Monitoring report form for CDM project activity
(Version 07.0)

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

MONITORING REPORT		
Title of the project activity	N_2O Abatement Project of Capro Corporation	
UNFCCC reference number of the project activity	4665	
Version number of the PDD applicable to this monitoring report	8.1	
Version number of this monitoring report	1.0	
Completion date of this monitoring report	17/09/2019	
Monitoring period number	11	
Duration of this monitoring period	01/11/2018 ~ 30/04/2019 (first and last day included)	
Monitoring report number for this monitoring period	N/A	
Project participants	Capro Corporation Hyosung Corporation Hyosung Ebara Engineering Co., Ltd.(Withdrawn)	
Host Party	The Republic of Korea	
Applied methodologies and standardized baselines	AM0028(Version 05) N_2O destruction in the tail gas of Nitric Acid Plants or Caprolactam Production Plants Standardized baselines: NA	
Sectoral scopes	Scope No. 5, Chemical industries	
Amount of GHG emission reductions or net anthropogenic GHG removals achieved by the project activity in this monitoring period	Amount achieved before 1 January 2013	Amount achieved from 1 January 2013
	N/A	151,571 tCO_2e
Amount of GHG emission reductions or net anthropogenic GHG removals estimated ex ante for this monitoring period in the PDD	173,788 tCO_2e (Annual total amount in PDD : 660,995 tCO_2e/y)	

SECTION A. Description of project activity

A.1. General description of project activity

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(a) Purpose of the project activity and the measures taken for GHG emission reductions;
The proposed project is to reduce N_2O emissions of the tail gas emitted from Caprolactam production process in Capro Corporation (hereinafter “Capro”) by installing catalytic N_2O destruction system.

(b) Brief description of the installed technology and equipments;
N_2O treatment system for this project is CRI N_2O abatement system, which is N_2O 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_2O 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_2O abatement system
20/04/2011	Commissioning start(Plant 1)
27/04/2011	Commissioning start(Plant 2)
02/05/2011	Completing Construction of N_2O abatement system and the N_2O 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_2O 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

(d) Total emission reductions achieved in this monitoring period: **151,571** ton CO_2e

A.2. Location of project activity

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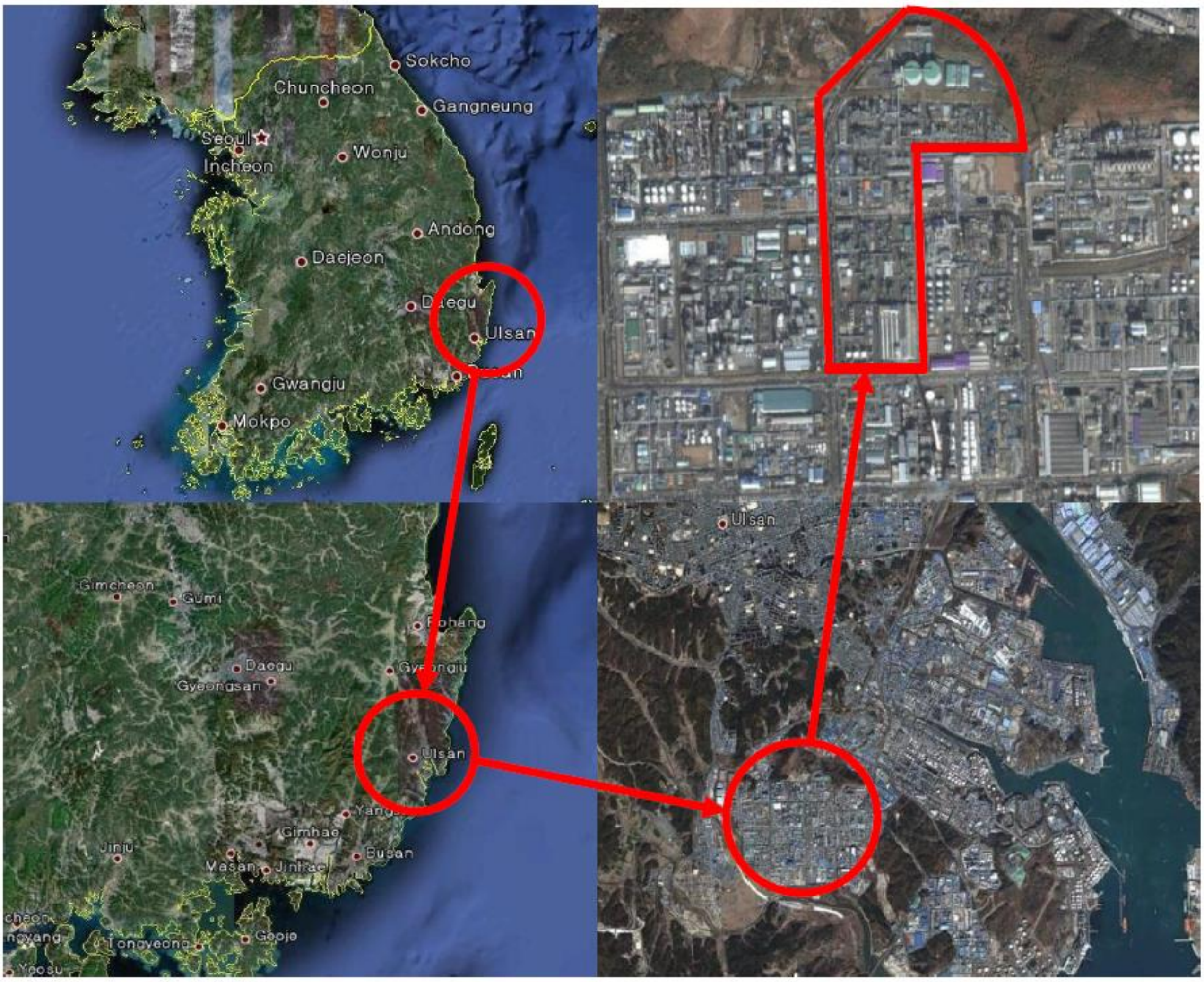
(a) Host Parties
: The Republic of Korea
(b) Region/State/Province, etc.
: Ulsan Metropolitan City
(c) City/Town/Community etc.
: 402-1, Bugok-dong, Nam-gu
(d) Physical/ Geographical Location
: The east longitude is about 129.3280° and the north latitude is about 35.4958°



