



**Monitoring report form for CDM project activity  
(Version 08.0)**

*Complete this form in accordance with the instructions attached at the end of this form.*

**MONITORING REPORT**

<b>Title of the project activity</b>	N <sub>2</sub> O Abatement Project of Capro Corporation		
<b>UNFCCC reference number of the project activity</b>	4665		
<b>Version number of the PDD applicable to this monitoring report</b>	8.1		
<b>Version number of this monitoring report</b>	1.0		
<b>Completion date of this monitoring report</b>	20/08/2021		
<b>Monitoring period number</b>	14		
<b>Duration of this monitoring period</b>	01/05/2020 ~ 31/12/2020		
<b>Monitoring report number for this monitoring period</b>	N/A		
<b>Project participants</b>	Capro Corporation Hyosung Corporation Hyosung Ebara Engineering Co., Ltd.(Withdrawn)		
<b>Host Party</b>	Republic of Korea		
<b>Applied methodologies and standardized baselines</b>	AM0028(Version 05) N <sub>2</sub> O destruction in the tail gas of Nitric Acid Plants or Caprolactam Production Plants  Standardized baselines: NA		
<b>Sectoral scopes</b>	Scope 5: Chemical industry		
<b>Amount of GHG emission reductions or net anthropogenic GHG removals achieved by the project activity in this monitoring period</b>	Amount achieved before 1 January 2013	Amount achieved from 1 January 2013 until 31 December 2020	Amount achieved from 1 January 2021
	N/A	51,804 tCO <sub>2</sub> e	N/A
<b>Amount of GHG emission reductions or net anthropogenic GHG removals estimated ex ante for this monitoring period in the PDD</b>	235,238 tCO <sub>2</sub> e (245 days)		

**SECTION A. Description of project activity****A.1. General description of project activity**

&gt;&gt;

- (a) Purpose of the project activity and the measures taken for GHG emission reductions;  
The proposed project is to reduce N<sub>2</sub>O emissions of the tail gas emitted from Caprolactam production process in Capro Corporation (hereinafter "Capro") by installing catalytic N<sub>2</sub>O destruction system.
- (b) Brief description of the installed technology and equipments;  
N<sub>2</sub>O treatment system for this project is CRI N<sub>2</sub>O abatement system, which is N<sub>2</sub>O decomposition catalyst at the tail gas. Therefore, CRI system applies to tertiary treatment, which does not affect the existing yield of caprolactam as it just treats the tail gas. In addition, the catalyst system is remarkably efficient as CRI technology is direct N<sub>2</sub>O decomposition process that does not require the addition of any reductant and its pressure drop is small.
- (c) Relevant dates for the project activity.

Relevant dates (dd/mm/yyyy)	The Actions for Implementation of Project activity
16/11/2010	Starting Construction of N <sub>2</sub> O abatement system
20/04/2011	Commissioning start(Plant 1)
27/04/2011	Commissioning start(Plant 2)
02/05/2011	Completing Construction of N <sub>2</sub> O abatement system and the N <sub>2</sub> O abatement system started normal operation
23/05/2011 ~27/05/2011	Field Test for Quality Assurance of installation and calibration of AMS(QAL2)
09/06/2011	Registration date of this project, which means the starting date of the crediting period of this project.
26/09/2011 ~29/09/2011	Additional Field Test for Quality Assurance (QAL2) of installation and calibration of AMS
14/05/2012 ~17/05/2012	Taking Annual Surveillance test(AST) for Quality Assurance of AMS
22/05/2013 ~23/05/2013	Taking Annual Surveillance test(AST) for Quality Assurance of AMS for Plant 2
23/05/2013 ~25/05/2013	Taking Annual Surveillance test(AST) for Quality Assurance of AMS for Plant 1
16/11/2013 ~29/05/2016	Plant 1, Plant 2 Stopped operating
29/05/2016	Operation restart(Plant 2)
19/07/2016	The N <sub>2</sub> O abatement system started normal operation (Plant 2)
25/07/2016 ~28/07/2016	Field Test for Quality Assurance of installation and calibration of AMS(QAL2)
24/07/2017 ~25/07/2017	Taking Annual Surveillance test(AST) for Quality Assurance of AMS for Plant 2
18/07/2018 ~19/07/2018	Taking Annual Surveillance test(AST) for Quality Assurance of AMS for Plant 2
17/07/2019 ~19/07/2019	Field Test for Quality Assurance of installation and calibration of AMS(QAL2)

01/04/2020  
~22/10/2020

Plant 2 Stopped operating

(d) Total emission reductions achieved in this monitoring period: **51,804 tCO<sub>2</sub>e**

## A.2. Location of project activity

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### (a) Host Parties

: The Republic of Korea

### (b) Region/State/Province, etc.

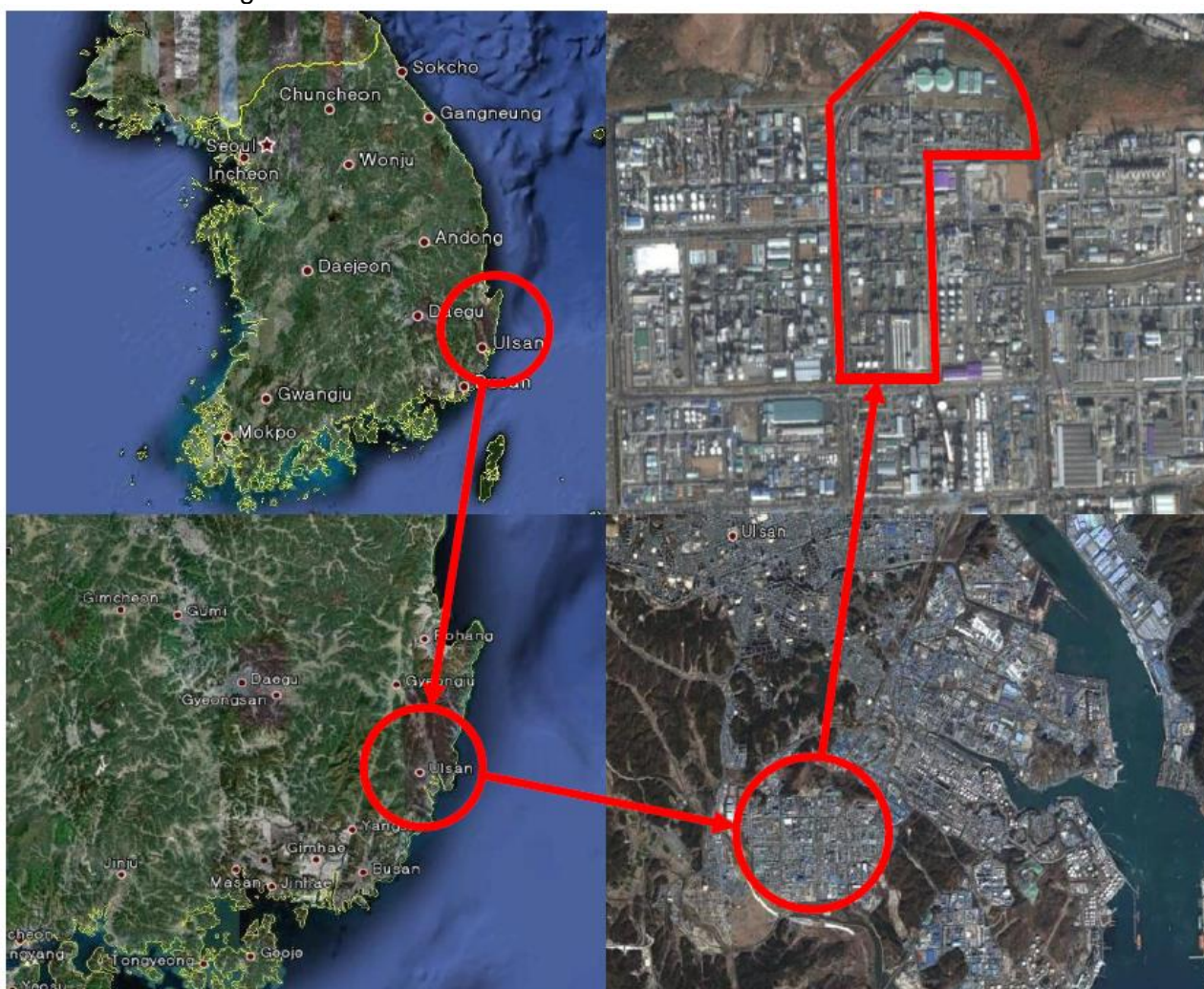
: Ulsan Metropolitan City

### (c) City/Town/Community etc.

: 402-1, Bugok-dong, Nam-gu

### (d) Physical/ Geographical Location

: The east longitude is about 129.3280° and the north latitude is about 35.4958°



## A.3. Parties and project participants

Parties involved	Project participants	Indicate if the Party involved wishes to be considered as project participant (Yes/No)
Republic of Korea	Private entity • Capro Corporation • Hyosung Corporation • Hyosung Ebara Engineering Co., Ltd.(Withdrawn)	No

**A.4. References to applied methodologies and standardized baselines**

&gt;&gt;

**1. The reference of:****(a) The applied methodology:**

AM0028 "Catalytic N<sub>2</sub>O destruction in the tail gas of Nitric Acid Plants or Caprolactam Production" (Version 05)

**(b) Any tools to which the applied methodology refers:**

"Tool for the demonstration and assessment of additionality" (Version 05.2)

**2. UNFCCC CDM website for:****(a) The applied methodology:**

<https://cdm.unfccc.int/filestorage/8/Y/A/8YAF9IE2N07DVCJP5UBQGLTR6SK3Z4/N2O%20destruction%20in%20the%20tail%20gas%20of%20Caprolactam%20production%20plants.pdf?t=NXV8b3plM3J3fDBdo-C1IWZZ0LFtubCs7XEY>

**(b) Any tools to which the applied methodology refers:**

<http://cdm.unfccc.int/methodologies/PAMethodologies/tools/am-tool-01-v5.2.pdf>

**A.5. Crediting period type and duration**

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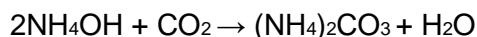
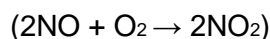
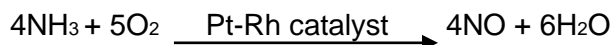
- Type : Fixed
- Start date : 09/06/2011
- Length of the crediting period : 09/06/2011 ~ 08/06/2021

**SECTION B. Implementation of project activity****B.1. Description of implemented project activity**

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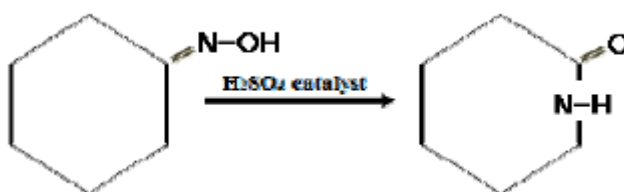
**(a) General Introduction**

Caprolactam is produced by cyclohexane, ammonia, and sulphur as its primary raw materials, and Ammonium sulfate comes out as a by-product, which is supplied as nitrogen fertilizer and a chemical feedstock for industrial uses. In Capro, the main process of caprolactam production is as follows:

**Hydroxylamine sulfate preparation :****Ammonium carbonate preparation****Ammonia oxidation****Ammonium Nitrite Preparation:****Hydroxylamine disulfonic ammonia Preparation:**

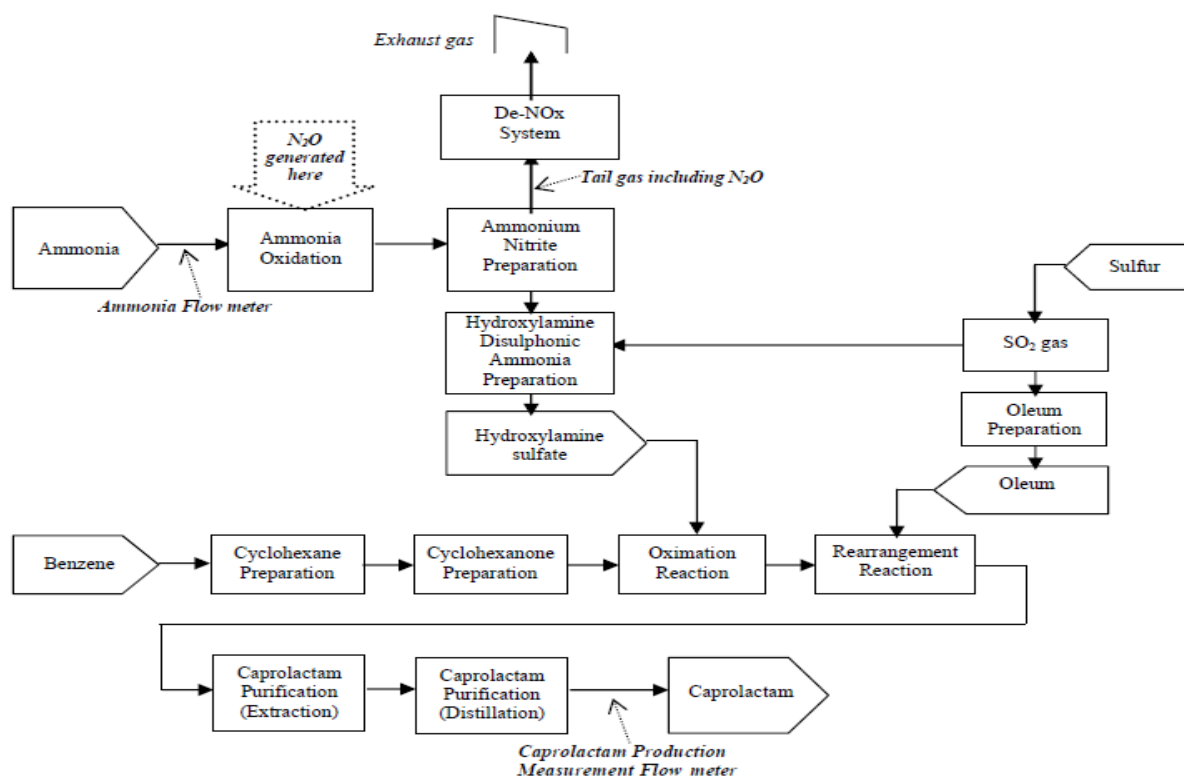
Hydroxylamine Sulfate Preparation:Cyclohexanone preparationOximation Reaction:Beckmann rearrangement:

Cyclohexanone oxime reacts with sulfuric acid catalyst to caprolactam as final product. The structural formula of Beckmann rearrangement is shown in Figure B1-1.



**Figure B1-1.** Structural formula of Beckmann rearrangement

The block flow diagram for existed caprolactam production process of Capro is shown in Figure B1-2.

