valve and open foreline valve.
13. Turn the Hi-vac switch to unprotected open position.
14. Turn the Torr gauge filament (power) on (above).
15. Turn the terminal LN2 Switch to Auto Position (sta. no. 1 on LN2 Control Panel).
16. Turn the Hi-vac switch to the Protected Open Position.
OPERATIONS AND SAFETY CHECKLIST
ION IMPLANTER

SYSTEM ROUTINE
REFERENCE 1

F. TERMINAL ROOM
17. Turn Source Gas on. (Allow to stabilize monitor NRC 855 gauge) (Hi-voltage).
18. Lock Terminal door and remove key.

G. PUMP STATION NO. 1
19. Turn Hi-vac valve switch to Protected open position.
20. Turn isolation valve switch to Protected open position.

H. WAFER MATIC
21. Turn wafer matic power on (Switch located inside of the function cabinet.)
22. Turn Buffer-Tee's power on (Switches on instruments).

I. CONTROL CONSOLE
23. Turn the Current Intergrater Function Switch to the operate position.
24. Turn the magnet control (power) on.
25. Insert key (in Ion Control Panel) and turn keyed power on.
26. Turn Terminal power on (ion control panel).
27. Turn Hi-voltage power supply on (adjust to desired level).
28. Turn Ion Beam on (ion control panel).
29. Fine tune ion beam, machine ready to operate.

J. WAFER-MATIC
30. Set Buffer-Tee's to the proper operating position (function panel feed/load reset buttons).
31. Load wafers.
32. Press run button.

SHUT DOWN PROCEDURE

K. CONTROL CONSOLE
1. Turn Beam off.
2. Run Hi-voltage control to zero volts, then off.
3. Turn Terminal Power off.
4. Turn console key off and remove key.
5. Turn magnet current to zero, then off.
6. Turn current Intergrater Function Switch to the A.C. OFF Position.
7. Turn the NRC 855 Gauge Power off.
8. Turn source gas off. (In Terminal Room).
OPERATIONS AND SAFETY CHECKLIST
ION IMPLANTER

SYSTEM ROUTINE
REFERENCE 1

L. PUMP STATION NO. 1
9. Turn isolation valve to closed position.
10. Turn (diffusion) Pump off.
11. Turn Hi-vac valve switch to the closed position.

M. CHAMBER STATION
12. Turn Torr Gauge filament off (panel above).
13. Turn Hi-vac valve switch to the closed position.
15. Turn all LN2 station off (LN2 Control Panel).
16. System secured at the normal pre-operation condition.

EMERGENCY SHUT DOWN PROCEDURE

N. AT CONSOLE
1. Turn power off with key (remove key).
2. Turn current integrater (ac power) off.
3. Turn magnet power off.
4. Turn NRC 855 Gauge off.
5. Turn wafer-matic and Buffer's-"T"'s off.

O. AT PUMP AND CHAMBER STATION
1. Turn (diffusion) pumps off.
2. Turn Torr Gauge filament off, then power off.
3. Turn all LN2 off.

P. AT TERMINAL ROOM
1. Turn source gas off.
2. Make sure the roughing pump at station no. 1 continues to run.
OPERATIONS AND SAFETY CHECKLIST
ETCHING AND CLEANING

1-PRECONDITIONING/CALIBRATION STEPS

Utilities and Gasses

1. Turn-on N₂ to both etch stations. Set pressure regulator at 40 PSI. (Ref. 1; Ref. 2).

2. Turn-on N₂ to wafer track and load stations. Set pressure regulator at 80 psi (Ref. 1; Ref. 2).

3. Turn-on DI water circulation system.

4. Switch-on main AC electrical power (Ref. 1).

CAUTION: Make sure all equipment is properly grounded. (Ref. 5, P. 82-93).

Equipment Check

1. Switch-on and check proper operations and flow rate of etch facility vent gas system. (Ref. 1; Ref. 3; Ref. 4, Sec. 1, P. 2).

2. Check operations of vent gas scrubber. Replenish limestone bed as needed. (Ref. 1; Ref. 4, Sec. 9, P. 78).

3. Check and balance operations of total room ventilation and comfort control system.

4. Turn-on and check operations of DI water circulation system. Check operations of polishers and resistivity monitors. (Ref. 1, Ref. 3).

5. Check operations of liquid waste effluent system. Check for proper operations of neutralization and pH monitoring system.

6. Check operations of wafer track and load stations. (Ref. 1).

7. Check operations, flow rate and resistivity in six DI water rinse tanks. (Ref. 1; Ref. 3).
8. Check acid etching solutions in seven individual tanks. Replace or replenish each specific solution as needed. (Ref. 1; Ref. 4, Sec. 5, P. 35, Appendix A, P. 80).

**CAUTION:** Face, hand and body protection required when exposed to or handling acids. Extreme care is required in handling HF acid solutions. Absolute integrity of hand protection is essential. (Ref. 5, P. 11-14, P. 143-144, P. 159-160, P. 165-166, P. 213-216). In case of acid splash or spill use safety shower or eye wash as needed. Neutralize and absorb spills to eliminate liquid hazard. Ventilate room to eliminate vapor hazard.