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(host)	Private entity • Capro Corporation • Hyosung Corporation • Hyosung Ebara Engineering Co., Ltd.(Withdrawn)	No

A.4. References to applied methodologies and standardized baselines

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1. The reference of :
   (a) The applied methodology :
   AM0028 “Catalytic N_2O 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-C1lWZZ0LFtubCs7XEY

(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

$2NH_4OH + CO_2 \rightarrow (NH_4)_2CO_3 + H_2O$

Ammonia oxidation

$4NH_3 + 5O_2 \xrightarrow{\text{Pt-Rh catalyst}} 4NO + 6H_2O$

$(2NO + O_2 \rightarrow 2NO_2)$

Ammonium Nitrite Preparation;

$(NH_4)_2CO_3 + NO + NO_2 \rightarrow 2NH_4NO_2 + CO_2$

Hydroxylamine disulfonic ammonia Preparation;

$NH_4NO_2 + NH_4OH + 2SO_2 \rightarrow NOH(SO_3NH_4)_2$

Hydroxylamine Sulfate Preparation;

$NOH(SO_3NH_4)_2 + H_2O \rightarrow NHOHSO_3NH_4 + NH_4HSO_4$

$2NHOHSO_3NH_4 + 2H_2O \rightarrow (NH_2OH)_2H_2SO_4$ (Hydroxylamine sulfate) + $(NH_4)_2SO_4$

Cyclohexanone preparation

$C_6H_{12} \xrightarrow{\text{Co catalyst, } [O_2]} C_6H_{10}O$ (Cyclohexanone)

Oximation Reaction;

$(NH_2OH)_2H_2SO_4 + 2C_6H_{10}O \rightarrow 2C_6H_{10}NOH$ (Cyclohexanone oxime)+ $H_2SO_4 + H_2O$

Beckmann rearrangement;

$C_6H_{10}NOH \xrightarrow{H_2SO_4 \text{ catalyst}} C_6H_{10}NOH$ (Caprolactam)