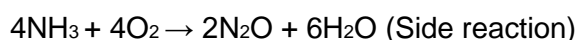
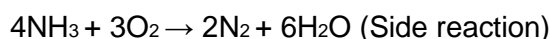
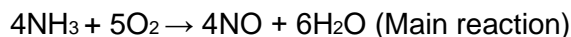


**Figure B1-2.** Block flow diagram for caprolactam production process



Ammonia oxidation reaction is necessary to generate NO and NO<sub>2</sub>, which are going to be the reactants for Ammonium nitrite. (This Ammonium nitrite will induce Hydroxylamine sulphate, and finally caprolactam will be produced, through the complicated reaction pathway, as previous stated at the paragraph to explain the main process of caprolactam production.)

Nitrous oxide (N<sub>2</sub>O) is generated as an undesired by-product through the side reaction of Ammonia oxidation as follows:



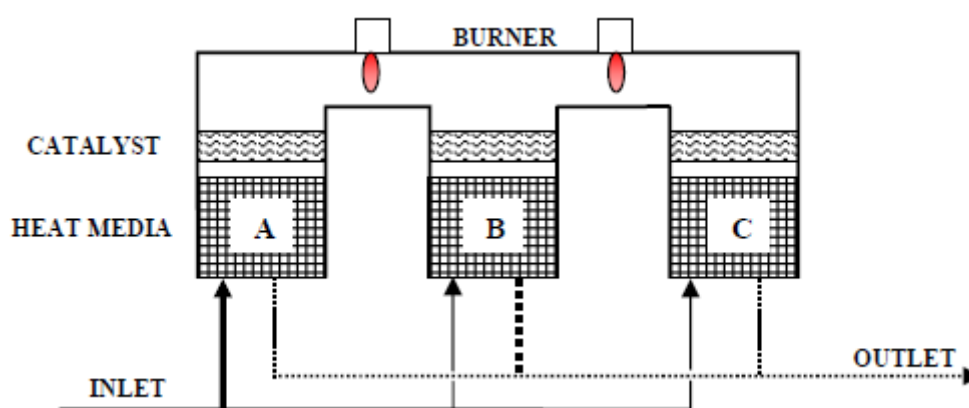
In this project, two plants (Plant I, Plant II) are included. In each plant, there are two of the Ammonium Oxidation Reactors (AORs), the ammonia gas is equally fed to the both of AORs through the one line with one flow meter. Input ammonia is oxidized by passing through the Pt-Rh Catalyst gauze located in AOR.

**(b) Description of the installed technology, technical processes and equipments:**

De-N<sub>2</sub>O system for this project is to destruct the N<sub>2</sub>O included in tail gas by catalyst without any reducing agent.



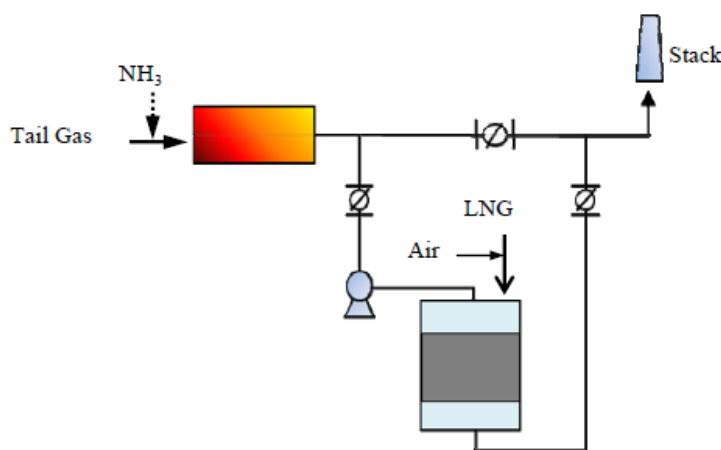
The catalytic reactor designed by Hyosung Ebara Engineering Co. was derived from RTO (Regenerative Thermal Oxidizer), to save the energy required for catalytic reaction to decompose N<sub>2</sub>O, and this N<sub>2</sub>O destruction facility is the so-called "Regenerative Catalytic System". Where, liquefied natural gas (LNG, hereafter "natural gas") is put in to this system as a fuel, not reducing agent, to supply the energy required for the de-N<sub>2</sub>O catalytic reaction. Catalyst is provided by CRI.



**Figure B1-3.** Overview of Regenerative Catalytic System

The principle of performance can be step-wisely described with Figure B1-3 as follows: At the inlet of De-N<sub>2</sub>O system, in-flowed tail-gas is heated up to 550°C by going to heat media A (previously heated), before N<sub>2</sub>O included in the heated tail is decomposed while that tail gas is pass through catalytic bed located on the top of heat storage media A. And then, N<sub>2</sub>O in the once treated tail gas is decomposed again by the next catalyst bed and the heat storage media B, to which the heat

hold in two-times-treated tail gas is transfer. After this, two-times-treated tail gas is going out. Next, tail gas is injected in to the heat media B which is charged with heat transferred from the outflow according to the way explain just above. And the tail gas passed through the heat storage media B and the upper catalyst bed is going to the other catalyst bed and the heat media C. Finally, the tail gas from the plant goes to the media C heated by the previous outflow, this tail gas is flowed reversely to the media B and comes out. In this way, tail gas in-and-out is continuously rotated. The same De-N<sub>2</sub>O processes have been applied to Plant I and II.



**Figure B1-4.** Overview of the De-N<sub>2</sub>O process in Plant I and II

### (c) Information on the implementation and actual operation of the project activity

The information on the implementation and actual operation of the project activity including relevant dates is summarized as following table

**Table B1-1.** The information on the implementation and actual operation of the project activity

The information on the implementation and Actual operation of the project activity	Relevant dates(dd/mm/yyyy)	
	Plant I	Plant II
Starting Construction of N <sub>2</sub> O abatement system	16/11/2010	16/11/2010
Commissioning start	20/04/2011	27/04/2011
Starting continued normal operation	02/05/2011	02/05/2011
Regular overhaul (period 2)	08/10/2011~20/10/2011	None
Regular overhaul (period 4)	11/10/2012~24/10/2012	11/10/2012~29/10/2012
Regular overhaul (period 5)	10/10/2013~15/11/2013	10/10/2013~31/10/2012
Normal operation	None	19/07/2016~24/10/2016
Regular overhaul (period 7,8)	None	24/10/2016~04/11/2016
Regular overhaul (period 9,10)	None	09/05/2018~26/05/2018
Regular overhaul (period 11,12)	None	14/10/2019~03/11/2019
Regular overhaul (period 13)	None	01/11/2019~03/11/2019
Regular overhaul (period 14,15)	None	21/12/2020~24/12/2020

Plant I has not been operated after 5<sup>th</sup> monitoring period.

In order to avoid that the operation of the caprolactam production plant is manipulated in a way to increase the N<sub>2</sub>O generation, thereby increasing the CERs, the operating temperature and pressure of the ammonia oxidation reactor (AOR), and NH<sub>3</sub> input to the AOR, have been monitored every working day. During the monitoring period 14, the actual average daily AOR operation conditions are monitored as below Table B1-2.

**Table B1-2.** Summary of the AOR operation data

Plant	$T_{g,a}$	$T_{g,b}$	$P_{g-1}$	AOR,d-1
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I	Permit range in PDD	656.57~731.66	662.08~743.92	43,320~98,564	42.250 (Upper limit)
	Actual average in period 14	N/A			
	The number of days outside permit range				
Plant II		$T_{g,c}$	$T_{g,d}$	$P_{g-2}$	$A_{OR,d-2}$
	Permit range in PDD	738.95~774.85	734.53~770.57	79,317~96,381	44.557 (Upper limit)
	Actual average in period 14	755.36	749.70	84,971	40.335
	The number of days outside permit range	0	0	0	0

The all of catalysts for ammonia oxidation reaction used during the crediting period are the same as those described in registered PDD.

**Table B1-3.** The status of ammonia oxidation catalysts installed in AOR

		Plant I	Plant II
Historical composition of AOR catalyst $G_{com,hist}$		Pt(90%): Rh(10%)	Pt(90%): Rh(10%)
Historical supplier of AOR catalyst $G_{sup,hist}$		Johnson Matthey	Johnson Matthey
in period 14	The composition ( $G_{com}$ )	Pt(90%): Rh(10%)	Pt(90%): Rh(10%)
	Supplier ( $G_{sup}$ )	Johnson Matthey	Johnson Matthey

In the case of a nitric acid plant or a caprolactam plant using the Raschig process, baseline emissions are limited to the design capacity of the existing nitric acid or caprolactam production plant. If the actual production of caprolactam ( $P_{product}$ ) exceeds the design capacity ( $P_{product,max}$ ) then emissions related to the production above  $P_{product,max}$  will not be claimed for the baseline scenario. Therefore,  $P_{product}$  of each plant should be monitored. All of the data for production of caprolactam for this period were listed in detail in the emission reductions calculation spreadsheet.

**Table B1-4.** The information of Caprolactam production

		Plant I	Plant II
PDD	$P_{product,max}$ (tCaprolactam/yr)	63,307	64,965
	Maximum operating day(day/yr)	363	355
	Average daily output(ton/day)	174	183
Period 14	Sub-total output for period(tCaprolactam/period)	N/A	9,085.82
	No. of operating days(day/period)		245
	Average daily output(ton/day)		37.08

The actual production of caprolactam ( $P_{product}$ ) did not exceed the design capacity ( $P_{product,max}$ )



**(d) Events or situations occurred during the monitoring****(1) Events information of Plant II**

Sites	No.	Date(yyyy.mm.dd)&Time		Description
		from	to	
N2O Abatement System (NAS)	1	2020.05.01. 01:00	2020.10.26. 11:13	Plant 2 stopped operating
	2	2020.11.06. 11:53	2020.11.08. 09:03	Load change
	3	2020.11.08. 10:56	2020.11.08. 11:13	
	4	2020.11.08. 23:47	2020.11.09. 10:06	
	5	2020.11.09. 17:52	2020.11.10. 03:18	
	6	2020.11.10. 06:48	2020.11.10. 07:26	
	7	2020.11.11. 18:43	2020.11.12. 03:11	
	8	2020.11.17. 16:49	2020.11.17. 24:03	
	9	2020.12.02. 11:51	2020.12.02. 14:12	
	10	2020.12.02. 19:54	2020.12.02. 20:08	
	11	2020.12.03. 19:42	2020.12.03. 20:11	
	12	2020.12.08. 21:53	2020.12.08. 23:16	
	13	2020.12.09. 05:49	2020.12.09. 06:22	
	14	2020.12.17. 06:50	2020.12.17. 14:12	
	15	2020.12.19. 02:41	2020.12.21. 12:07	
	16	2020.12.21. 18:43	2020.12.24. 17:10	OVERHAUL
	17	2020.12.29. 11:53	2020.12.29. 13:17	Load change

**(2) Action to the events of Plant II**

Sites	No.	Date(yyyy.mm.dd)&Time		Description
		from	to	
N2O Abatement System (NAS)	1	2020.05.01. 01:00	2020.10.26. 11:13	The events resulted from the data signal out because of unstable process, while the NAS was on operation to reduce the emission of the N2O. Emission reductions during the periods of events are set to zero for conservative purpose.
	2	2020.11.06. 11:53	2020.11.08. 09:03	
	3	2020.11.08. 10:56	2020.11.08. 11:13	
	4	2020.11.08. 23:47	2020.11.09. 10:06	
	5	2020.11.09. 17:52	2020.11.10. 03:18	
	6	2020.11.10. 06:48	2020.11.10. 07:26	
	7	2020.11.11. 18:43	2020.11.12. 03:11	
	8	2020.11.17. 16:49	2020.11.17. 24:03	
	9	2020.12.02. 11:51	2020.12.02. 14:12	
	10	2020.12.02. 19:54	2020.12.02. 20:08	
	11	2020.12.03. 19:42	2020.12.03. 20:11	
	12	2020.12.08. 21:53	2020.12.08. 23:16	
	13	2020.12.09. 05:49	2020.12.09. 06:22	
	14	2020.12.17. 06:50	2020.12.17. 14:12	
	15	2020.12.19. 02:41	2020.12.21. 12:07	
	16	2020.12.21. 18:43	2020.12.24. 17:10	
	17	2020.12.29. 11:53	2020.12.29. 13:17	

**B.2. Post-registration changes****B.2.1. Temporary deviations from the registered monitoring plan, applied methodologies, standardized baselines or other methodological regulatory documents**

>>  
N/A

**B.2.2. Corrections**

>>  
N/A

**B.2.3. Changes to the start date of the crediting period**

>>  
N/A

**B.2.4. Inclusion of monitoring plan**

>>  
N/A

**B.2.5. Permanent changes to the registered monitoring plan, or permanent deviation of monitoring from the applied methodologies, standardized baselines, or other methodological regulatory documents**

>>  
N/A

**B.2.6. Changes to project design**

>>  
N/A

**B.2.7. Changes specific to afforestation or reforestation project activity**

>>  
N/A

**SECTION C. Description of monitoring system**

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**(a) Monitoring points to be measured**

(1) Monitoring Points in Plant I

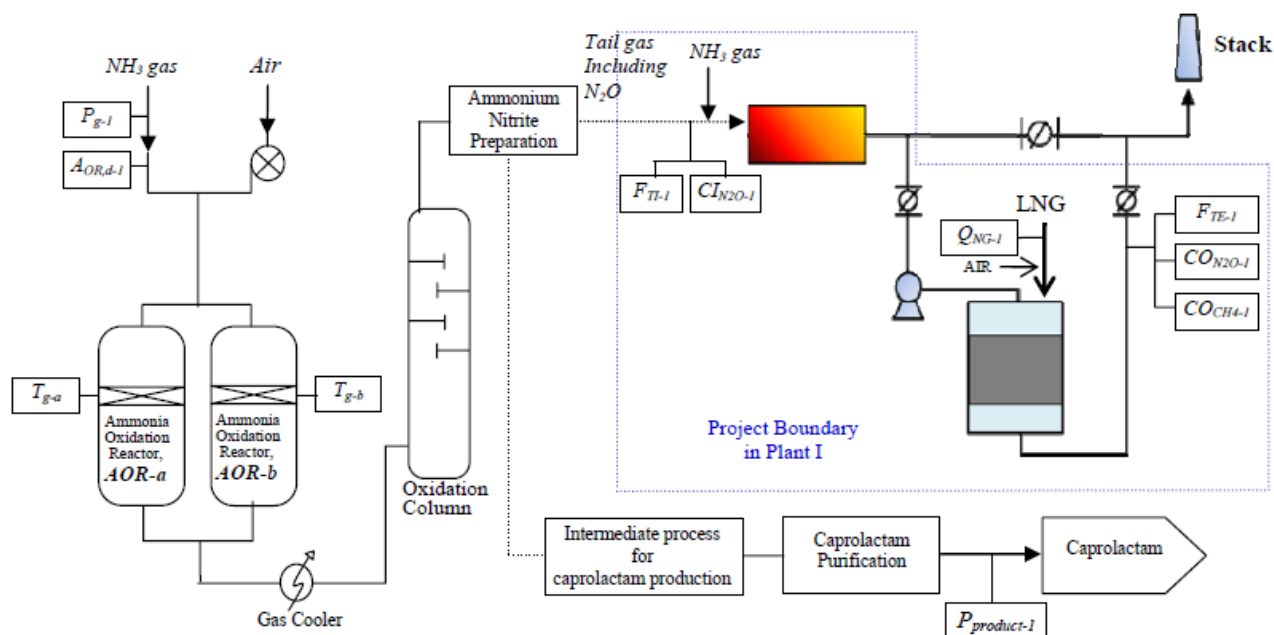


Figure C1. Monitoring Points in Plant I

Parameter	Description	Tag No.
$AOR,d-1$	Actual ammonia flow rate to AOR in Plant I	FIC-1201
$P_{g-1}$	Actual operating pressure of the AOR-a, b in Plant I	PI-1205
$T_{g-a}$	Actual operating temperature of the AOR-a in Plant I	TI-1204
$T_{g-b}$	Actual operating temperature of the AOR-b in Plant I	TI-1206
$F_{TI-1}$	Volume flow rate at the inlet of the destruction facility in Plant I	FI-1521
$F_{TE-1}$	Volume flow rate at the exit of the destruction facility in Plant I	FI-1522
$CI_{N2O-1}$	$N_2O$ concentration at destruction facility inlet in Plant I	AI-1521
$CO_{N2O-1}$	$N_2O$ concentration at destruction facility outlet in Plant I	AI-1522(a)
$Q_{NG-1}$	Additional natural gas input for re-heating the tail gas in Plant I	FI-1523
$CO_{CH4-1}$	$CH_4$ concentration at destruction facility outlet in Plant I	AI-1522(b)
$P_{product-1}$	Plant output of caprolactam in Plant I	FR-7705