9. Check temperature of the BOE acid solution in tank no. 18. Establish at 50°c. All other tanks are at room temperature. (Ref. 1).

10. Check photoresist strip solutions in two tanks. Replace or replenish as needed. (Ref. 1).

**CAUTION:** Face and hand protection required when exposed to or handling photoresist strip solutions (Ref. 5, P. 1-14, P. 94-106).

11. Check silicon etch solution in tank No. 11. Replace or replenish as needed. (Ref. 1; Ref. 4, Appendix A, P. 81).

**CAUTION:** Face and hand protection required when exposed to or handling this base solution. (Ref. 5, P. 11-14).

Avoid mixing of acid and base solutions because of possible explosive reaction.

12. Check solvents in tanks No. 9 and No. 10. Replace or replenish as needed. (Ref. 1; Ref. 4, Sec. 5, P. 35).

**CAUTION:** Face and hand protection suggested when exposed to or handling solvents. (Ref. 5, P. 11-14, P. 94-106, P. 133-134, P. 167-171).

Avoid mixing of strong acids with acetone because of possible explosive reaction.
13. Check operations of tank-to-tank automatic transfer system. (Ref. 1; Ref. 2; Ref. 3). .............................................

14. Check operations of instrument and control systems on each module (Ref. 1; Ref. 3). .............................................

15. Check operations of wafer washer and drier system. Check control system (Ref. 1; Ref. 3). .............................................

Initializing System

1. Load prepared wafers. (Ref. 1). .............................................

2. Select etch sequence and time. (Ref. 1; Ref. 2; Ref. 3). ........................

3. Start-up wafer track. (Ref. 1). .............................................

4. Start-up load stations. (Ref. 1). .............................................

2-OPERATING/PROCESS STEPS

Operations of the system are done in the automatic mode.

1. Check to make sure initializing conditions have been set. ............... 

2. Feed wafers into system. .................................................. 

3. Start specific programmed etch sequence (Ref. 1; Ref. 2; Ref. 3). .... 

4. Completed wafers are removed from system. (Ref. 1). ............... 

5. Check for depleted etch solutions. (Ref. 1; Ref. 4; Sec. 5; P. 35). ............

6. Start additional specific etch sequence (Ref. 1; Ref. 2). ............... 

7. Make sure DI water resistivity quality specifications and interlocks are maintained. (Ref. 2; Ref. 3). ............... 

3-NORMAL SHUT-DOWN STEPS

Operations of the system are completed in the automatic mode. All wafers are removed from system. Shut down can be short term (several hours) or long term (several days).
Short-Term Shut-Down

1. Shut-down wafer track. (Ref. 1).
2. Shut-down loading stations. (Ref. 1).
3. Switch-off instrument and control systems on each etch module and the wafer washer and dryer module. (Ref. 1; Ref. 3).
4. Switch-off DI water monitor (Ref. 3).
5. Shut-down DI water circulation (Ref. 1).
6. Switch-off heat to etch station No. 18.

Long-Term Shut-Down

The following steps are done in addition to the short-term shut-down steps.

1. Drain and dispose of short-life acid and base etching solutions as needed. (Ref. 1; Ref. 4, Sec. 5, P. 35).

   CAUTION: Face, hands and body protection required when exposed to or handling acids or bases. Do not mix concentrated acids and bases. (Ref. 5, P. 11-14).

2. Drain and dispose of photoresist strip solutions as needed. (Ref. 1; Ref. 4; Sec. 5, P. 35).

   CAUTION: Face and hand protection required when exposed to or handling photoresist strip solutions. (Ref. 5, P. 11-14).

3. Drain and dispose of solvents as needed. (Ref. 1, Ref. 4, Sec. 5, P. 35).

   CAUTION: Use care in handling solvents. Do not allow acetone to come in contact with strong acids. (Ref. 5, P. 94-106).

4. Drain DI water rinse tanks. (Ref. 1).
5. Shut-off N₂ to etch stations. (Ref. 1; Ref. 2).
6. Shut-off N\textsubscript{2} to wafer track and load stations. (Ref. 1)...

7. Shut-off etch facility vent gas system. (Ref. 1)...

8. Switch-off main AC electrical power. (Ref. 1)...

9. Normal maintenance and preventative maintenance is done after normal shut-down (Ref. 2)...

4-EMERGENCY SHUT-DOWN STEPS

Chemical Problem Shut-Down

This can be caused by accidental mixing of strong acids with acetone or strong base solution. A fire can be caused by ignition of acetone vapor. Fire in an adjacent area can also require shut-down wafers in acid etch solutions should be aborted. Other wafers in process may be salvagable.

1. Activate fire extinguisher system as needed...

2. Shut-down etch facility vent gas system. (Ref. 1; Ref. 4, Sec. 1, P. 2)...

3. Switch-off main AC electric power. (Ref. 1; Ref. 5, P. 82-93)...

4. Turn-off N\textsubscript{2} to etch stations...

5. Turn-off N\textsubscript{2} to wafer track and load station...

6. Drain or dispose of all acid and base etch solutions. (Ref. 4, Sec. 5, P. 35)...

CAUTION: Face, hand, and body protection required when exposed to or handling acids, bases and solvents. Do not mix concentrated acid with concentrated bases or acetone.