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

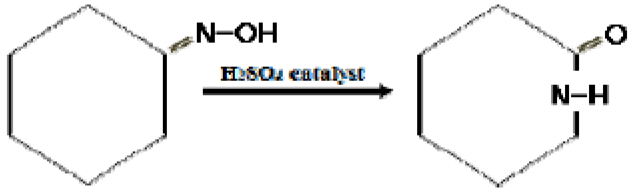

Figure B1-1. Structural formula of Beckmann rearrangement

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

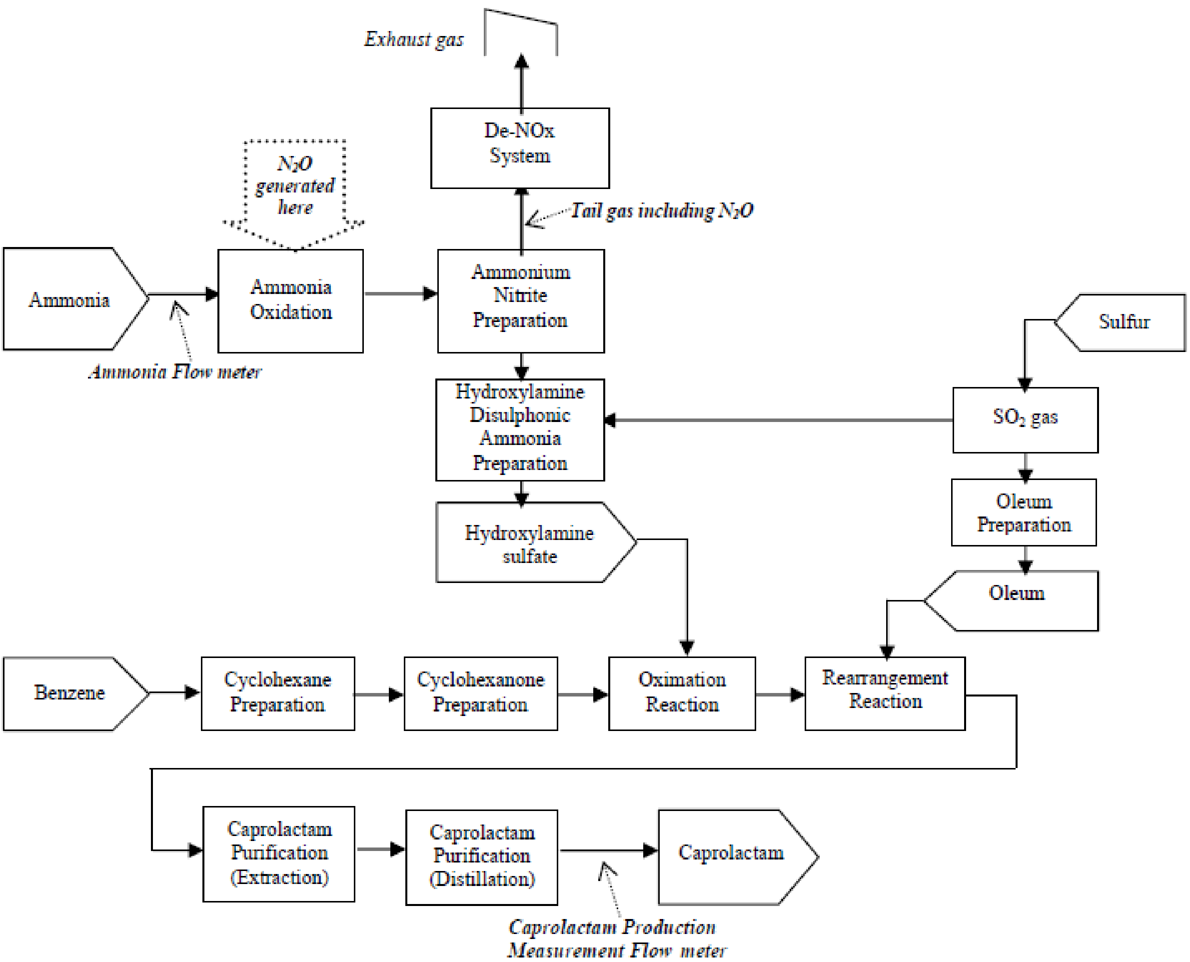

Figure B1-2. Block flow diagram for caprolactam production process

Ammonia oxidation reaction is necessary to generate NO and NO_2, 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_2O) is generated as an undesired by-product through the side reaction of Ammonia oxidation as follows:

$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$ (Main reaction)

($2NO + O_2 \rightarrow 2NO_2$) (Desired in the NO oxidation process)

$4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$ (Side reaction)

$4NH_3 + 4O_2 \rightarrow 2N_2O + 6H_2O$ (Side reaction)

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) <u>Description of the installed technology, technical processes and equipments;</u>

De-N_2O system for this project is to destruct the N_2O included in tail gas by catalyst without any reducing agent.

$$2N_2O \xrightarrow{\text{Catalyst}} 2N_2 + O_2$$

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_2O, and this N_2O 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_2O catalytic reaction. Catalyst is provided by CRI.