Some tag numbers of measuring devices were specified to avoid confusion, because the same tag number had been allocated to two kind of different measuring devices described in PDD. Therefore new tag numbers were given to be clearly identified as follows:

	Parameters	Tag No. in PDD	Actual Tag No. in Period 14
Plant I	$CO_{N2O-1}$	AI-1522	AI-1522(a)
	$CO_{CH4-1}$	AI-1522	AI-1522(b)

## (2) Monitoring Points in Plant II

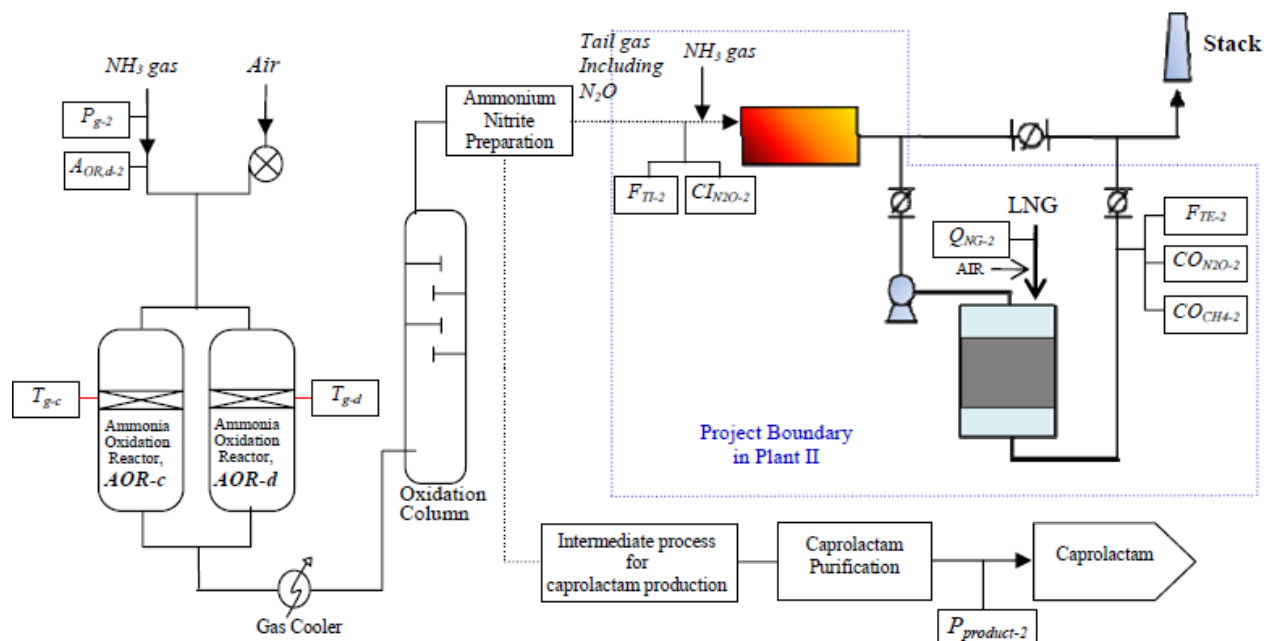


Figure C2. Monitoring Points in Plant II

Parameter	Description	Tag No.
$AOR_{d-2}$	Actual ammonia flow rate to AOR in Plant II	2FIC-1201
$P_{g-2}$	Actual operating pressure of the AOR-a, b in Plant II	2PI-1205
$T_{g-c}$	Actual operating temperature of the AOR-a in Plant II	2TI-1204
$T_{g-d}$	Actual operating temperature of the AOR-b in Plant II	2TI-1206
$F_{TI-2}$	Volume flow rate at the inlet of the destruction facility in Plant II	2FI-1521
$F_{TE-2}$	Volume flow rate at the exit of the destruction facility in Plant II	2FI-1522
$CI_{N2O-2}$	$N_2O$ concentration at destruction facility inlet in Plant II	2AI-1521
$CO_{N2O-2}$	$N_2O$ concentration at destruction facility outlet in Plant II	2AI-1522(a)
$Q_{NG-2}$	Additional natural gas input for re-heating the tail gas in Plant II	2FI-1523
$CO_{CH4-2}$	$CH_4$ concentration at destruction facility outlet in Plant II	2AI-1522(b)
$P_{product-2}$	Plant output of caprolactam in Plant II	2FI-7705

Some tag numbers of measuring devices were specified to avoid confusion, because the same tag number had been allocated to two kind of different measuring devices described in PDD. Therefore new tag numbers were given to be clearly identified as follows:

	Parameters	Tag No. in PDD	Actual Tag No. in Period 14
Plant II	$CO_{N2O-2}$	2AI-1522	2AI-1522(a)
	$CO_{CH4-2}$	2AI-1522	2AI-1522(b)

**(b) Data collection procedure**

The data of the AOR operating parameters ( $A_{OR}$ ,  $T_g$ ,  $P_g$ ) and the productivity of caprolactam are logged and stored by the existed DCS (Distributed Control System) which has been independently operated for Plant I and II before starting this project. Besides, DAS (Data Acquisition System) is newly installed to log the relevant data to the  $N_2O$  decomposition amount and  $CH_4$  emission by operating  $N_2O$  abatement system. DAS consists of an 'Electronic Evaluation Unit (EEU)' and two of 'Data Communication Units (DCUs)' located at Plant I and II.

Major function of DCU is to record the raw measurement data from Automated Measuring System (AMS), and to transmit those to EEU. DCU can store temporarily the record of raw measurement data with the ring memory of 16 days minute values. In addition, the data of AOR operation and caprolactam productivity are delivered from DCS and recorded by DCU respectively, and then transmitted to EEU.  $Q_{NG}$  is measured by Flow meter separately installed from AMS and  $CO_{CH_4}$  are also measured at the outlet by dual channel-NDIR by which the concentration of  $N_2O$  and  $CH_4$  is measured separately. Therefore it is aggregated, recorded and stored by EEU that not only the AMS data but also the AOR data and productivity data. However, if there is a discrepancy between the DCS data and the EEU and/or DCU data, DCS data should be taken.

EEU satisfies the requirements described in AM0028 / Version 05 as below:

- (a) Evaluation unit needs to take into account registration, mean average determination, validation, and evaluation;
- (b) The system and concept of emission data processing needs to be described;
- (c) Protocols and out-prints are required.

With EEU, these raw measurement data transmitted from DCUs are integrated after the measurement uncertainty determined by QAL 2 test is subtracted from them. Then, those are converted to the average values at the end of the every integration interval (1 hour), and validated. Negatively validated average values are set to zero. Validated average values outside the valid calibration range are to be stored with the associated time and with their status and are to be logged on EEU at the end of the day and year. EEU has the storage capacity of 5 year-ring memory.

The calibration curve for the measuring instrument is determined using a standard reference method. The validity of the calibration curve is proved by EEU. The validity range for the calibration is specified in the calibration report. This calibration reports are printed and kept for back-up.

External hard disk drive (HDD) is installed for back-up and long storage of the data and relevant reports for verification, replaced by new one every 4 years, old HDDs are kept holding with attention during the 10 years of crediting period and 2 additional years according to AM0028 / Version 05.

**Table C1.** The information of the data collection and storage devices except DCS

		Supplier	Model No.	Serial No.
DCU(Data Communication Unit)	Plant I	DURAG	D-EMS 500KE	1301581
	Plant II	DURAG	D-EMS 500KE	1301582
EEU (Electronic Evaluation Unit)		DURAG	D-EMS 2000SWE	1301567
External Hard disk drive(HDD) for backup		DURAG	D-EMS 2000RED	1301578

The role of the new PC for back-up is to display and record the hourly data from EEU, the monthly data of supplied LNG, and the other information including the events list, working diary and so on.

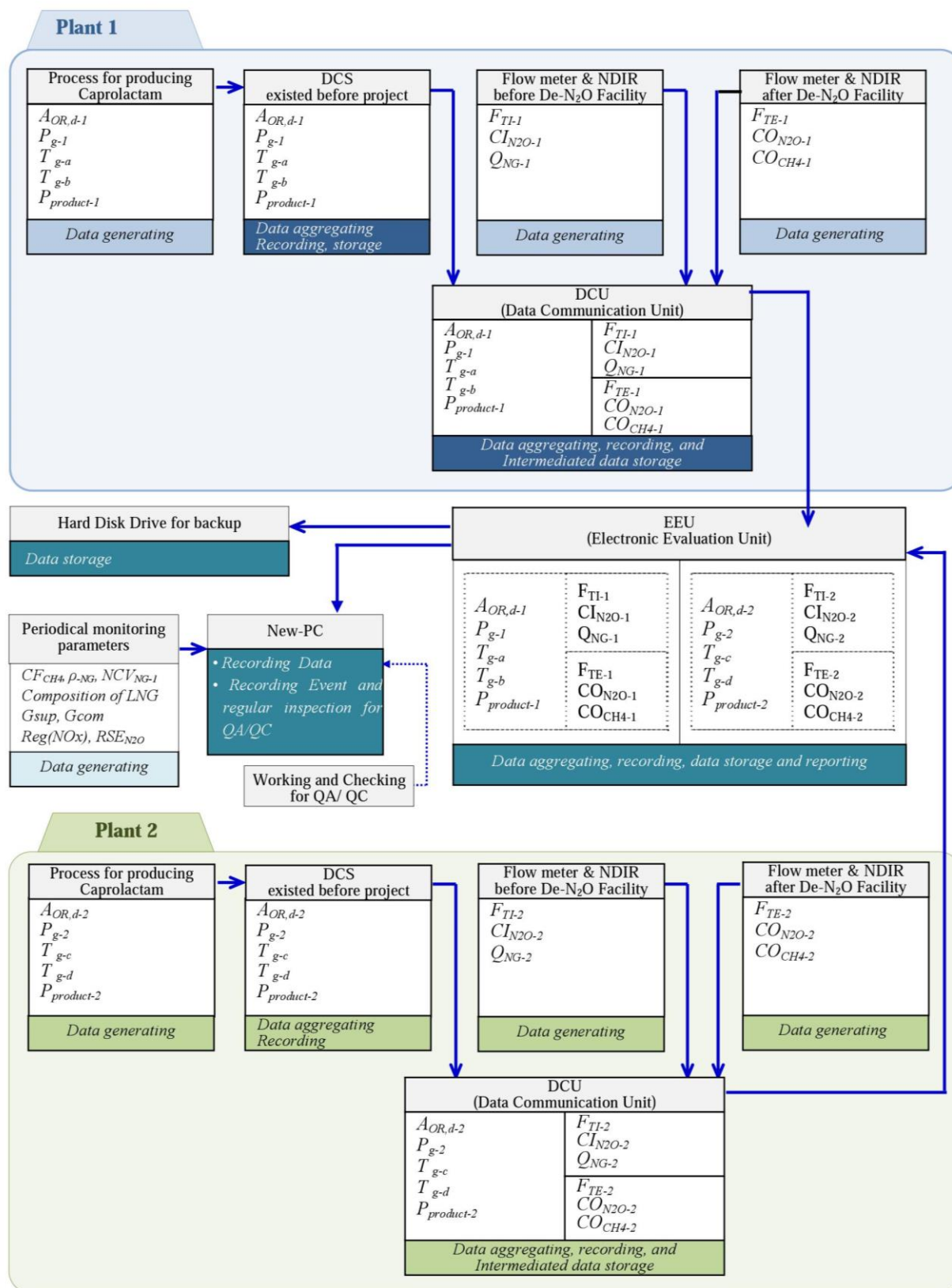
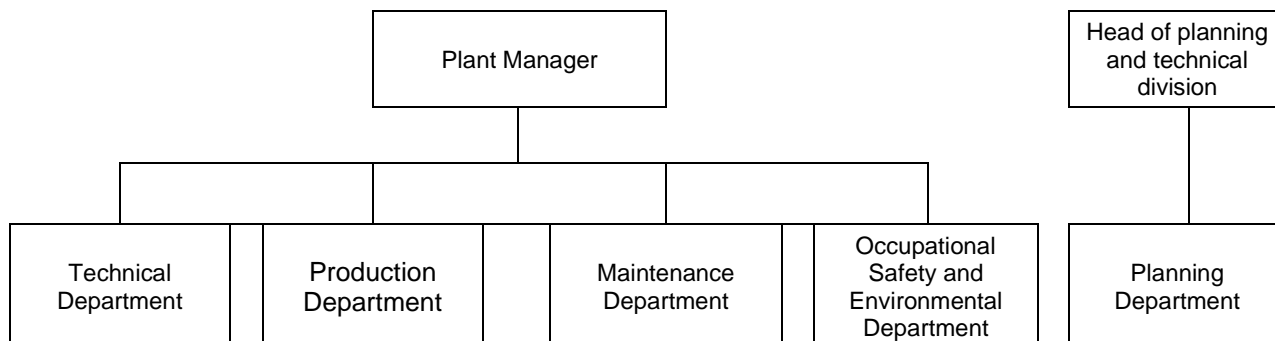


Figure C.3 Data Collecting Flow



**(c) Organizational structure, roles and responsibilities of personnel****(1) Organization Structure****Figure C.4** The scheme of the operational and management structure**(2) Roles and responsibilities of personnel****Plant Manager**

The Plant Manager takes overall responsibility for the operation and maintenance of the N<sub>2</sub>O monitoring system. In addition, the Plant Manager has authority to approve monitoring report provided by the Technical Department.

**Production Department**

The responsible Production Engineers in Production Department are in charge of the operation and supervision of N<sub>2</sub>O monitoring system that will be implemented to record plant operation data.