7. Drain or dispose of all acid and base etch solutions. (Ref. 4, Sec. 5, P. 35)...

8. Drain and dispose of solvents as needed. (Ref. 4, Sec. 5, P. 35)...

9. Turn-off DI water circulation System. (Ref. 1)...

10. Switch-off individual etch modules. (Ref. 1)...

11. Inventory extent of damage.
Electrical/Mechanical Problem Shut-Down

This can be caused by power outages, electrical shorts, and defects or malfunction in mechanical and electrical equipment (motors, solenoids, etc.)

1. Switch-off individual etch modules (Ref. 3).

   CAUTION: Check for possible electrical shock hazard (Ref. 5, P. 79-93).

2. Switch-off wafer cleaner and dryer.

3. Shut-down wafer track and loading stations. (Ref. 1).

4. Switch-off heat to etch station No. 18.

5. Do steps 1 through 8 of normal long-term shut-down.


5-EMERGENCY SHUT-DOWN CLEAN-UP, INSPECTION AND REPAIR STEPS

1. Make sure main electrical power is switched-off (Ref. 1).

2. Clean-up any fire extinguisher or splash damage on modules or wafer handling equipment.

3. Inspect/test and repair electrical wire and insulation damage.

   CAUTION: Make sure that all equipment is properly grounded. Make sure that there are no electrical shorts. (Ref. 5, P. 79-93).

4. Inspect and test for residual acids, photoresist strip, alkaline etch, oil solvents in tanks. Remove residue and clean tanks as needed. (Ref. 2; Ref. 3).

   CAUTION: Face, hand and body protection required because of possible exposure to acids, bases and solvents (Ref. 5, P. 11-14).
5. Inspect, test and repair as needed the vent gas system.

6. Switch-on main AC electrical power and then selectively switch-on all electric powered equipment, controllers and instrumentation for operational testing. (Ref. 2).

7. Test mechanical equipment and make repairs as needed.

8. Check operations of wafer track and loading stations. (Ref. 1).

9. When system checks are successfully completed then either go to normal long-term shut-down stable conditions or to the precondition/calibration steps for additional runs. (Ref. 1; Ref. 2).
6-APPENDIX

References


3. Equipment Photo, Etch Station.


5. Safety and Environmental Health Standards, MM 1700. 4B, MSFC, October 15, 1974.
OPERATIONS AND SAFETY CHECKLIST
PHOTOLITHOGRAPHY

I. PRECONDITION/CALIBRATION STEPS

Utilities and Gasses

1. Turn on N₂ to coater and developer. Set system pressure regulator at 35 PSI and aspirator pressure regulator at 60 PSI. (Ref. 1, Ref. 2, Table 1-1, P. 1-4, Fig. 2-1, P. 2-2)

2. Turn on N₂ to wafer track and buffer tees. Set pressure regulator at 35 PSI. (Ref. 1, Ref. 3, Sec. 2-9, P. 2-1)

3. Switch on main AC electric power (Ref. 1)

   CAUTION: Make sure all equipment is properly grounded. (Ref. 4, P. 82-93)

4. Selectively switch on individually the coater, aligner, developer, bake stations, and buffer tees. (Ref. 1, Ref. 2, Table 1-1, P. 1-4, Fig. 3-1, P. 3-3, Ref. 5, Ref. 6, Ref. 7)

5. Turn on N₂ to soft bake and bake ovens. (Ref. 1, Ref. 6, Sec. 2-11, P. 2-1, Ref. 7, Sec. 2-11, P. 2-1)

6. Turn on vacuum to bake oven. (Ref. 7, Sec. 2-12, P. 2-1)

Equipment Check

1. Switch on and check operations and flow rate of total vent gas system. Ref. 1, Ref. 2, Sec. 2-7, P. 2-6, Ref. 7, Sec. 2-12, P. 2-1)

2. Check operations of wafer track and buffer tees. (Ref. 1, Ref. 3, Sec. 3, P. 3-1 to 3-7)

3. Check operations of coater system. Check photoresist liquid level in reservoir. Replenish as needed. Prime pump, adjust dispensing volume and adjust suckback as needed. (Ref. 1, Ref. 2, Sec. 2-18, P. 2-7, Sec. 3-17, P. 3-15, Sec. 3-17, P. 3-5)

   CAUTION: Face and hand protection required when handling or exposed to photoresist fluids. (Ref. 4, P. 94-106 & 137)
4. Check operations of coater exhaust system. (Ref. 2, Table 1-1, P. 1-4, Sec. 2-8, P. 2-6.)

5. Check operations of soft bake oven. Set controls for required temperature and time. (Ref. 6, Sec. 3-10, P. 3-1, 3-2).

6. Check operations of wafer aligner system in manual and auto modes. Set exposure time. Insert required mask. (Ref. 5, Description of controls and operator instructions.)

CAUTION: Avoid direct eye exposure to UV radiation from Hg ARC lamp. Use eye protection when exposure is possible. (Ref. 4, P. 75-76).