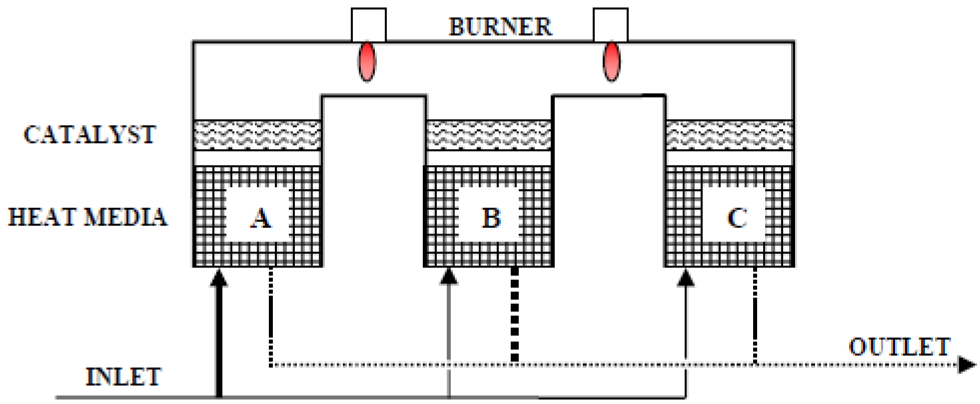

Figure B1-3. Overview of Regenerative Catalytic System

The principle of performance can be step-wisely described with Figure B1-3 as follows: At the inlet of De-N_2O system, in-flowed tail-gas is heated up to 550℃ by going to heat media A(previously heated), before N_2O 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_2O 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_2O processes have been applied to Plant I and II.

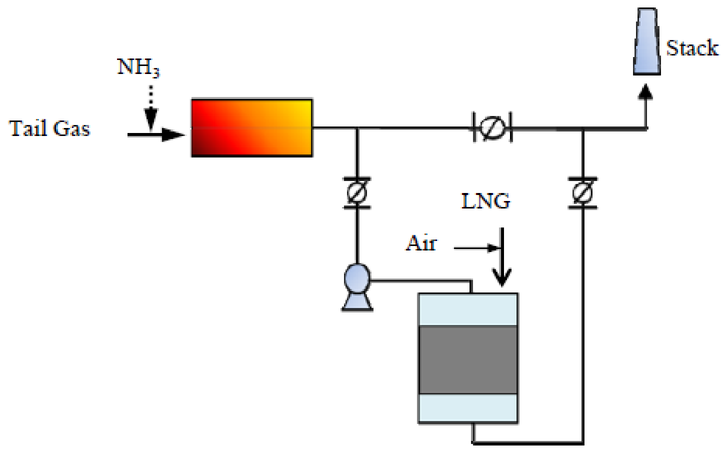

Figure B1-4. Overview of the De-N_2O process in Plant I and II

(c) <u>Information on the implementation and actual operation of the project activity</u>

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 N2O 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

Plant I has not been operated after 5th monitoring period.

In order to avoid that the operation of the caprolactam production plant is manipulated in a way to increase the N_2O generation, thereby increasing the CERs, the operating temperature and pressure of the ammonia oxidation reactor (AOR), and NH_3 input to the AOR, have been monitored every working day. During the monitoring period 10, the actual average daily AOR operation conditions are monitored as below Table B1-2.