**Technical Department**

Monitoring engineers in Technical Department are responsible for collecting, validating and processing the data to determine GHG emission reduction and making report periodically. Moreover, the monitoring engineer is in charge of archiving the data as well. The monitoring engineers archive all required data and reports for verification.

**Maintenance Department**

Maintenance Department is responsible for maintaining and repairing the instrument associated with this project. Calibration for instruments is concerned by maintenance department as well.

**Occupational Safety and Environment Department**

The OSHES Department plays a role for indicating the direction and managing according to the monitoring plan.

**Planning Department**

Planning Department conducts the internal audit of N<sub>2</sub>O monitoring system periodically.

**(d) Emergency procedures for the monitoring system**

In case of the data deviation, following procedures are taken.

- (a) Production Engineer in Production Department identifies whether the deviation results from processing or other factors such as temperature and pressures.
- (b) Production engineer compares the deviated data with other parameter data if the deviation results from processing.
- (c) If the reason for the data deviation is not identified, production engineer informs Maintenance Department to correct the error after inspecting all gauges and analyzers.

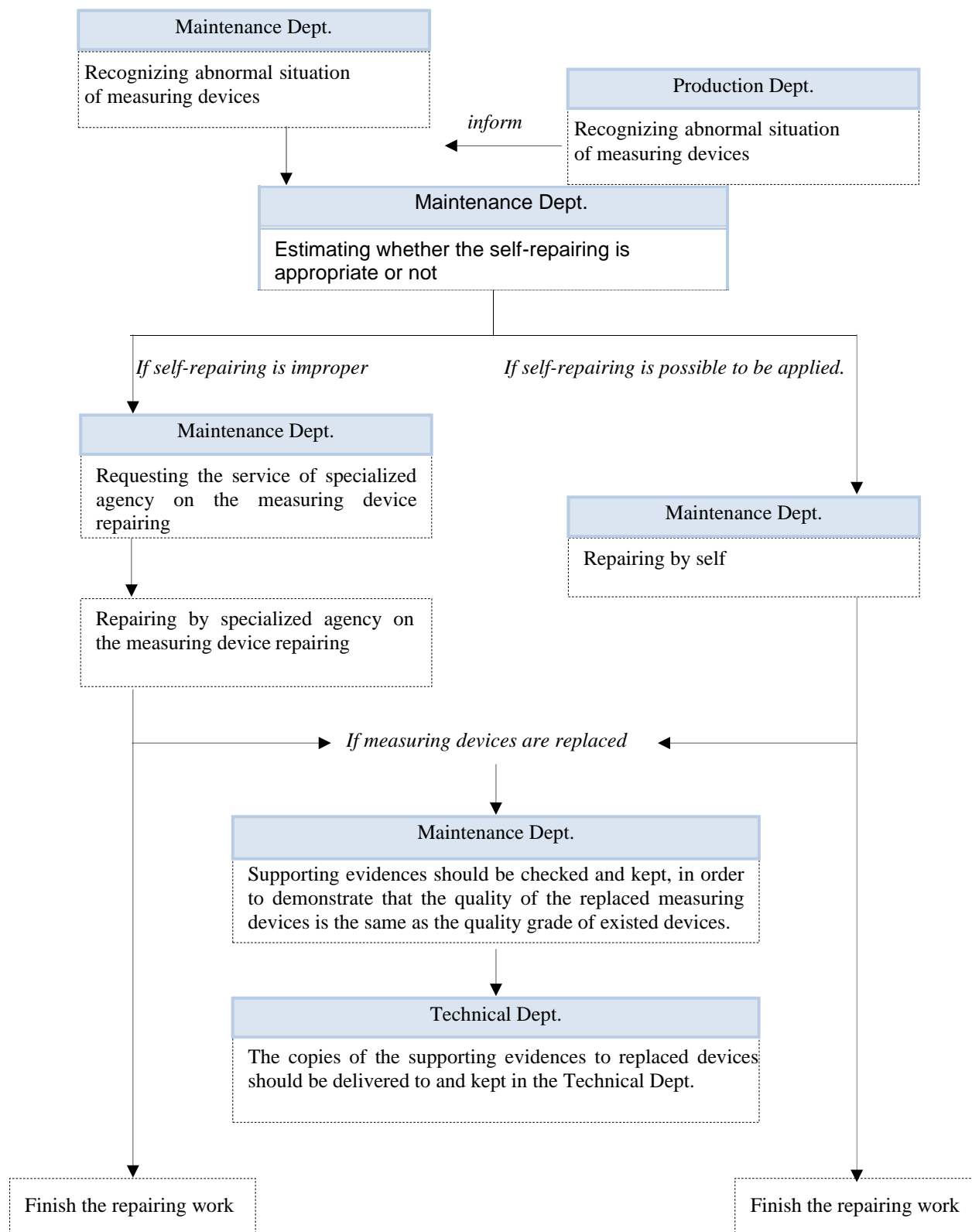
If the data deviation is not covered by procedures above, Technical Department makes the decision to correct figures or to abandon the data. In addition, any data correction is in compliance with the applied methodology and done in a conservative bias

When the malfunction of measuring instruments is occurred, following procedures are taken.

- (a) If production engineer recognizes the malfunction of measuring instruments, he informs person in Maintenance Department of this abnormal situation.
- (b) Maintenance Department estimates whether performing repairing action to solve problem is appropriate or not.
- (c) If it is decided that self-repairing by Maintenance Department is appropriate, self-repairing is carried out. However, if the instrument is out of repair, Maintenance Department requests external institution specialized in repairing to have it serviced.

If measuring devices have to be replaced, related supporting evidences should be checked and kept by Maintenance Department, in order to demonstrate that the quality of the replaced measuring devices is the same as the quality grade of existed devices, before the copies of the supporting evidences to replaced devices should be delivered to and kept in the Technical Department.

Specially, if any malfunction situation of the measuring devices composing AMS(Automated measuring system) is continued during the 8hrs after it is detected, Maintenance Department should request the service of official measuring agency to measuring the N<sub>2</sub>O concentration or flow rate at the monitoring points of inlet and outlet of N<sub>2</sub>O decomposition system. If the services by the official measuring agency cannot be taken for some unavoidable reason, it will be taken instead of measuring by the external official measuring agency that the AMS data measured at the most similar operating condition among those of the recent 1 month just before the abnormal situation is happen, with the conservative understanding of that the N<sub>2</sub>O concentration of inlet is replaced with the lowest number, and that of outlet is with highest one.



**Figure C.5** Emergency Procedures for malfunctions of measuring devices in general

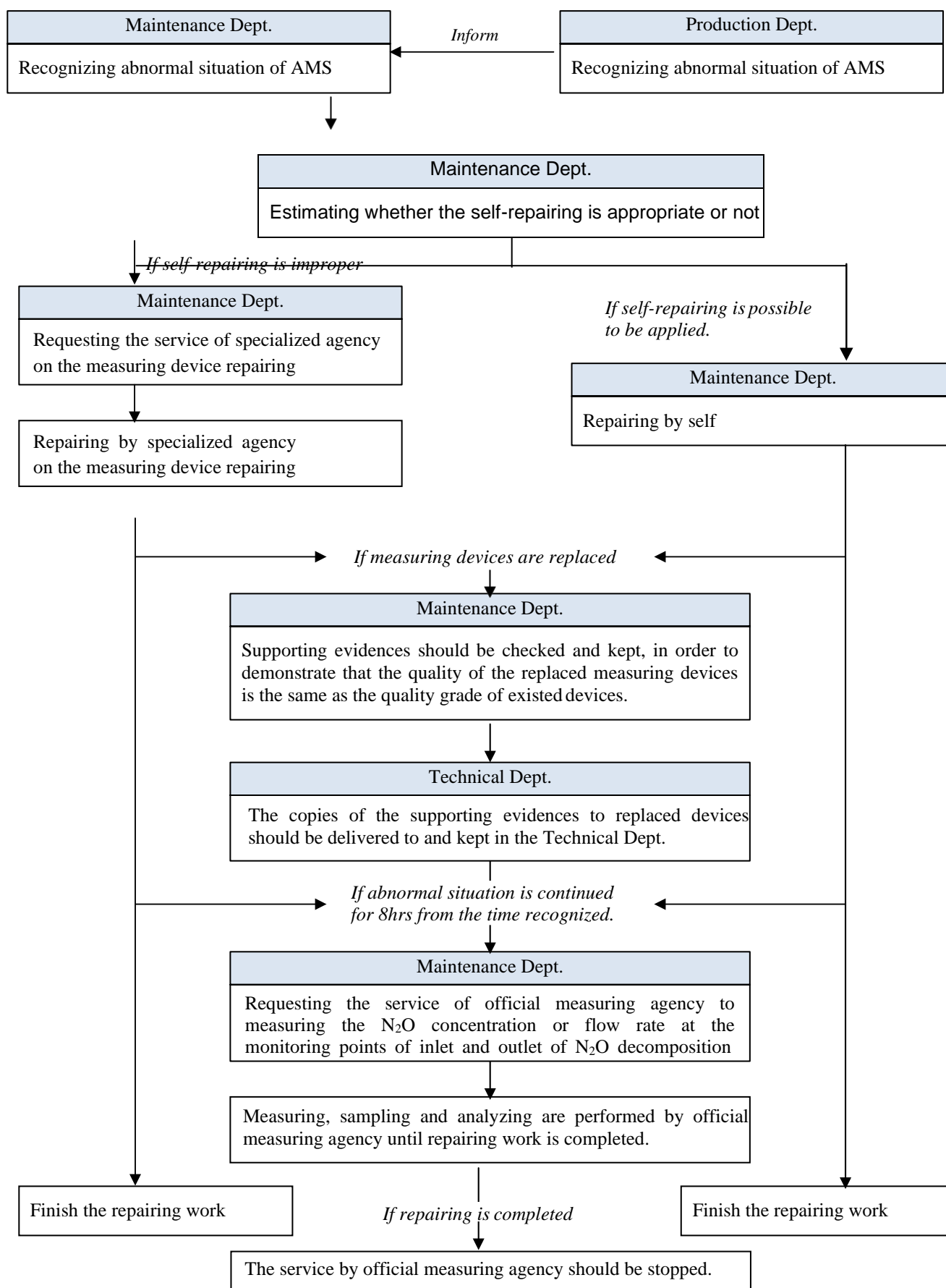
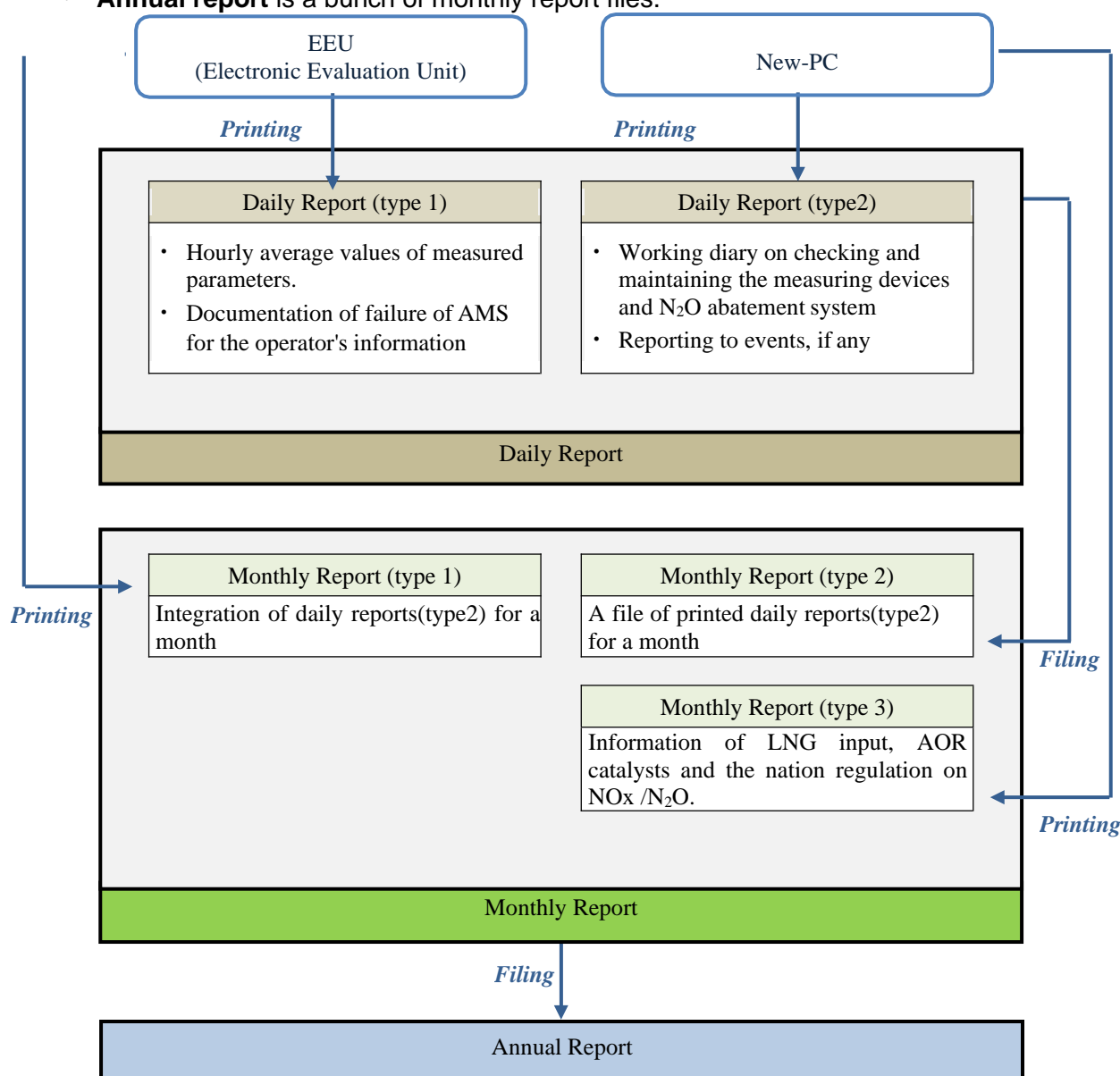


Figure C.6 Emergency Procedures for malfunction of AMS

**(e) Reporting**

- **Daily report** consists of the parts printed out from EEU and from New-PC. EEU report is to show the data generated by AMS and related to the AOR operation condition and to the productivity of caprolactam. Daily value of each parameter is calculated based on hourly average or hourly total value on the EEU report. The situation of the AMS failure is also documented on the EEU report. The other hand, new-PC daily report is about checking and maintaining the measuring device and N<sub>2</sub>O abatement system, and about monitoring events.
- **Monthly report** integrates the data and information in daily reports. LNG information is also reported monthly. Periodical monitoring parameters such as the composition and supplier of AOR catalysts, the national regulation on NO<sub>x</sub> and N<sub>2</sub>O are checked by monthly report too.
- **Annual report** is a bunch of monthly report files.