7. Check operations of developer system. Check stoddard solvent and N-butyl acetate liquid level in reservoirs. Replenish as needed. Prime pumps and adjust dispensing volumes as needed. (Ref. 1, Ref. 2, Sec. 2-18, P. 2-7, Sec. 2-37, P. 2-15.)

CAUTION: Face and hand protection needed when handling or exposed to solvents. (Ref. 4, P. 94-100, P. 135).

8. Check operations of developer exhaust system. (Ref. 2, Table 1-1, P. 1-4, Sec. 2-8, P. 2-6).

9. Check operations of bake oven. Set controls for required temperature and time. Check for proper operations of exhaust system. (Ref. 7, Sec. 2-13, P. 2-1 and 2-4, Sec. 3-3 and 3-9, P. 3-1).

Initializing System

1. Load prepared wafers.

2. Start up coater module. Load program into memory as needed. (Ref. 2, Fig. 3-1, P. 3-3, Sec. 3-9, P. 3-4, Sec. 4-26 to 4-38, P. 4-5 to 4-7).

3. Start up soft bake station. (Ref. 6, Sec. 3-11 and 3-12, P. 3-2).

4. Start up wafer aligner module. (Ref. 5, Operator Instructions).

5. Start up developer module. Load program into memory as needed. (Ref. 2, Fig. 3-1, P. 3-3, Sec. 3-9, P. 3-4, Sec. 4-26 to 4-38, P. 4-5 to 4-7).
6. Start up bake station. (Ref. 7, Sec. 3-9, and 3-10, P. 3-1).
7. Start up buffer tees. (Ref. 3, Sec. 3-5 to 3-28, P. 3-1 to 3-6).
8. Start up wafer track. (Ref. 1).
2-OPERATIONS/PROCESS STEPS

Operations of the system are normally done in the automatic mode. The individual modules can be operated in the manual mode.

1. Check to make sure initializing steps have been completed. (Ref. 1, Ref. 2, Ref. 3, Ref. 5, Ref. 6, Ref. 7).

2. Check that wafers are properly loaded. (Ref. 1).

3. Automatic Mode. Operate total system in remote/auto mode. (Ref. 1, Ref. 2, Sec. 3-11 and 3-13, P. 3-4 and 3-5, Ref. 3, Sec. 3-6, P. 3-1, Ref. 6, Sec. III, P. 3-1 and 3-2, Ref. 5, Operator Instructions, 31, P. 2, Ref. 7, Sec. III, P. 3-1).

4. Manual Mode. Operate individual stations in local/manual mode. (Ref. 1, Ref. 2, Sec. 3-4, 3-13, P. 3-1, 3-2, 3-3, 3-5, Ref. 5, Operator Instructions P. 1 to 3).

5. Completed wafers are removed from the total system into storage or transferred to etch and cleaning system.

6. Run will continue until wafer fees ceases or a station malfunction stops process. (Ref. 1, Ref. 2, Sec. 3-13, P. 3-5, Ref. 2, Sec. 3-8, P. 3-1, Ref. 5, Manual Eject).

7. Change mask in aligner and start another run in either auto or manual mode. (Ref. 1, Ref. 5, Mask Load Instructions).

8. Remove wafers from system. (Ref. 1).
3-NORMAL SHUT DOWN STEPS

Operations of the system are completed in the automatic or manual mode. All wafers are removed from the coater, soft bake oven, aligner, developer and bake oven. Short term storage of wafers in buffer tees is possible.

Short Term Shut Down

1. Shut down wafer track. Turn off N2 supply. (Ref. 1).
2. Shut down buffer tees. Switch off electric power and turn off N2 supply. (Ref. 3, Sec. 2-10, P. 2-1, Fig. 3-1, P. 3-2, Sec. 3-23, P. 3-5).
3. Shut down coater module. Switch off system electric power. (Ref. 1, Ref. 2, Fig. 3-1, P. 3-3, Sec. 3-19 to 3-22, P. 3-5 to 3-8).
4. Shut down wafer aligner module. Switch off UV source and machine electric power. (Ref. 1, Ref. 5, Operator Instructions).
5. Shut down developer module. Switch off system electric power. Clean drain cup and dispenser heads if necessary. (Ref. 1, Ref. 2, Fig. 3-1, P. 3-3, Sec. 3-19 to 3-22, P. 3-5 to 3-8).
6. Switch off electric power to soft bake oven. (Ref. 1, Ref. 6, Sec. 2-10, P. 2-1, Fig. 3-1, P. 3-3).
7. Switch off electric power to bake oven. (Ref. 1, Ref. 7, Sec. 2-10, P. 2-1, Fig. 3-1, P. 3-2).
8. Turn off vacuum supply to bake oven. (Ref. 7, Sec. 2-12).
9. Turn off N2 to soft bake and bake ovens. (Ref. 1, Ref. 6, Sec. 2-11, P. 2-1, Ref. 7, Sec. 2-11, P. 2-1).
10. Turn off N2 to coater and developer modules. (Ref. 1, Ref. 2, Fig. 2-1, P. 2-2).

Long Term Shut Down

The following steps are done in addition to the short term shut down steps.