Table B1-2. Summary of the AOR operation data

		$T_{g,a}$	$T_{g,b}$	P_{g-1}	$A_{OR,d-1}$
Plant 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 11	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 11	751.98	750.50	91,429	42,063

	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 11	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 11	Sub-total output for period(tCaprolactam/period)	N/A	31,816.88
	No. of operating days(day/period)		181
	Average daily output(ton/day)		175.78

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	2018.11.01. 21:55	2018.11.02. 02:28	Data signal out on account of unstable process(cooler fault)
	2	2018.11.01. 21:55	2018.11.12. 15:19	Data signal out on account of unstable process(over range))
	3	2018.11.14. 02:47	2018.11.14. 04:20	Data signal out on account of unstable process(over range)
	4	2018.11.15. 14:43	2018.11.15. 16:10	Data signal out on account of unstable process(over range)
	5	2018.12.04. 18:16	2018.12.05. 00:11	Data signal out on account of unstable process(over range)
	6	2018.12.08. 23:25	2018.12.09. 04:32	Data signal out on account of unstable process(over range)
	7	2018.12.16. 01:49	2018.12.16. 03:35	Data signal out on account of unstable process(over range)
	8	2018.12.17. 10:29	2018.12.17. 13:22	Data signal out on account of unstable process(over range)
	9	2018.12.20. 01:49	2018.12.20. 07:06	Data signal out on account of unstable process(over range)
	10	2018.12.31. 14:26	2018.12.31. 14:59	Data signal out on account of unstable process(cooler fault)
	11	2019.01.04. 10:54	2019.01.04. 11:29	Data signal out on account of unstable process(cooler fault)

B.2. Post-registration changes

B.2.1. Temporary deviations from the registered monitoring plan, applied methodologies, standardized baselines or other methodological regulatory documents

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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

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N/A

B.2.6. Changes to project design

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N/A

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

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N/A

SECTION C. Description of monitoring system

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(a) Monitoring points to be measured

(1) Monitoring Points in Plant I

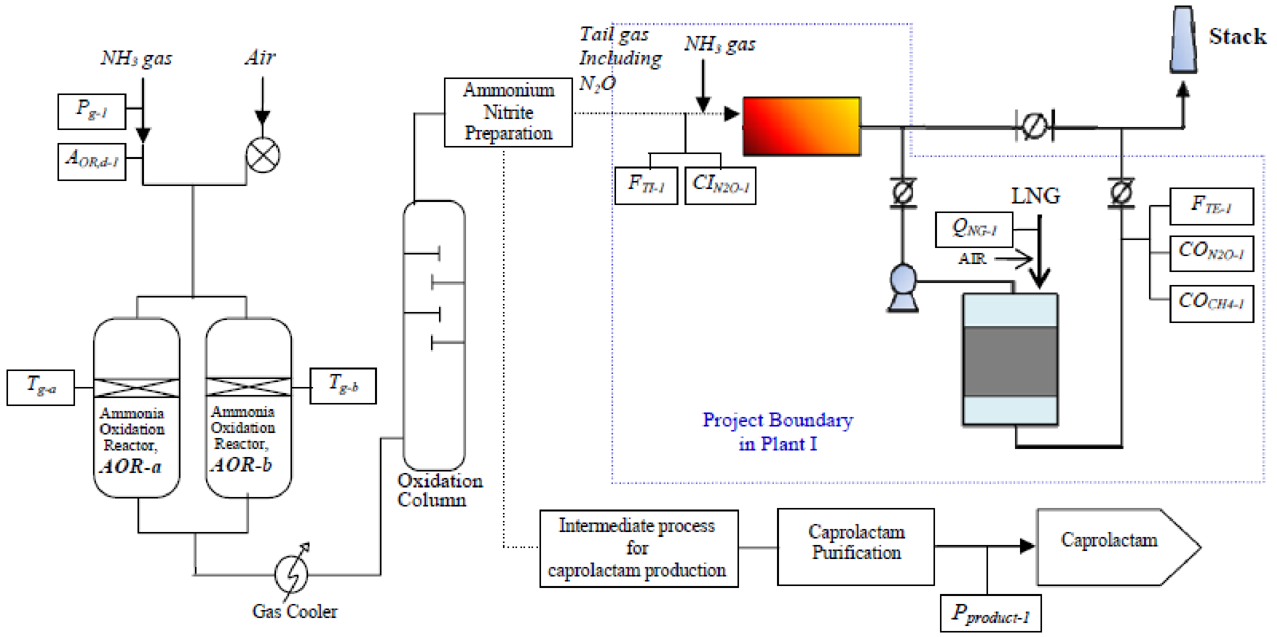

Figure C1. Monitoring Points in Plant I

Parameter	Description	Tag No.
$A_{OR,d-1}$	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 11
Plant I	CO_{N2O-1}	AI-1522	AI-1522(a)
	CO_{CH4-1}	AI-1522	AI-1522(b)