**Figure C.7** The consists of the periodical reports

**(f) Quality Assurance of AMS(Automated measuring system)**

AMS(Automated measuring system) has been applied to measure the amount of N<sub>2</sub>O emission at the two monitoring points of the inlet and outlet of N<sub>2</sub>O destruction facility of each plant involved in this project. By AMS, the concentration of N<sub>2</sub>O and the volume flow rate of tail gas are measured simultaneously(F<sub>Ti</sub>, Cl<sub>N2O</sub>, and F<sub>TE</sub>, CO<sub>N2O</sub>) at same basis (wet or dry), and these values are expressed on the same basis (wet or dry) with correcting to normal conditions (101.324kPa, 0deg C) through the algorithm based on procedures of EN14181.

“European Norm EN14181: Quality assurance of automated measuring systems, 2004” is selected as a guidance document to the Quality Assurance and Control procedure of the AMS for this project. This means that the three levels of quality assurance tests(QAL1, QAL2 and QAL3) and one annual functional test must be carried out regarding the selection, installation, and operation of AMS under the monitoring methodology in AM0028(ver.05).

**Quality assurance of tested AMS (:QAL1)**

The quality assurance of tested AMS was accomplished with that the flow meters and N<sub>2</sub>O gas analyzers having the performance certificate with calculation uncertainty were selected as summarized in following tables.

**Table C.2 (a) Information of the quality assurance of tested AMS located in Plant I**

Parameters	Type	Model	Serial number	Standard for Performance certification	Certificate No.	The date of Certificate Issued (dd/mm/yyyy)	Approved Methods to calculate of uncertainty
<b>F<sub>Ti-1</sub></b>	Ultrasonic flow meter	D-FL 200 System	HEAD A: 1217007 HEAD B: 1217008 EVALUATION UNIT : 1216861 CASE OF EVALUATION : 1216999	MCERTS	Sira MC 060072/01	22/05/2007	
<b>Cl<sub>N2O-1</sub></b>	NDIR (Nondispersion infrared absorption analyzer)	ULTRAMAT 6	AO-748	TUV	Report Nr. 1290727	May 2009	
				TUV	BB-EG1-KAR Gr02X	29/07/2003	EN 50016 EN 60079-14 Guidelines for explosion protection of GB Chemie (GRG 104)
				FM Approvals	3016050	15/07/2003	
				CSA INTERNATIONAL	1431560	17/04/2003	
<b>F<sub>TE-1</sub></b>	Ultrasonic flow meter	D-FL 200 System	HEAD A: 1217009 HEAD B: 1217010 EVALUATION UNIT : 1216862 CASE OF EVALUATION : 1217001	MCERTS	Sira MC 060072/01	22/05/2007	
<b>CO<sub>N2O-1</sub></b>	NDIR	ULTRAMAT 6	AO-750	TUV	Report Nr. 1290727	May 2009	
				TUV	BB-EG1-KAR Gr02X	29/09/2003	EN 50016 EN 60079-14 Guidelines for explosion protection of GB Chemie (GRG 104)
				FM Approvals	3016050	15/07/2003	
				CSA INTERNATIONAL	1431560	17/04/2003	



**Table C.2 (b)** Information of the quality assurance of tested AMS located in Plant II

Parameters	Type	Model	Serial number	Standard for Performance certification	Certificate No.	The date of Certificate Issued (dd/mm/yyyy)	Approved Methods to calculate of uncertainty
$F_{Ti-2}$	Ultrasonic flow meter	D-FL 200 System	HEAD A: 1217011 HEAD B: 1217012 EVALUATION UNIT : 1216866 CASE OF EVALUATION : 1217002	MCERTS	Sira MC 060072/01	22/05/2007	
$Cl_{N2O-2}$	NDIR	ULTRAMAT 6	AO-749	TUV	Report Nr. 1290727	May 2009	
				TUV	BB-EG1 KAR Gr02X	29/09/2003	EN 50016 EN 60079-14 Guidelines for explosion protection of GB Chemie (GRG 104)
				FM Approvals	3016050	15/07/2003	
				CSA INTERNATIONAL	1431560	17/04/2003	
$F_{TE-2}$	Ultrasonic flow meter	D-FL 200 System	HEAD A: 1217013 HEAD B: 1217014 EVALUATION UNIT : 1216867 CASE OF EVALUATION : 1217003	MCERTS	Sira MC 060072/01	22/05/2007	
$CO_{N2O-2}$	NDIR	ULTRAMAT 6	AO-751	TUV	Report Nr. 1290727	May 2009	
				TUV	BB-EG1-KAR Gr02X	29/09/2003	EN 50016 EN 60079-14 Guidelines for explosion protection of GB Chemie (GRG 104)
				FM Approvals	3016050	15/07/2003	
				CSA INTERNATIONAL	1431560	17/04/2003	

Quality assurance of installation and calibration of AMS (:QAL2)

QAL2 has been performed according to the Standard Reference Measurement Method (17/07/2019~19/07/2019) by AIR-TEC, which is the one of the organizations having an accredited quality assurance system on ISO/IEC 17025.

The results to the tests for QAL2 were summarized on the QAL2 reports in the major items following:

- Section of the location of measurement
- Duly installation of the monitoring equipment
- Correct choice of measurement range
- Calibration of AMS using the standard-Reference-Method(SRM) as guidance
- Calibration curve either as linear regression or as straight line from absolute zero to centre of a scatter-plot
- Calibration of the standard deviation at the 95% confidence interval

Continuous quality Assurance through the local operator/manager (:QAL3)

QAL3 has been implemented since the project start up. This includes:

- Permanent quality assurance during the plant operation by the operating staff
- Assurance of reliable and correct operation of the monitoring equipment
- Regular controls : zero point, span, drift, meet schedule of manufacturer maintenance intervals

Annual Surveillance test (AST)

The AST is a procedure which is used to evaluate whether the measured values obtained from the AMS still meet the required uncertainty criteria – as demonstrated in the previous QAL2 test. It also determines whether the calibration function obtained during the previous QAL2 test is still valid.

**(g) Conservative calculation on tail gas flow**

Measurement value by a flow meter at inlet of destruction facility ( $F_{TI}$ ) and Measurement value by a flow meter at outlet of destruction facility ( $F_{TE}$ ), both parameters shall be cross checked to ensure that no leak of  $N_2O$  is taking place, and in case of discrepancy, conservative calculation of emission reduction is provided. In order to achieve conservative approach, the measured inlet flow ( $F_{TI}$ ) would be adjusted to the value ( $F_{TI}^*$ ) by the below equation.

$$F_{TI}^* = \min \left[ F_{TI} ; \left( \frac{F_{TE}}{1+VEF} - Q_{NG} \times \frac{Q_{NG \text{ combustion gas}}}{Q_{NG}} \right) \right]$$

Where:

- $F_{TI}^*$  : Conservative volume flow at the inlet of destruction facility used for emission reduction calculation ( $Nm^3/h$ )
- $F_{TI}$  : Measurement value by a flow meter at inlet of destruction facility ( $Nm^3/h$ )
- $F_{TE}$  : Measurement value by a flow meter at outlet of destruction facility ( $Nm^3/h$ )
- $Q_{NG}$  : Natural gas input for re-heating the tail gas ( $Nm^3/h$ )
- $Q_{NG \text{ combustion gas}}$  : Combustion gas of natural gas ( $Nm^3/h$ )
- VEF : Volumetric Expansion Factor

For monitoring, the gas generated by combusting natural gas ( $Q_{NG \text{ combustion gas}}$ ) has been estimated on the supposition that air input according to the theoretical oxygen demand on the natural gas composition which information is provided by the natural gas supplier for Capro (Kyung Dong city gas CO., Ltd).

And for the conservative approach, any volume change from De-NO<sub>x</sub> and/or De-N<sub>2</sub>O system will be considered by the Volumetric Expansion Factor (VEF). Before the first monitoring period, the Volumetric Expansion Factor (VEF) was determined as 0.001 which was provided by CRI, N<sub>2</sub>O abatement catalysts supplier. This value of VEF is applied as a fixed official value.

#### (h) Training

The supplier of the NDIR system provided complete training to the monitoring engineers in charge of operation and maintenance of the monitoring system. The provider of the De-N<sub>2</sub>O system, (Hyosung Ebara Engineering Co., Ltd.) initiated the operation technique for the system to the staff in the Technical department of Capro.

### SECTION D. Data and parameters

#### D.1. Data and parameters fixed ex ante

Data/Parameter	GWP <sub>N<sub>2</sub>O</sub>
Unit	Not applicable
Description	Global warming potential of the nitrous oxide
Source of data	IPCC, The Second Assessment Report
Value(s) applied	298
Choice of data or measurement methods and procedures	As per EB 69 Report, Annex 3 the GWP of N <sub>2</sub> O is defined in the 2 <sup>nd</sup> commitment period (starting 01/01/2013) as 298 tCO <sub>2</sub> /tN <sub>2</sub> O.
Purpose of data/parameter	Baseline Emission / Project Emission Calculation
Additional comments	Not applicable

Data/parameter:	GWP <sub>CH<sub>4</sub></sub>
Unit	Not applicable
Description	Global warming potential of the nitrous oxide
Source of data	IPCC, The Second Assessment Report
Value(s) applied)	25
Choice of data or measurement methods and procedures	As per EB 69 Report, Annex 3 the GWP of CH <sub>4</sub> is defined in the 2 <sup>nd</sup> commitment period (starting 01/01/2013) as 25 tCO <sub>2</sub> /tCH <sub>4</sub> .
Purpose of data	Project Emission Calculation
Additional comments	Not applicable

Data/parameter:	$P_{product, max}$
Unit	t Caprolactam /yr
Description	Design capacity of caprolactam production of the targeted line
Source of data	PDD
Value(s) applied)	$P_{product1, max}$ : 63,307 ton/yr (design capacity in Plant I) for 363 days $P_{product2, max}$ : 64,965 ton/yr (design capacity in Plant II) for 355 days Each plant has an individual design capacity.

Choice of data or measurement methods and procedures	Specified in the methodology All of ammonia oxidation reactors of these plants are keeping with the same as they were installed at the beginning. Each plant of Capro's design capacity is established upon the maximum daily production and maximum operating days till 31 December 2005.		
		Plant I	Plant II
	Maximum Daily production (ton/day)	174.4	183.0
	Maximum operating day (day/yr)	363	355
	Design Capacity for each plant (ton/yr)	63,307	64,965
Purpose of data	Baseline Emission / Project Emission Calculation		
Additional comments	Not applicable		

<b>Data/parameter:</b>	<b><i>AOR<sub>hist</sub></i></b>
Unit	tNH <sub>3</sub> /day
Description	Maximum of historical ammonia flow rate of the ammonia oxidation reactor (AOR)
Source of data	PDD
Value(s) applied)	AOR <sub>hist-1</sub> : 42.250tNH <sub>3</sub> /d (total flow rate for AOR-a and AOR-b in Plant I) AOR <sub>hist-2</sub> : 44.557tNH <sub>3</sub> /d (total flow rate for AOR-c and AOR-d in Plant II)
Choice of data or measurement methods and procedures	These values are set based on maximum values of historical daily data within latest 3 years (1 <sup>st</sup> Jan.2007 - 31 <sup>st</sup> Dec.2009). Since, the historical operating data on maximum daily average ammonia flow is existed in each plant on Capro, the upper limit on ammonia flow is determined on this historical data.
Purpose of data	Baseline Emission Calculation
Additional comments	Not applicable

<b>Data/parameter:</b>	<b><i>T<sub>g,hist</sub></i></b>
Unit	°C
Description	Historical operating temperature range of the ammonia oxidation reactor
Source of data	PDD
Value(s) applied)	<i>T<sub>g,hist-a</sub></i> : 656.57– 731.66°C (for AOR-a in Plant I) <i>T<sub>g,hist-b</sub></i> : 662.08–743.92 °C (for AOR-b in Plant I) <i>T<sub>g,hist-c</sub></i> : 738.95– 774.85°C (for AOR-c in Plant II) <i>T<sub>g,hist-d</sub></i> : 734.53– 770.57°C (for AOR-d in Plant II)
Choice of data or measurement methods and procedures	The permitted range of operating temperatures is set based on historical data within latest 3 years (1 <sup>st</sup> Jan.2007 - 31 <sup>st</sup> Dec.2009).
Purpose of data	Baseline Emission Calculation
Additional comments	Not applicable

<b>Data/parameter:</b>	<b><i>P<sub>g,hist</sub></i></b>
Unit	<i>Pa gauge</i>
Description	Historical operating pressure range of the ammonia oxidation reactor
Source of data	PDD
Value(s) applied)	<i>P<sub>g,hist_1</sub></i> : 43,320 – 98,564 Pa gauge (for AOR-a and AOR-b in Plant I) <i>P<sub>g,hist_2</sub></i> : 79,317 – 96,381 Pa gauge (for AOR-c and AOR-d in Plant II)
Choice of data or measurement methods and procedures	The permitted range of operating pressure is set based on historical data within latest 3 years (1 <sup>st</sup> Jan.2007 - 31 <sup>st</sup> Dec.2009).