1. Remove photoresist fluid from the coater module reservoir. Flush reservoir, lines and head with solvent. Purge fluid system with N2.
2. Remove stoddard solvent and N-Butyl acetate solvent from reservoirs, lines and spray heads of the developer module. Purge solvent systems with N₂.

3. Switch off main AC electric power supply. (Ref. 1).

4. Turn off vent gas system. (Ref. 1).

5. Normal maintenance and preventative maintenance is done after normal shut down. (Ref. 2, Sec. VI, P. 6-1 to 6-14, Ref. 3, Sec. V, P. 5-1 to 5-32, Ref. 5, Ref. 6 and 7, Sec. 5-1 and 5-2, P. 5-1 to 5-5).
4-EMERGENCY SHUT DOWN STEPS

Chemical Problem Shut Down

This can be caused by localized ignition of solvent vapors or by fire in an adjacent area. These conditions will probably result in an aborted run.

1. Activate fire extinguisher system as needed.
2. Shut down total vent gas system. (Ref. 1).
3. Switch off main AC electric power. (Ref. 1).
4. Turn off N₂ to coater, aligner, bake ovens, developer, buffer tees and wafer track. (Ref. 1).
5. Drain and dispose of photoresist fluid in coater module and solvents in developer module.

CAUTION: Face and hand protection required when handling or exposed to photoresist fluid and solvents. (Ref. 4, P. 94-106 and 137.)

6. Switch off electric power to individual modules in system. (Buffer tees, coater, soft bake oven, aligner, developer and bake oven). (Ref. 1).
7. Turn off vacuum supply to bake oven. (Ref. 1).
8. Inventory extent of damage.

Electrical/Mechanical Problem Shut Down

This can be caused by power outages, electrical shorts and defects on malfunctions in mechanical and electrical equipment (Motors, solenoids, switches, Etc.).

1. Switch off electric power to individual modules in system. (Buffer tees, coater, soft bake, aligner, developer and bake). (Ref. 1).

CAUTION: Check for possible electrical shock hazard. (Ref. 4, P. 79-93).
2. Shut down wafer track.

3. Turn off vacuum supply to bake oven. (Ref. 7, Sec. 2-12).

4. Turn off N₂ to individual modules in system. (Buffer tees, coater, soft bake, aligner, developer and bake). (Ref. 1).

5. Inventory extent of defects and damage.
5-EMERGENCY SHUT DOWN
CLEAN UP, INSPECTION AND REPAIR STEPS

1. Make sure main AC electrical power is switched OFF. (Ref. 1)

2. Clean up any fire extinguisher, solvent splash, or fire damage on modules or wafer track.

3. Inspect/Test and repair electric cable and insulation damage.

   CAUTION: Make sure all equipment is properly grounded. Make sure there are no electrical shorts. (Ref. 4, P. 79-93).

4. Selectively switch on electric power to each module in system. Check for proper operations of buffer tees, coater soft bake oven, aligner, developer and bake oven.

5. Inspect, test and repair as needed the total vent gas system.

6. Do normal maintenance on each module in system. (Ref. 2, Sec. VI, P. 6-1 to 6-14, Ref. 3, Sec. V, P. 5-1 to 5-32, Ref. 5, Ref. 6 & 7, Sec. 5-1, and 5-2, P. 5-1 to 5-5).

7. When system checks and required maintenance is completed, then either go to normal shut down steps or to Precondition/Calibration steps as needed.
6-APPENDIX


February 2, 1979

Mr. Ralph Grubb, Sr. Engineer
NASA Fabrication Laboratory
National Aeronautics & Space Administration
Geo. C. Marshall Space Flight Center
Huntsville, Alabama 35812

Dear Ralph:

Please find enclosed a brief report on the disposal of vent gases from epitaxial reactors.

ICE recommends that burn-off procedures be used. Please also find attached a copy of a page from Motorola's safety handbook, which strongly supports ICE's recommendation.

Should you have any further questions, please do not hesitate to call me.

Yours truly,

Howard K. Dicken
Executive Vice President

Enclosures
5. DISPOSAL OF EPITAXIAL VENT GAS
DISPOSAL OF VENT GAS FROM

EPITAXIAL PROCESSING

Epitaxial processing of semiconductor wafer does produce a vent gas that has to be discarded in a safe manner. The main constituents of this gas are N₂, and H₂, with smaller sporatic amounts of PH₃, B₂, H₆, AsH₃, HCL, NH₃, and N₂O. Safe disposal must consider the flammability of H₂ as well as the toxicity of the dopant gases. The disposal techniques currently used by industry are dispersion and flaring. There are advantages to both of these techniques.

Dispersion

If satisfactory dilution can be safely achieved, then the dispersion technique will give adequate disposal. This does require that the H₂ be kept below the lower flammability limit (< 4% in air) and that the exhaust be kept away from the occupied facilities to avoid exposure to the residues of the dopant gases. If these conditions can be achieved reliably, then this system does result in the lowest capital and operating cost. However, there is still an element of risk. In some areas of the exhaust system at certain times in the process sequence there will be sufficient H₂ in the air to be in the explosive range. If a source of ignition is present, then a hazardous condition will result. The composition of a flammable H₂-air mixture is not significantly changed going through a scrubber. Thus using a scrubber is not a satisfactory way to eliminate
a potential explosion hazard. Leaks in ducts or scrubber malfunctions can allow build-up of toxic dopant gasses. If a scrubber is not used and straight outside venting is employed then variations in atmospheric conditions can cause misdirection of the gas flow so that other work areas could be subject to toxic gas exposure.