Purpose of data	Baseline Emission Calculation
Additional comments	Not applicable

<b>Data/parameter:</b>	<b><math>G_{sup,hist}</math></b>
Unit	Not applicable
Description	Historical supplier of the ammonia oxidation catalyst
Source of data	PDD
Value(s) applied)	Name of the supplier: Johnson Matthey
Choice of data or measurement methods and procedures	Specified in the methodology.
Purpose of data	Baseline Emission Calculation
Additional comments	Not applicable

<b>Data/parameter:</b>	<b><math>G_{com,hist}</math></b>
Unit	%
Description	Historical composition of the ammonia oxidation catalyst
Source of data	PDD
Value(s) applied)	Pt (90%): Rh (10%)
Choice of data or measurement methods and procedures	Specified in the methodology.
Purpose of data	Baseline Emission Calculation
Additional comments	Not applicable

<b>Data/parameter:</b>	<b><math>OXID_{HC}</math></b>
Unit	%
Description	Oxidation factor of natural gas, with two or more molecules of carbon
Source of data	PDD
Value(s) applied)	100%
Choice of data or measurement methods and procedures	Specified in the methodology.
Purpose of data	Project Emission Calculation
Additional comments	Not applicable

<b>Data/parameter:</b>	<b><math>EF_{CH_4}</math></b>
Unit	tCO <sub>2</sub> /tCH <sub>4</sub>
Description	Emission factor of methane
Source of data	PDD
Value(s) applied)	2.75(tCO <sub>2</sub> /tCH <sub>4</sub> )
Choice of data or measurement methods and procedures	This value is theoretically calculated as follows; 44 gCO <sub>2</sub> /16gCH <sub>4</sub>
Purpose of data	Project Emission Calculation
Additional comments	Not applicable

<b>Data/parameter:</b>	<b><math>\rho_{CH_4}</math></b>
Unit	t/m <sup>3</sup>
Description	Density of methane
Source of data	Tool to determine project emissions from flaring gases containing methane
Value(s) applied)	0.000716 t/m <sup>3</sup> (0°C, 1atm)
Choice of data or measurement methods and procedures	The value converted into the normal condition is applied as this parameter. In case of the normal condition, this parameter can be given by theoretical value.
Purpose of data	Project Emission Calculation
Additional comments	Not applicable

<b>Data/parameter:</b>	<b><math>M_i</math></b>
Unit	Hour
Description	Length of measuring interval
Source of data	AMS
Value(s) applied)	1 hour (to be measured continuously for 24 hours)
Choice of data or measurement methods and procedures	Specified in the methodology. This parameter is set based on recording frequencies for volume flow rates and N <sub>2</sub> O concentrations at N <sub>2</sub> O destruction facility inlet and outlet.
Purpose of data	Baseline Emission Calculation / Project Emission Calculation
Additional comments	Not applicable

<b>Data/parameter:</b>	<b><math>Reg_{NO_x}</math></b>
Unit	tNO <sub>x</sub> /Nm <sup>3</sup>
Description	National regulation on NO <sub>x</sub> emissions
Source of data	The "Clean Air Conservation Act", one of the National environmental legislation, Ministry of Environment
Value(s) applied)	4.10714×10 <sup>-7</sup> tNO <sub>x</sub> /Nm <sup>3</sup> (as a NO <sub>2</sub> concentration)
Choice of data or measurement methods and procedures	Calculated. According to Article 15 of the Enforcement Regulation Of The Clean Air Conservation Act, the highest permit limit for NO <sub>x</sub> emission is 200 ppm(v) as a NO <sub>2</sub> concentration level.  The unit of (tNO <sub>x</sub> /Nm <sup>3</sup> ) is adjusted from the ppm(v) unit by following equation : 4.10714×10 <sup>-7</sup> [tNO <sub>x</sub> /Nm <sup>3</sup> ] = 200 ppm(v) × 10 <sup>-6</sup> × 46/22.4/1,000
Purpose of data	Not applicable
Additional comments	Not applicable



**D.2. Data and parameters monitored**

Data/Parameter	F <sub>TI,i</sub>		
Unit	Nm <sup>3</sup> /hr		
Description	Volume flow rate at the inlet of the destruction facility		
Measured/calculated/default	Measured		
Source of data	Flow meter with normalizing functions		
Value(s) of monitored parameter	For this period, the average values of F <sub>TI</sub>		
		Plant I	Plant II
	F <sub>TI</sub> (Nm <sup>3</sup> /hr) average	N/A	38,704.36
Monitoring equipment		Plant I	Plant II
	Type	Ultrasonic flow meter	Ultrasonic flow meter
	Accuracy class	< 2%	< 2%
	Serial No.	N/A	HEAD A : 1217011 HEAD B : 1217012 Evaluation Unit : 1216866 Case of Evaluation : 1217002
	Calibration frequency	Every day by Auto calibration manner	Every day by Auto calibration manner
	Date of last calibration	N/A	31/12/2021
	Validity	N/A	Yes
	Measuring/reading/recording frequency	•Measuring period : Continuously •Recording frequency : Hourly	
Calculation method (if applicable)	Not applicable		
QA/QC procedures	QAL 1, 2, 3 and AST for AMS		
Purpose of data/parameter	Baseline Emission Calculation		
Additional comments	Not applicable		

Data/parameter:	$F_{TE,i}$		
Unit	Nm <sup>3</sup> /hr		
Description	Volume flow rate at the exit of the destruction facility		
Measured/calculated/default	Measured		
Source of data	Flow meter with normalizing functions		
Value(s) of monitored parameter	For this period, the average values of $F_{TE}$		
		Plant I	Plant II
	$F_{TE}$ (Nm <sup>3</sup> /hr) average	N/A	43,441.73

Monitoring equipment	Type	Plant I	Plant II
	Accuracy class	Ultrasonic flow meter	Ultrasonic flow meter
	Serial No.	< 2%	< 2%
	Calibration frequency	N/A	HEAD A : 1217013 HEAD B : 1217014 Evaluation Unit : 1216867 Case of Evaluation : 1217003
	Date of last calibration	Every day by Auto calibration manner	Every day by Auto calibration manner
	Validity	N/A	31/12/2020
		N/A	Yes
Measuring/reading/recording frequency:	•Measuring period : Continuously •Recording frequency : Hourly		
Calculation method (if applicable):	Not applicable		
QA/QC procedures:	QAL 1, 2, 3 and AST for AMS		
Purpose of data:	Project Emission Calculation		
Additional comments:	Not applicable		

Data/parameter:	$Cl_{N_2O,i}$		
Unit	N <sub>2</sub> O/Nm <sup>3</sup>		
Description	N <sub>2</sub> O concentration at destruction facility inlet		
Measured/calculated/default	Measured		
Source of data	Non-dispersion infrared absorption analyzer (NDIR)		
Value(s) of monitored parameter	For this period, the average values of $Cl_{N_2O}$		
	Average value	Plant I	Plant II
	$Cl_{N_2O,i}$ as tN <sub>2</sub> O/Nm <sup>3</sup>	N/A	4.04167x10 <sup>-6</sup>
Monitoring equipment	Type	Plant I	Plant II
	Accuracy class (repeatability)	NDIR	NDIR
	Serial No.	> 95%	> 95%
	Calibration frequency	N/A	AO-749
	Date of last calibration	Every 2 weeks	Every 2 weeks
	Validity	N/A	23/12/2020
		N/A	Yes
Measuring/reading/recording frequency:	•Measuring period : Continuously •Recording frequency : Hourly		
Calculation method (if applicable):	Not applicable		
QA/QC procedures:	QAL 1, 2, 3 and AST for AMS		
Purpose of data:	Baseline Emission Calculation		
Additional comments:	Not applicable		

Data/parameter:	$CO_{N_2O,i}$		
Unit	N <sub>2</sub> O/Nm <sup>3</sup>		
Description	N <sub>2</sub> O concentration at destruction facility outlet		
Measured/calculated/default	Measured		
Source of data	Non-dispersion infrared absorption analyzer (NDIR)		
Value(s) of monitored parameter	For this period, the average values of $Cl_{N_2O}$		
	Average value	Plant I	Plant II
	$CO_{N_2O,i}$ (tN <sub>2</sub> O/Nm <sup>3</sup> )	N/A	6.56475x10 <sup>-7</sup>

Monitoring equipment		Plant I	Plant II
	Type	NDIR	NDIR
	Accuracy class (repeatability)	> 95%	> 95%
	Serial No.	N/A	AO-751
	Calibration frequency	Every 2 weeks	Every 2 weeks
	Date of last calibration	N/A	23/12/2020
	Validity	N/A	Yes
Measuring/reading/recording frequency:	•Measuring period : Continuously •Recording frequency : Hourly		
Calculation method (if applicable):	Not applicable		
QA/QC procedures:	QAL 1, 2, 3 and AST for AMS		
Purpose of data:	Project Emission Calculation		
Additional comments:	Not applicable		

<b>Data/parameter:</b>	<b><math>P_{product,y}</math></b>		
Unit	t Caprolactam/yr		
Description	Plant output of caprolactam		
Measured/calculated/default	Measured		
Source of data	The value measured by Mass flow meter		
Value(s) of monitored parameter		Plant I	Plant II
	<b><math>P_{product, period}</math> (ton/period)</b>	N/A	9,085.82
Monitoring equipment		Plant I	Plant II
	Type	Mass flow meter	Mass flow meter
	Accuracy class (repeatability)	Within $\pm 0.1\%$	Within $\pm 0.15\%$
	Serial No.	N/A	28 529138
	Calibration frequency	Every 2 years	Every 2 years
	Date of last calibration	N/A	15/10/2019
	Validity	N/A	Yes
Measuring/reading/recording frequency:	•Measuring period : Continuously •Recording frequency : Hourly		
Calculation method (if applicable):	Not applicable		
QA/QC procedures:	Cross-check of amount of the produced caprolactam is performed on the basis of stock change data and weighbridge data.		
Purpose of data:	Baseline emission Calculation		
Additional comments:	Not applicable		

<b>Data/parameter:</b>	<b><math>A_{OR,d}</math></b>		
Unit	tNH <sub>3</sub> /day		
Description	Actual ammonia flow rate to the ammonia oxidation reactor (AOR)		
Measured/calculated/default	Measured		
Source of data	Differential pressure transmitter with normalizing functions		
Value(s) of monitored parameter	Average ammonia flow rate a day (tNH <sub>3</sub> /day) of AOR in this period		
		Plant I	Plant II
	<b><math>A_{OR,d}</math> (tNH<sub>3</sub>/day)</b>	N/A	40.335

Monitoring equipment		Plant I	Plant II
	Type	Differential Pressure	Differential Pressure
	Accuracy class (repeatability)	Within $\pm 0.1\%$	Within $\pm 0.1\%$
	Serial No.	N/A	121080055040028
	Calibration frequency	Every 2 years	Every 2 years
	Date of last calibration	N/A	16/10/2019
	Validity	N/A	Yes
Measuring/reading/recording frequency:	•Measuring period : Continuously •Recording frequency : Hourly		
Calculation method (if applicable):	Since this parameter is measured		
QA/QC procedures:	Every two years, the measuring instrument is calibrated by the authorized organization providing the calibration service on the basis of the national standard. Otherwise, the measuring instrument is replaced with new instrument calibrated according to the national standard.		
Purpose of data:	Baseline Emission Calculation		
Additional comments:	Not applicable		

Data/parameter:	$T_{g,d}$					
Unit	°C					
Description	Actual daily ( <i>d</i> ) operating temperature of the ammonia oxidation reactor					
Measured/calculated/default	Measured					
Source of data	Thermocouple					
Value(s) of monitored parameter	Average daily temperature (°C) of AOR in this period					
	Plant I		Plant II			
	$T_{g,a}$ (°C)	$T_{g,b}$ (°C)	$T_{g,c}$ (°C)	$T_{g,d}$ (°C)		
	N/A		755.36	749.70		
Monitoring equipment						
	Plant II		$T_{g-c}$		$T_{g-d}$	
	Type		Thermocouple K		Thermocouple K	
	Accuracy class (Maximum error)		600°C	-0.5°C	600°C	-0.5°C
			800°C	-0.9°C	800°C	-1.1°C
			1000°C	-1.7°C	1000°C	-2.2°C
	Serial No.		5351312		5351313	
	Calibration frequency		Every 2 years		Every 2 years	
	Date of last calibration		15/10/2019		15/10/2019	
	Validity		Yes		Yes	
Measuring/reading/recording frequency:	•Measuring period : Continuously •Recording frequency : Hourly					
Calculation method (if applicable):	Not applicable					
QA/QC procedures:	Every two years, the measuring instrument is calibrated by the authorized organization providing the calibration service on the basis of the national standard. Otherwise, the measuring instrument is replaced with new instrument calibrated according to the national standard.					
Purpose of data:	Baseline emission Calculation					
Additional comments:	Not applicable					

Data/parameter:	$P_{g,d}$
Unit	Pa gauge

Description	Actual operating pressure of the ammonia oxidation reactor on day $d$		
Measured/calculated/default	Measured		
Source of data	Pressure gauge		
Value(s) of monitored parameter	Average daily Pressure (Pa/day) of AOR in this period		
		Plant I	Plant II
	$P_{g,d}$ (Pa/day)	N/A	84,971
Monitoring equipment		Plant I	Plant II
	Type	Gauge Pressure	Gauge Pressure
	Accuracy class	Within $\pm 0.1\%$	Within $\pm 0.1\%$
	Serial No.	N/A	1211 8005540030
	Calibration frequency	Every 2 years	Every 2 years
	Date of last calibration	N/A	16/10/2019
	Validity	N/A	Yes
Measuring/reading/recording frequency:	•Measuring period : Continuously •Recording frequency : Hourly		
Calculation method (if applicable):	Not applicable		
QA/QC procedures:	Every two years, the measuring instrument is calibrated by the authorized organization providing the calibration service on the basis of the national standard. Otherwise, the measuring instrument is replaced with new instrument calibrated according to the national standard.		
Purpose of data:	Baseline emission Calculation		
Additional comments:	Not applicable		

<b>Data/parameter:</b>	<b><math>G_{sup}</math></b>
Unit	Not applicable
Description	Supplier of the ammonia oxidation catalyst
Measured/calculated/default	Not applicable
Source of data	Supplier information on catalyst delivery confirmation document
Value(s) of monitored parameter	Johnson Matthey
Monitoring equipment	Not applicable
Measuring/reading/recording frequency:	Recording frequency : Date of changing catalyst
Calculation method (if applicable):	Not applicable
QA/QC procedures:	Not applicable
Purpose of data:	Baseline emission Calculation
Additional comments:	Not applicable

<b>Data/parameter:</b>	<b><math>G_{com}</math></b>
Unit	%
Description	Composition of the ammonia oxidation catalyst
Measured/calculated/default	Not applicable
Source of data	Supplier information on catalyst delivery confirmation document
Value(s) of monitored parameter	Pt (90)% : Rh(10)%
Monitoring equipment	Not applicable
Measuring/reading/recording frequency:	Recording frequency : Date of changing catalyst

Calculation method (if applicable):	Not applicable
QA/QC procedures:	Not applicable
Purpose of data:	Baseline emission Calculation
Additional comments:	Not applicable

<b>Data/parameter:</b>	<b>Type<sub>HC</sub></b>
Unit	Not applicable
Description	Type of hydrocarbon / Natural gas
Measured/calculated/default	Not applicable
Source of data	Natural gas supplier : KyungDong city gas CO., Ltd. This company is one of the city gas companies in the Republic of Korea. The most of natural gas supplied by KyungDong city gas CO., Ltd. is provided from Korea Gas Corporation (hereafter, KOGAS), which imports natural gas from around the world and supplies it to power generation plants, gas-utility companies and city gas companies throughout the country.
Value(s) of monitored parameter	Natural Gas
Monitoring equipment	Not applicable
Measuring/reading/recording frequency:	Monthly
Calculation method (if applicable):	Not applicable
QA/QC procedures:	Not applicable
Purpose of data:	Project emission Calculation
Additional comments:	Not applicable

Data/parameter:	CF <sub>CH4</sub>		
Unit	-		
Description	Methane content of hydrocarbon, natural gas		
Measured/calculated/default	Not applicable		
Source of data	Information provided by the natural gas supplier		
Value(s) of monitored parameter	Date	Plant I	Plant II
	May. 2020	N/A	0.9302
	Jun. 2020		0.9291
	Jul. 2020		0.9294
	Aug. 2020		0.926
	Sep. 2020		0.9274
	Oct. 2020		0.9299
	Nov. 2020		0.9329
	Dec. 2020		0.9359
	Period 14		0.9301
Monitoring equipment	Not applicable		
Measuring/reading/recording frequency:	Recording frequency : Monthly		
Calculation method (if applicable):	Not applicable		
QA/QC procedures:	Not applicable		
Purpose of data:	Project Emission Calculation		
Additional comments:	Not applicable		