Flaring
Burn-off of the vent gas as it is produced at the epitaxial module is the safest method of disposal. Deliberate controlled ignition does not rely on avoiding the explosive range of H₂, but is always safe under any set of operating conditions. By converting the dopant gasses to oxides, the toxicity limits are increased, the possibility of harmful exposure with leaks is reduced, and removal of boron, phosphorous and arsenic in the scrubber is enhanced. Even if straight outside venting is done the harmful exposure is dramatically reduced. Flaring does increase the capital and operating costs, however, most of the more conservative, safety-conscious semiconductor manufacturers will opt for flaring because of its inherent reduction of risk. Some attempts have been made to recover H₂ gas for recycling in the process or the conservation of the H₂ thermal energy for process heat or space heating. Under present economic conditions, none of the proposed recovery systems have proven to be cost effective.
HYDROGEN

FORMULA: \( \text{H}_2 \)

PHYSICAL STATE: Colorless, odorless gas.

CORROSIVITY: Noncorrosive.

REACTIVITY: Can react vigorously with oxidizers.

FLASH POINT: Combustible gas.

EXPLOSIVE LIMITS: 4.0% to 75.0% in air.

FIRE CONTROL: Extinguish fire after shutting off source of gas. \( \text{CO}_2 \) or Dry Chemical are effective.

VENTILATION REQUIREMENTS: Local exhaust, and enclosure of process equipment is required.

HEALTH HAZARD: May cause asphyxiation by displacing Oxygen in an enclosed space.

STORAGE REQUIREMENTS: Storage in compressed gas cylinders. (See Safety Instruction No. 6 & 106.)

SPECIAL PRECAUTIONS: All furnaces using Hydrogen shall be equipped with automatic purge and burn-off devices.
6. SUMMARY REPORT
September 4, 1979

Mr. Ralph Grubb
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Dear Ralph:

Attached please find a final safety report on your new facility expansion. The recommendations in the summary are:

1. The CVD reactor effluent gases should go to an exit stack and out to a specially designed shower burn-box that we described to you on our visit. The sketch for the shower burn-box is attached and is designed by Dr. Jim Fordemwalt.

2. A scrubber should be connected to your epi exit gases which should include an H₂ burn-box located in the scavenger box of each epi furnace. These H₂ burn boxes are available from Thermco Products, 1465 North Batavia Street, Orange, California, Phone 714 639 2340. Contact: Jim Rhodes.

3. The third separate line coming out of your facility should be an ammonia line (open NH₃). The ammonia line should be on a separate exit and should not mix with SiCl₄ (Silicon Tetrachloride). For specific detail, please see the attached.

Sincerely,

Daniel J. Shelton
Senior Staff Engineer

Enclosure
RESEARCH STUDY:
HAZARD AND OPERATIONS
ANALYSIS OF FACILITY
FOR ELECTRONIC DEVELOPMENT

FINAL REPORT

PREPARED FOR
GEORGE C. MARSHALL SPACE FLIGHT CENTER, NASA
MARSHALL SPACE FLIGHT CENTER, ALABAMA

PREPARED BY
INTEGRATED CIRCUIT ENGINEERING CORPORATION
6710 EAST CAMELBACK ROAD
SCOTTSDALE, ARIZONA
602-945-4564

SEPTEMBER 1979
SUMMARY FOR FACILITIES INSTALLATIONS

1. To dispose of silane which has a molecular weight of 32.112, has a density of 1.44 gr/l and is pyrophoric (burns in air), the following are conditions for disposing of silane correctly:

Silane should be burned in a remote location through a steam burn-box. The silane should be piped from the CVD reactor to a remote location and exhausted under a shower of water to burn. Other gases that are evolving from the CVD reactor should be treated in the same manner. Those gases are phosphine, argon, nitrous oxide, ammonia, nitrogen, diborane, dichlorosilane and hydrogen chloride.

2. The effluent gas from the epitaxial reactor should go to an adequate scrubber. The hydrogen may be exhausted into a scavenger box and burned, if necessary. Alternatively, it may be mixed with an adequate volume of air to ensure that it never reaches an explosive mixture.

3. The use of Baccharach hydrogen sensors in the line stack are recommended to monitor the hydrogen-oxygen ratio. Hydrogen-oxygen mixtures are explosive at percentage mixtures of from 4 percent to 75 percent.

4. A separate warning panel at your location C-180A for hydrogen sensing and other gas identification. This enunciator panel would give a "what's wrong" alarm indicator in the event if alarm bells are activated. A typical system for this is the Foxborough ID system that Ralph Grubb and ICE discussed during our visit.

5. The concrete protection posts are recommended outside your remote gas storage building, on the north side of the building next to the street. These posts are similar in concept to the ones that are located near the nitrogen tanks across from building 4476.

The scrubber to be used for the main epi gas exhaust is a Ducon-Savko from Beaver Falls, Oregon. The proper stack size is 16" diameter, and it should rise 8' above the building top. The scrubber that you have for the CVD system is a Paramount scrubber. It appears to be very adequate for the job. We would recommend that the Paramount scrubber, manufactured by Paramount Plastics Fabricators, in Downey, California, have heaters to prevent freeze-up in winter and be in a lean-to.
ICE would recommend that the air flow tunnels between the gas storage building and your main facility have air flow sensors installed in them. The relay-pulsed flow sensor that Ralph Grubb mentioned would be an appropriate model to use. Portable sniffers are also recommended to check for any leaks from the origin gas building into epi reactor or CVD reactor. We would also recommend that you seal all air ducts and that they be stainless steel and preferably heliarc welded.

In general, ICE will provide and continue to provide literature and information that is required to make your NASA facility as safe as humanly possible. We also have training seminars, and other employee acquaintance procedures that would be in your best interest to pursue. In conversations with Bobby Kennedy and Ralph Grubb, ICE has proposed a separate startup and training project to acquaint all your employees with the use and handling of dangerous gases or other gases that relate to IC manufacture. Basically, education is as much as important part for good safety as any mechanical safety interlock or warning device.

Pursuing an avenue where the computer can take each system to standby is another very good option. As discussed with Mike Martin, Ralph Grubb, et al, it was proposed that all equipment should be nitrogen purged in the event of a system malfunction.
WATER INLET

EXHAUST

SPRAY NOZZLE

FINE WATER SPRAY

STAINLESS STEEL

SILANE, & CVD INLETS - as many as necessary one for each separate line - eg. - epi vent line, manifold over-pressure pop-off line, etc. (No H₂ lines)

SAFETY ENCLOSURE (Chainlink Fence)

SANITARY CHEMICAL OR STORM DRAIN

FLOOR or recessed drain
ADDENDUM
TO
FACILITY SAFETY STUDY

A REPORT FOR NASA
MARSHALL SPACE FLIGHT CENTER
CONTRACT # NAS8-32812

PREPARED BY
INTEGRATED CIRCUIT ENGINEERING CORPORATION
6710 EAST CAMELBACK ROAD
SCOTTSDALE, ARIZONA 85251
(602) 945-4564
APRIL 1980
1. **BACKGROUND**

The following is an initial report on the emission control requirements for the FED operation, which is located at the NASA facility in Huntsville, Alabama. This work was requested by Mr. Ralph Grubb, and is part of Contract No. NAS8-32812. This study and initial report involves the determination of the safety of the present exhaust gas system of the laboratory, and other equipment would be required to meet acceptable industry and OSHA standards. The following report presents the detailed calculations and ICE's recommendations.

To provide more flexibility in the use of the data, the laboratory was divided into four sections, as shown on the attached chart. Calculations for each section were made individually, in addition calculations are made on the combined results to allow for any unique chemical combinations which might occur during exhaust gas mixing. These areas are as follows:

(a) Diffusion  
(b) Etch Stations (Chemical Hoods)  
(c) Photoresist  
(d) Epi  
(e) CVD

The specific assumptions and backgrounds are given under each section.
2. **SUMMARY**

Based upon the chemical and air-flow data, as supplied by NASA, the present exhaust system, which includes the diffusion, etch stations, and photoresist operations, will exceed OSHA limits for two materials and be near the OSHA limit for one other, as shown in Figure 2.

Calculations were based both on normal operations and worst case conditions. As shown in Figure 3, under normal operations the acetone and trichlorehylene from the etch station area will exceed OSHA limits. Thus, ICE would recommend the insulation of a gas scrubber to handle this exhaust system. This facility would then be compatible, with semiconductor practices with regard to safety and pollution control.

Figure 4 shows that the exhaust directly from the etch facility also exceeds OSHA limits for acetone and TCE. The exhaust from the photoresist area of approximately 1280 cubic feet per minute (36 m³/min), is sufficient and none of the chemicals will exceed OSHA limits.

Figure 5 is a summary of the total combined exhaust from the system.

The epitaxial area was treated separately because it did have a separate exhaust system. Figure 6 shows that six chemicals in the epitaxial area will exceed OSHA limits. These are ammonia, hydrogen chloride, nitrous oxide, diborane, phosphine, and arsine. This confirms the requirement of the scrubber for that system which has already been ordered and is now being installed. Additional studies also show that the epitaxial exhaust will need a hydrogen burn-off.