<b>Data/parameter:</b>	<b><math>Q_{NG,y}</math></b>		
Unit	Nm <sup>3</sup>		
Description	Natural gas input for re-heating the tail gas		
Measured/calculated/default	Measured		
Source of data	Flow meter with normalizing functions		
Value(s) of monitored parameter	<b>Data</b> <b><math>Q_{NG}</math> (Nm<sup>3</sup>/day)</b>	<b>Plant I</b> N/A	<b>Plant II</b> 1,235.42
Monitoring equipment	<b>Contents</b>	<b>Plant I</b>	<b>Plant II</b>
	Type	Orifice	Orifice
	Accuracy class	±0.90%	±0.90%
	Serial No.	N/A	02319623
	Calibration frequency	Every 2 years	Every 2 years
	Date of last calibration	N/A	16/10/2019
	Validity	N/A	Yes
Measuring/reading/recording frequency:	•Measuring period : Continuously •Recording frequency : Hourly		
Calculation method (if applicable):	Not applicable		
QA/QC procedures:	Not applicable		
Purpose of data:	Project emission Calculation		
Additional comments:	Not applicable		

<b>Data/parameter:</b>	<b><math>Q_{CH4,y}</math></b>		
Unit	Nm <sup>3</sup> /yr		
Description	Methane part of the natural gas used.		
Measured/calculated/default	Calculated		
Source of data	Information provided by the natural gas supplier		
Value(s) of monitored parameter	Average values of daily used ( $Q_{CH4,d}$ ) in this period		
	<b>Data</b> <b><math>Q_{CH4}</math> (Nm<sup>3</sup>/day)</b>	<b>Plant I</b> N/A	<b>Plant II</b> 266.23
Monitoring equipment	Not applicable		
Measuring/reading/recording frequency:	Not applicable		
Calculation method (if applicable):	$Q_{CH4,y} = Q_{NG,y} \times CF_{CH4}$		
QA/QC procedures:	Not applicable		
Purpose of data:	Project Emission Calculation		
Additional comments:	Not applicable		

<b>Data/parameter:</b>	<b><math>Q_{HC,y}</math></b>		
Unit	Nm <sup>3</sup> /yr		
Description	The hydrocarbon with two or more molecules of carbon in natural gas		
Measured/calculated/default	Calculated		
Source of data	Information provided by the natural gas supplier		
Value(s) of monitored parameter	Average values of daily used ( $Q_{HC,y}$ ) in this period		
	<b>Data</b> <b><math>Q_{HC}</math> (Nm<sup>3</sup>/day)</b>	<b>Plant I</b> N/A	<b>Plant II</b> 20.1433

Monitoring equipment	Not applicable
Measuring/reading/recording frequency:	Not applicable
Calculation method (if applicable):	$Q_{HC,y} = Q_{NG,y} \times (1 - CF_{CH4})$
QA/QC procedures:	Not applicable
Purpose of data:	Project Emission Calculation
Additional comments:	Not applicable

Data/parameter:	$\rho_{NG}$		
Unit	t/Nm <sup>3</sup>		
Description	Density of the natural gas		
Measured/calculated/default	Not applicable		
Source of data	Monthly report provided by the fuel supplier		
Value(s) of monitored parameter	Data	Plant I	Plant II
	May. 2020	N/A	$0.7766 \times 10^{-3}$
	Jun. 2020		$0.7759 \times 10^{-3}$
	Jul. 2020		$0.7769 \times 10^{-3}$
	Aug. 2020		$0.7801 \times 10^{-3}$
	Sep. 2020		$0.7773 \times 10^{-3}$
	Oct. 2020		$0.7765 \times 10^{-3}$
	Nov. 2020		$0.7768 \times 10^{-3}$
	Dec. 2020		$0.7740 \times 10^{-3}$
	Period 14		$0.7768 \times 10^{-3}$
Monitoring equipment	Not applicable		
Measuring/reading/recording frequency:	Recording frequency : Monthly		
Calculation method (if applicable):	Not applicable		
QA/QC procedures:	Not applicable		
Purpose of data:	Project Emission Calculation		
Additional comments:	Not applicable		

Data/parameter:	$\rho_{HC}$		
Unit	t/Nm <sup>3</sup>		
Description	Density of the hydrocarbon with two or more molecules of carbon in natural gas		
Measured/calculated/default	Calculated		
Source of data	Information provided by the natural gas supplier		
Value(s) of monitored parameter	Data	Plant I	Plant II
	May. 2020	N/A	1.5842 × 10 <sup>-3</sup>
	Jun. 2020		1.5609 × 10 <sup>-3</sup>
	Jul. 2020		1.5786 × 10 <sup>-3</sup>
	Aug. 2020		1.5822 × 10 <sup>-3</sup>
	Sep. 2020		1.5604 × 10 <sup>-3</sup>
	Oct. 2020		1.5791 × 10 <sup>-3</sup>
	Nov. 2020		1.6221 × 10 <sup>-3</sup>
	Dec. 2020		1.6208 × 10 <sup>-3</sup>
	Period 14		1.5860 × 10 <sup>-3</sup>
Monitoring equipment	Not applicable		
Measuring/reading/recording frequency:	Not applicable		



Calculation method (if applicable):	$\rho_{HC} = (\rho_{NG} - \rho_{CH_4} \times CF_{CH_4}) / (1 - CF_{CH_4})$
QA/QC procedures:	Not applicable
Purpose of data:	Project Emission Calculation
Additional comments:	Not applicable

Data/parameter:	EF <sub>NG</sub>		
Unit	tCO <sub>2</sub> /tNG		
Description	Emission factor of the natural gas		
Measured/calculated/default	Calculated		
Source of data	Information provided by the natural gas supplier		
Value(s) of monitored parameter		Plant I	Plant II
	May. 2020	N/A	2.7685
	Jun. 2020		2.7711
	Jul. 2020		2.7746
	Aug. 2020		2.7762
	Sep. 2020		2.7761
	Oct. 2020		2.7782
	Nov. 2020		2.7771
	Dec. 2020		2.7790
	Period 14		2.7751
Monitoring equipment	Not applicable		
Measuring/reading/recording frequency:	Not applicable		
Calculation method (if applicable):	EF <sub>NG</sub> = COEF <sub>NG</sub> × NCV <sub>NG</sub> /ρ <sub>NG</sub> × 44/12 Where COEF <sub>NG</sub> : Carbon Emission factor of natural gas [tC/TJ] 15.3[tC/TJ] is applied to this project as Ex-ante value by IPCC DEFAULT VALUES OF CARBON CONTENT of “Natural Gas” in TABLE 1.3 (2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 2, Energy) NCV <sub>NG</sub> : Net calorific value of the natural gas [TJ/Nm <sup>3</sup> ] For this project, NCV <sub>NG</sub> is offered by KOGAS. ρ <sub>NG</sub> : Density of the natural gas[t/Nm <sup>3</sup> ] For this project, based on data source by natural gas supplier.		
QA/QC procedures:	Not applicable		
Purpose of data:	Project Emission Calculation		
Additional comments:	Not applicable		

<b>Data/parameter:</b>	<b><math>EF_{HC}</math></b>
Unit	tCO <sub>2</sub> /tHC
Description	Emission factor of the hydrocarbon with two or more molecular of carbon, which is existed as a contents of the natural gas
Measured/calculated/default	Calculated
Source of data	Calculated based on the followings: Methane content offered by the fuel supplier ; The density of the natural gas provided by the fuel supplier ; Estimated emission factor of the natural gas, and Specified methane density

Value(s) of monitored parameter	Date	Plant I	Plant II
	May. 2020	N/A	2.8801
	Jun. 2020		2.8981
	Jul. 2020		2.9214
	Aug. 2020		2.9245
	Sep. 2020		2.9291
	Oct. 2020		2.9476
	Nov. 2020		2.9434
	Dec. 2020		2.9661
	Period 14		2.9263
Monitoring equipment	Not applicable		
Measuring/reading/recording frequency:	Not applicable		
Calculation method (if applicable):	$EF_{HC} = (EF_{NG} \times \rho_{NG} - EF_{CH4} \times \rho_{CH4} \times CF_{CH4}) / (1 - CF_{CH4}) / \rho_{HC}$ Where $EF_{NG}$ : CO <sub>2</sub> emission factor of NG (tCO <sub>2</sub> /tNG) $\rho_{NG}$ : Density of natural gas (tNG/m <sub>3</sub> ) $EF_{CH4}$ : CO <sub>2</sub> emission factor of CH <sub>4</sub> (tCO <sub>2</sub> /tCH <sub>4</sub> ). $\rho_{CH4}$ : Density of methane (tCH <sub>4</sub> / m <sub>3</sub> ). $CF_{CH4}$ : Methane fraction in the natural gas		
QA/QC procedures:	Not applicable		
Purpose of data:	Project Emission Calculation		
Additional comments:	Not applicable		

Data/parameter:	SE <sub>N2O</sub>		
Unit	kgN <sub>2</sub> O/tCaprolactam		
Description	N <sub>2</sub> O emission rate per ton of caprolactam		
Measured/calculated/default	Calculated		
Source of data	Baseline and Monitoring Methodology (AM0028 ver05)		
Value(s) of monitored parameter	SE <sub>N2O</sub> is for this period.		
	Data	Plant I	Plant II
	SE <sub>N2O</sub> (kgN <sub>2</sub> O/tCaprolactam)	N/A	23.49
Monitoring equipment	Not applicable		
Measuring/reading/recording frequency:	Not applicable		
Calculation method (if applicable):	SE <sub>N2O,period</sub> = Q <sub>I</sub> N <sub>2O,period</sub> / P <sub>product,period</sub> × 1000 Where, Q <sub>I</sub> N <sub>2O,period</sub> means the monitored quantity of N <sub>2</sub> O emissions at the inlet of the destruction facility (t N <sub>2</sub> O), and P <sub>product,period</sub> is the actual output of caprolactam for this period.		
QA/QC procedures:	Not applicable		
Purpose of data:	Baseline Emission Calculation		
Additional comments:	Not applicable		

Data/parameter:	OXID <sub>CH4</sub>		
Unit	%		
Description	Oxidation factor of CH <sub>4</sub> in natural gas for re-heating tail gas		
Measured/calculated/default	Calculated		
Source of data	Not applicable		
Value(s) of monitored parameter	Average value in this period		
	Data	Plant I	Plant II
	OXID <sub>CH4</sub>	N/A	97.84

Monitoring equipment	Not applicable
Measuring/reading/recording frequency:	Not applicable
Calculation method (if applicable):	$OXID_{CH_4} = \{Q_{CH_4} - (\sum_i^n F_{TE,i} \times 10^{-6})\} / Q_{CH_4} \times 100\}$
QA/QC procedures:	Not applicable
Purpose of data:	Project Emission Calculation
Additional comments:	Not applicable

<b>Data/parameter:</b>	<b>CO<sub>CH4</sub></b>		
Unit	ppm(v)		
Description	Methane concentration at destruction facility outlet.		
Measured/calculated/default	Measured		
Source of data	Non-dispersion infrared absorption analyser with dual-channel as a gas path		
Value(s) of monitored parameter	Average value in this period		
	<b>Data</b>	<b>Plant I</b>	<b>Plant II</b>
	CO <sub>CH4</sub> (ppm(v))	N/A	23.75
Monitoring equipment	<b>Contents</b>	<b>Plant I</b>	<b>Plant II</b>
	Type	NDIR	NDIR
	Accuracy class	>95%	>95%
	Serial No.	AO-750	AO-751
	Calibration frequency	Every 2 weeks	Every 2 weeks
	Date of last calibration	N/A	23/12/2020
	Validity	N/A	Yes
	Model	ULTRAMAT 6	ULTRAMAT 6
Measuring/reading/recording frequency:	•Measuring period : Continuously •Recording frequency : Hourly		
Calculation method (if applicable):	Not applicable		
QA/QC procedures:	Every two years, the measuring instrument is calibrated by the authorized organization providing the calibration service on the basis of the national standard. Otherwise, the measuring instrument is replaced with new instrument calibrated according to the national standard.		
Purpose of data:	Project Emission Calculation		
Additional comments:	Not applicable		

<b>Data/parameter:</b>	<b>Reg<sub>NOx</sub></b>
Unit	tNO <sub>x</sub> /Nm <sup>3</sup>
Description	National regulation on NO <sub>x</sub> emissions
Measured/calculated/default	Not applicable
Source of data	The "Clean Air Conservation Act", one of the National environmental legislation, Ministry of Environment
Value(s) of monitored parameter	4.10714 x 10 <sup>-7</sup> tNO <sub>x</sub> /Nm <sup>3</sup> (as a NO <sub>2</sub> concentration)
Monitoring equipment	Not applicable
Measuring/reading/recording frequency:	Recording frequency : Date of Regulation
Calculation method (if applicable):	Not applicable
QA/QC procedures:	Not applicable
Purpose of data:	Baseline Emission Calculation

Additional comments:	Not applicable
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<b>Data/parameter:</b>	<b><math>RSE_{N_2O,y}</math></b>
Unit	tN <sub>2</sub> O/tCaprolactam
Description	Regulatory limit of N <sub>2</sub> O emissions per unit of outlet of caprolactam (tN <sub>2</sub> O/t caprolactam)
Measured/calculated/default	Not applicable
Source of data	National legislation in Republic of Korea (That may be mostly like environmental regulation.)
Value(s) of monitored parameter	Not applicable
Monitoring equipment	Not applicable
Measuring/reading/recording frequency:	Recording frequency : Date of Regulation
Calculation method (if applicable):	Not applicable
QA/QC procedures:	Not applicable
Purpose of data:	Baseline Emission Calculation
Additional comments:	Not applicable

### D.3. Implementation of sampling plan

>>  
N/A

## SECTION E. Calculation of emission reductions or net anthropogenic removals

### E.1. Calculation of baseline emissions or baseline net removals

>>

In the case of a nitric acid plant or a caprolactam plant using the Raschig process, baseline emissions are limited to the design capacity of the existing nitric acid or caprolactam production plant. If the actual production of caprolactam ( $P_{\text{product,actual}}$ ) exceeds the design capacity ( $P_{\text{product,max}}$ ), the emissions related to the production above  $P_{\text{product,max}}$  will not be claimed for the baseline scenario. Therefore  $P_{\text{product,actual}}$  of each plant should be monitored. However, it is not able to be decided whether the actual production of caprolactam exceeds  $P_{\text{product,max}}$ , or not, because those values ( $P_{\text{product,max}}$  and  $P_{\text{product,actual}}$ ) should be compared on the annual values for comparing each other, and only 88 days have been monitored for this period, so in order to simply make rough estimation to the status of production, the actual average daily output for this period was compared with the expected average daily output described in PDD, as shown in the Table E.1-1. (All of the data for the actual daily production of caprolactam were listed in detail in the emission reductions calculation spreadsheet.)

**Table E.1-1** The actual value of Caprolactam Production for this period and the expected value of that on PDD

	Yearly expected in PDD			For this period		
	Design Capacity , $P_{\text{product,max}}$ (ton/yr)	No. of Operating days In PDD	Daily output (ton/day)	Period total output $P_{\text{product,period}}$ (ton/period)	No. of Operating days	Daily output (ton/day)
Plant I	63,307	363	174.40	-	-	-
Plant II	64,965	355	183.00	9,085.82	245	37.08

As a result, it can be said that actual production of caprolactam ( $P_{\text{product}}$ ) did not exceed the design capacity ( $P_{\text{product,max}}$ ). Therefore on the condition of  $P_{\text{product,y}} < P_{\text{product,max}}$ , baseline emissions ( $BE$ )

for the period are given by following equation :

$$BE_{Period, within permit range} = \sum_i^n F_{TI,i} \times Cl_{N2O,i} \times M_i \times GWP_{N2O}$$

Where

- $M_i$  : Length of Measuring Interval (hr),  
(1hr is set value at instrument for this project)
- $GWP_{N2O}$  : Global warming potential of the  $N_2O$ , (298: default value).
- $n$  : Number of intervals during this period
- $F_{TI,i}$  : Volume flow rate at the inlet of the DF during interval ( $Nm^3/hr$ )
- $Cl_{N2O,i}$  :  $N_2O$  concentration in the tail gas of the DF inlet during interval ( $tN_2O/Nm^3$ )

However, if the actual average daily operating temperature and/or pressure in the ammonia oxidation reactor ( $T_g$  and  $P_g$ ) are outside the bounds of the “permitted range” of AOR operation conditions (:  $T_{g,hist}$  and/or  $P_{g,hist}$ ), the calculation of baseline emission is the integration of the daily baseline emission ( $BE_{daily, out of permit range}$ ) for the respective day. The daily baseline emission is calculated for the respective time period as follows:

$$BE_{daily, out of permit range} = P_{product, day} \times EF_{N2O} \times GWP_{N2O} / 1000$$

$$BE_{period, out of permit range} = \sum BE_{daily, out of permit range}$$

Where

- $BE_{daily, out of permit range}$  : The daily baseline emission for the respective day in which AOR operation conditions were outside of “permitted range”(tonCO<sub>2</sub>/day)
- $P_{product, day}$  : The daily output of caprolactam for the respective day in which AOR operation conditions were outside of permitted range (ton caprolactam/day)
- $EF_{N2O}$  :  $N_2O$  Emission factor to the process of caprolactam production (kgN<sub>2</sub>O/ton caprolactam)

Emission factor of  $N_2O$  ( $EF_{N2O}$ ) is the lowest value among (a)  $EF_{N2O,IPCC}$ , (b)  $SE_{N2O,y}$  and (c) any related value as a result of legal regulation(e.g.  $RSE_{N2O,y}$ ). In Republic of Korea, there is no mandatory regulation for  $N_2O$  emission. Therefore, actually  $EF_{N2O}$  is the lower value between (a)  $EF_{N2O,IPCC}$  and (b)  $SE_{N2O,y}$ .

$EF_{N2O,IPCC}$  means Conservative IPCC default value of the latest IPCC GHG Inventory Guidelines accepted by the IPCC for the equivalent  $N_2O$  emission process. At this time,  $EF_{N2O,IPCC}$  is 5.4kgN<sub>2</sub>O/tonne of caprolactam.

$SE_{N2O,y}$  is the specific  $N_2O$  emission per unit of output of caprolactam defined as :

$$SE_{N2O,y} = QI_{N2O,y} / P_{product,y} \times 1000$$

Where,  $QI_{N2O,y}$  means Quantity of  $N_2O$  emissions at the inlet of the destruction facility in year, y given by :

$$QI_{N_2O,y} = \sum_i^n F_{TI,i} \times Cl_{N_2O,i} \times M_i$$

For this period,  $SE_{N_2O,y}$  and  $QI_{N_2O,y}$  should be converted as  $SE_{N_2O,period}$  and  $QI_{N_2O,period}$  as follows :

$$SE_{N_2O,period} = QI_{N_2O,period} / P_{product,period} \times 1000$$

The both of  $SE_{N_2O,y}$  values (23.60 for plant II) for Plant II are calculated as higher than  $EF_{N_2O,IPCC}$ , and thus the values of  $EF_{N_2O}$  are decided as 5.4kgN<sub>2</sub>O/tonne of caprolactam in order to calculate  $BE_{period, out of permit range}$ .

**Table E1-2**  $SE_{N_2O,y}$  for this period (period 14)

	Plant I	Plant II
$QI_{N_2O-Period}$ (ton N <sub>2</sub> O/period)	N/A	213.43
$P_{product-Period}$ (ton Caprolactam/yr)		9,085.82
$SE_{N_2O,period}$ (kgN <sub>2</sub> O/tCaprolactam)		23.49

If the actual daily ammonia flow rate exceeds the (upper) limit on maximum historical daily permitted ammonia flow rate, the baseline N<sub>2</sub>O emissions for this operating day are capped at conservative IPCC default values. Where, the upper limit on ammonia flow should be determined based on “the historical operating data on maximum daily average ammonia flow”.

Consequently, on condition of  $P_{product,y} < P_{product,max}$ , baseline emissions ( $BE$ ) for the period can be calculated as follows for this period.

$$BE_{period} = BE_{period, within permit range} + BE_{period, out of permit range}$$

#### (a) Baseline emission of Plant II

##### In Case of AOR operation conditions within “permitted range”

Hourly  $BE$  ( $BE_{hr-2}$ ) calculated on hourly integrated measured values of  $F_{T,i-2}$  and  $Cl_{N_2O,i-2}$  are aggregated to the daily  $BE$  ( $BE_{day-2}$ ), and total  $BE$  on the period ( $BE_{period-14}$ ) are estimate as sum of  $BE_{day-2}$ . The total  $BE$  on the period 14 for Plant II ( $BE_{period-14}$ ) is 52,046.27 tonCO<sub>2</sub>/period.  $BE$  calculated on hourly input data is explained in detail on the emission reductions calculation spreadsheet.

##### In Case of AOR operation conditions outside of “permitted range”

For this period, the number of days on which the condition of AOR deviation from permitted range is 3 (Refer to Table B.1-2). The baseline emission in which AOR operation conditions of Plant II were outside of permitted range for this period ( $BE_{period, out of permit range}$ ) is calculated as 11,556.350 tonCO<sub>2</sub>/period depends on following equation.

$$BE_{period, out of permit range} = \sum BE_{daily, out of permit range} = P_{product, day} \times EE_{N_2O,period} \times GWP_{N_2O}/1000$$

#### (b) The total BE of Period 14

Eventually, Total  $BE$  in this period is about 63,602.62 tCO<sub>2</sub>e/period as shown below table.

		$BE_{period-14}$ (tCO <sub>2</sub> e/period)	
		$BE_{period-14}$ in Plant I	$BE_{period-14}$ in Plant II
$BE_{period}$ on AOR condition	Within permitted range	N/A	52,046.27
	Outside permitted range		11,556.350

$BE_{period}$ total	$BE_{period}$ for each plant		63,602.62
	$BE_{period-total}$		63,602.62

## E.2. Calculation of project emissions or actual net removals

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The emission due to the project activity are composed of (a) the emissions of not destroyed  $N_2O$ , (b) on-site emissions due to the hydrocarbons (; Natural Gas) use as input to the  $N_2O$  destruction facility, and (c) the emissions from the operation of the destruction facility. Hydrocarbons can be used as reducing agent and/or re-heating the tail gas to enhance the catalytic  $N_2O$  reduction efficiency. In this project, natural gas is used for re-heating the tail gas to enhance the catalytic  $N_2O$  reduction efficiency.

$$PE_{period} = \left( \sum_i^n F_{TE,i} \times CO_{N2O,i} \times M_i \right) \times GWP_{N2O} \\ + [ (\rho_{HC} \times Q_{HC,y} \times EF_{HC} \times OXID_{HC}/100) + (\rho_{CH4} \times Q_{CH4,y} \times EF_{CH4} \times OXID_{CH4}/100)] \\ + [ \rho_{CH4} \times Q_{CH4,y} \times GWP_{CH4} \times (1-OXID_{CH4}/100)]$$

Where

- $n$  : Number of intervals during the year (period)
- $M_i$  : Length of Measuring Interval (hr), (1hr : set value at instrument for this project)
- $F_{TE,i}$  : Volume flow rate at the exit of the DF during interval  $i$  ( $Nm^3/hr$ )
- $CO_{N2O,i}$  :  $N_2O$  concentration in the tail gas of the DF exit during interval  $i$  ( $tN_2O/m^3$ )
- $GWP_{CH4}$  : Global warming potential of  $CH_4$ , (25 : default value)
- $GWP_{N2O}$  : Global warming potential of the nitrous oxide, (298 : default value)
- $\rho_{CH4}$  : Density of methane ( $tCH_4/m^3$ ), (0.000716 : ex ante value)
- $\rho_{HC}$  : Density of HC ( $tHC/m^3$ )
- $EF_{CH4}$  :  $CO_2$  emission factor of  $CH_4$  ( $tCO_2e/tCH_4$ ), (2.75 : ex ante value)
- $EF_{HC}$  :  $CO_2$  emission factor of HC with two or more carbon molecule in natural gas ( $tCO_2e/tHC$ )
- $Q_{CH4,y}$  : Methane used in period ( $Nm^3/period$ )
- $Q_{HC,y}$  : HC with two or more carbon molecule in natural gas used in period ( $Nm^3/period$ )
- $OXID_{CH4}$  : Oxidation factor of methane (%)
- $OXID_{HC}$  : Oxidation factor of HC(%), 100% (Fixed value)

Hourly calculated PE ( $PE_{hr}$ ) are aggregated into the daily PE ( $PE_{day}$ ), and total PE on the period ( $PE_{period}$ ) are estimated as sum of  $PE_{day}$ . ER calculation sheet for each plant which daily measured and calculated results were integrated into is in detail on the mission reductions calculation spreadsheet.

### (a) The total PE of Period 14

Total PE in this period is 11,798.31  $tCO_2$  as shown below table.

**Table E.2** Summary of PE for this period

	Plant I	Plant II
PE for each Plant( $tCO_2/period$ )	N/A	11,798.31
PE for Period total, $PE_{period-14}$ ( $tCO_2/period$ )	11,798.31	

**E.3. Calculation of leakage emissions**

&gt;&gt;

The installation of the N<sub>2</sub>O destruction facility doesn't result in significant additional energy consumption at the caprolactam production plant. In conclusion, no leakage is expected at this project as per the registered PDD. The emission by leakage is accounted as zero ( $LE_y = 0$ )

**E.4. Calculation of emission reductions or net anthropogenic removals**

	Baseline GHG emissions or baseline net GHG removals (t CO <sub>2</sub> e)	Project GHG emissions or actual net GHG removals (t CO <sub>2</sub> e)	Leakage GHG emissions (t CO <sub>2</sub> e)	GHG emission reductions or net anthropogenic GHG removals (t CO <sub>2</sub> e)			
				Before 01/01/2013	From 01/01/2013 until 31/12/2020	From 01/01/2021	Total amount
<b>Total</b>	63,602.62	11,798.31	0	-	51,804	-	51,804

**E.5. Comparison of emission reductions or net anthropogenic removals achieved with estimates in the registered PDD**

Amount achieved during this monitoring period (t CO <sub>2</sub> e)	Amount estimated ex ante for this monitoring period in the PDD (t CO <sub>2</sub> e)
51,804	235,238

**E.5.1. Explanation of calculation of “amount estimated ex ante for this monitoring period in the PDD”**

&gt;&gt;

According to the registered PDD, the ex-ante estimated ERs of the Plant II is 340,856 tCO<sub>2</sub>e and annual operating days of Plant II is 355 days. Therefore ER ex-ante values = 340,856 tCO<sub>2</sub>e × 245 days/355 days = 235,238 tCO<sub>2</sub>e:

		Ex-ante values	Actual values
		in PDD	for this period
Ex-ante values of ER in PDD (t CO <sub>2</sub> e/yr)	Plant 1	320,139	-
	Plant 2	340,856	-
	Plant total	660,995	-
No. of operating days	Plant 1	363	-
	Plant 2	355	245
Daily average values of ER (t CO <sub>2</sub> e/day)	Plant 1	881.93	-
	Plant 2	960.16	211.44
	Plant total	1,842.08	211.44
ER ex-ante, period and ER, period (t CO <sub>2</sub> e/period)	Plant 1	-	-
	Plant 2	235,239	51,804
	Plant total	235,238	51,804

**E.6. Remarks on increase in achieved emission reductions**

&gt;&gt;

N/A



**E.7. Remarks on scale of small-scale project activity**

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N/A

**Document information**

<i>Version</i>	<i>Date</i>	<i>Description</i>
08.0	6 April 2021	Revision to: <ul style="list-style-type: none"> <li>• Reflect the “Clarification: Regulatory requirements under temporary measures for post-2020 cases” (CDM-EB109-A01-CLAR).</li> </ul>
07.0	31 May 2019	Revision to: <ul style="list-style-type: none"> <li>• Ensure consistency with version 02.0 of the “CDM project standard for project activities” (CDM-EB93-A04-STAN);</li> <li>• Add a section on remarks on the observance of the scale limit of small-scale project activity during the crediting period;</li> <li>• Add "changes specific to afforestation or reforestation project activity" as a possible post-registration changes;</li> <li>• Clarify the reporting of net anthropogenic GHG removals for A/R project activities between two commitment periods;</li> <li>• Make editorial improvements.</li> </ul>
06.0	7 June 2017	Revision to: <ul style="list-style-type: none"> <li>• Ensure consistency with version 01.0 of the “CDM project standard for project activities” (CDM-EB93-A04-STAN);</li> <li>• Make editorial improvements.</li> </ul>
05.1	4 May 2015	Editorial revision to correct version numbering.
05.0	1 April 2015	Revisions to: <ul style="list-style-type: none"> <li>• Include provisions related to delayed submission of a monitoring plan;</li> <li>• Provisions related to the Host Party;</li> <li>• Remove reference to programme of activities;</li> <li>• Overall editorial improvement.</li> </ul>
04.0	25 June 2014	Revisions to: <ul style="list-style-type: none"> <li>• Include the Attachment: Instructions for filling out the monitoring report form (these instructions supersede the "Guideline: Completing the monitoring report form" (Version 04.0));</li> <li>• Include provisions related to standardized baselines;</li> <li>• Add contact information on a responsible person(s)/ entity(ies) for completing the CDM-MR-FORM in A.6 and Appendix 1;</li> <li>• Change the reference number from <i>F-CDM-MR</i> to <i>CDM-MR-FORM</i>;</li> <li>• Editorial improvement.</li> </ul>
03.2	5 November 2013	Editorial revision to correct table in page 1.
03.1	2 January 2013	Editorial revision to correct table in section E.5.

<i>Version</i>	<i>Date</i>	<i>Description</i>
03.0	3 December 2012	Revision required to introduce a provision on reporting actual emission reductions or net GHG removals by sinks for the period up to 31 December 2012 and the period from 1 January 2013 onwards (EB 70, Annex 11).
02.0	13 March 2012	Revision required to ensure consistency with the "Guidelines for completing the monitoring report form" (EB 66, Annex 20).
01.0	28 May 2010	EB 54, Annex 34. Initial adoption.
Decision Class: Regulatory Document Type: Form Business Function: Issuance Keywords: monitoring report		