Figure 7 shows the two chemicals in the CVD area that exceed OSHA limits. These are dichlorosilane and hydrogen chloride. This effluent should go to a separate burn box shower for disposal.
Figure 2

Critical Materials

1. Over OSHA Limits
   (a) Acetone
   (b) Trichlorethylene

2. Near OSHA Limits
   (a) Sulfuric Acid
**Figure 3**

**Critical Areas**

**Total Facility (Etch, Photoresist, Diffusion)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Normal Operation</th>
<th>Worse Case Operation</th>
<th>OSHA Limits</th>
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<tbody>
<tr>
<td>1. Acetone</td>
<td>2953</td>
<td>-</td>
<td>2400</td>
</tr>
<tr>
<td>2. Trichlorethylene</td>
<td>2338</td>
<td>-</td>
<td>535</td>
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**FIGURE 4**

**CRITICAL AREAS**

**ETCH FACILITY**

<table>
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<th>MATERIAL</th>
<th>NORMAL OPERATION</th>
<th>OSHA LIMITS</th>
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<td>1. Acetone</td>
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</tr>
<tr>
<td>2. TCE</td>
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<td>535</td>
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**Figure 5**

**Combined Total Emissions From**
**Etch Stations, Diffusion Stations, and Photoresist Stations**

<table>
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<tr>
<th>Station Type</th>
<th>Hydrofluoric Acid (g/d)</th>
<th>Hydrochloric Acid (g/d)</th>
<th>Nitric Acid (g/d)</th>
<th>Sulfuric Acid (g/d)</th>
<th>Phosphoric Acid (g/d)</th>
<th>Acetic Acid (g/d)</th>
<th>Acetone (g/d)</th>
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<th>Diborane (g/d)</th>
<th>Phospine (g/d)</th>
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</tr>
<tr>
<td>Normal Case</td>
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**NOTE:** This table does not include emissions from the EPT or CVD stations.
### Figure 6

**Critical Areas**

**Epitaxy Operations**

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<thead>
<tr>
<th>MATERIAL</th>
<th>EMISSIONS, mg/m³</th>
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<tr>
<td><strong>Worse Case Operation</strong></td>
<td><strong>OSHA Limits</strong></td>
</tr>
<tr>
<td>1. Ammonia</td>
<td>500,000</td>
</tr>
<tr>
<td>2. Hydrogen Chloride</td>
<td>750,000</td>
</tr>
<tr>
<td>3. Nitrous Oxide</td>
<td>25,300</td>
</tr>
<tr>
<td>4. Diborane</td>
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</tr>
<tr>
<td>5. Phosphine</td>
<td>1.29</td>
</tr>
<tr>
<td>6. Arsine</td>
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## Figure 7

Critical Areas
CVD Operations

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>EMISSIONS, mg/m³</th>
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<td>10.2</td>
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<td>2. Hydrogen Chloride</td>
<td>38.4</td>
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<table>
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<th>OSHA Limits</th>
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<td>7</td>
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3. ASSUMPTIONS

The conclusions and recommendations of this report are based upon raw data supplied by NASA with regard to typical and maximum gas flows on normal equipment usage. This data has not been confirmed or checked by ICE. ICE's calculations are based upon both typical and worse case conditions. Detailed assumptions as to gas flow and usage are given in the individual sections.
DIFFUSION
AND
C V D
4. **DIFFUSION**

Included in this group are the diffusion furnaces consisting of six tubes. The basic assumptions are given in Figure 8. It is assumed that the total vent flow from this area is 25.5 cubic meters per minute. Normal operation assumes that one tube is operating for each type of dopant. Worst case conditions assumes two tubes. Normal conditions for HCl cleaning assumes two tubes. The worst case condition assumes all six tubes. The various chemicals used in this system is listed in the following calculations. Figure 9 is the summary of the chemical outputs from this particular system. It should be noted that OSHA limits for hydrogen chloride are exceeded at the output of this system, but are not exceeded when this system is fully diluted at the total facility exhaust output.

5. **CVD**

During the inspection of this facility it was noted that the output of the CVD reactor was not protected with ventilation or a hood. If the glass chamber would break, during the reactor operation the chemicals could quickly disperse into the room. It is, thus, recommended that that end of the CVD reactor be included in a vent or hood arrangement.

Included in this system is the CVD system with two chambers. Normal operations assume that one chamber is operating, while worst case assumes two. The various chemicals used in this system are listed in the following calculations. Figure 9A is a summary of the chemical outputs from this system.
DIFFUSION OPERATION ASSUMPTIONS

2 Tubes Phosphine, 1% PH₃ in Argon (Nitrogen)
87cc/min Diluted with 11.2 l/min of Inert Gas

2 Tubes Diborane, 0.1% B₂H₆ in argon (Nitrogen)
87cc/Min Diluted with 5 l/min of Inert Gas

2 Oxidation Tubes
HCl Gas for Tube Cleaning - 15% in O₂ 99.999% HCl
HCl Gas Flow is 500 cc/min
Assume Normal 2, maximum of 6 tubes cleaned at one time.

Total Vent Flow 25.5 m³/min - No Dilution with CVD
Average Clean 300cc/min

Final Dilution with Total Exhaust
\[
\frac{25.5 \text{ m}^3/\text{min}}{188.7 \text{ m}^3/\text{min}} = .135 \text{ Diffusion and CVD Dilution Factor}
\]
**Figure 9**

**DIFFUSION OPERATIONS EMISSIONS**

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<tr>
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<th>DIBORANE ( B_2H_6 )</th>
<th>PHOSPHINE ( PH_3 )</th>
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*Exceeds OSHA limits*
# Figure 9A

## CVD Operations Emissions

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<th>Phosphine (PH₃)</th>
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*Exceeds OSHA Limits*