(2) Monitoring Points in Plant II

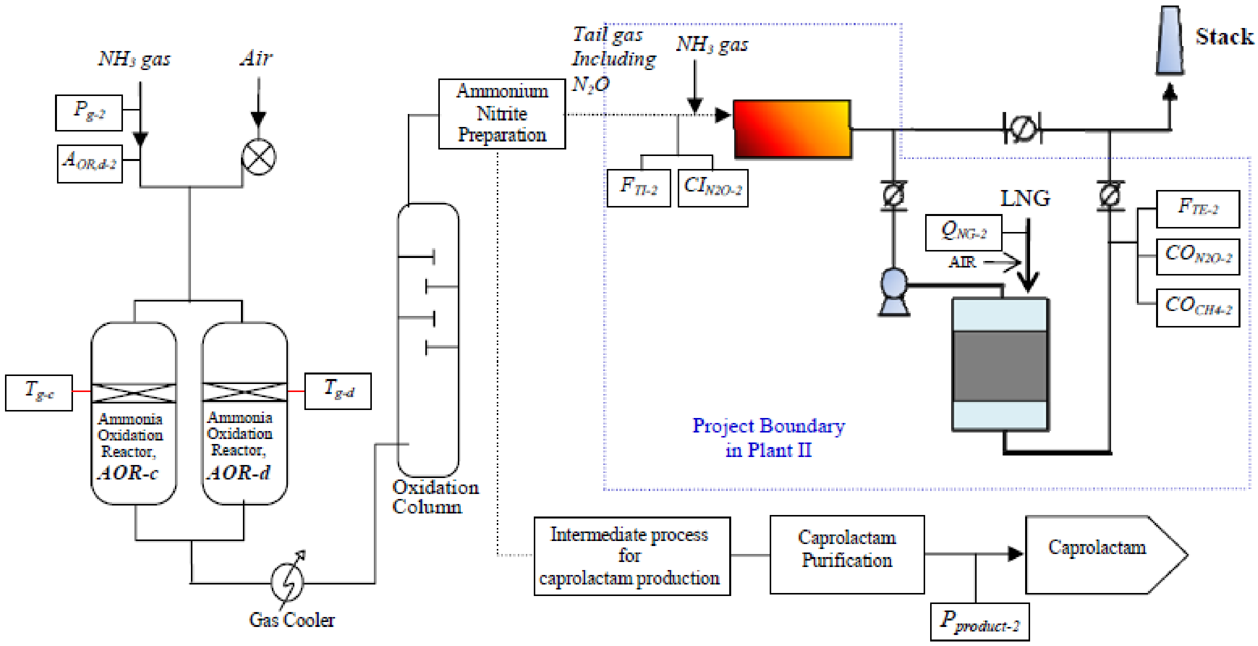

Figure C2. Monitoring Points in Plant II

Parameter	Description	Tag No.
$A_{OR,d\text{-}2}$	Actual ammonia flow rate to AOR in Plant II	2FIC-1201
$P_{g\text{-}2}$	Actual operating pressure of the AOR-a, b in Plant II	2PI-1205
$T_{g\text{-}c}$	Actual operating temperature of the AOR-a in Plant II	2TI-1204
$T_{g\text{-}d}$	Actual operating temperature of the AOR-b in Plant II	2TI-1206
$F_{TI\text{-}2}$	Volume flow rate at the inlet of the destruction facility in Plant II	2FI-1521
$F_{TE\text{-}2}$	Volume flow rate at the exit of the destruction facility in Plant II	2FI-1522
$CI_{N2O\text{-}2}$	N_2O concentration at destruction facility inlet in Plant II	2AI-1521
$CO_{N2O\text{-}2}$	N_2O concentration at destruction facility outlet in Plant II	2AI-1522(a)
$Q_{NG\text{-}2}$	Additional natural gas input for re-heating the tail gas in Plant II	2FI-1523
$CO_{CH4\text{-}2}$	CH_4 concentration at destruction facility outlet in Plant II	2AI-1522(b)
$P_{product\text{-}2}$	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 11
Plant II	$CO_{N2O\text{-}2}$	2AI-1522	2AI-1522(a)
	$CO_{CH4\text{-}2}$	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 respectably, and then transmitted to EEU. Q_{NG} is measured by Flow meter separately installed from AMS and CO_{CH4} 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.

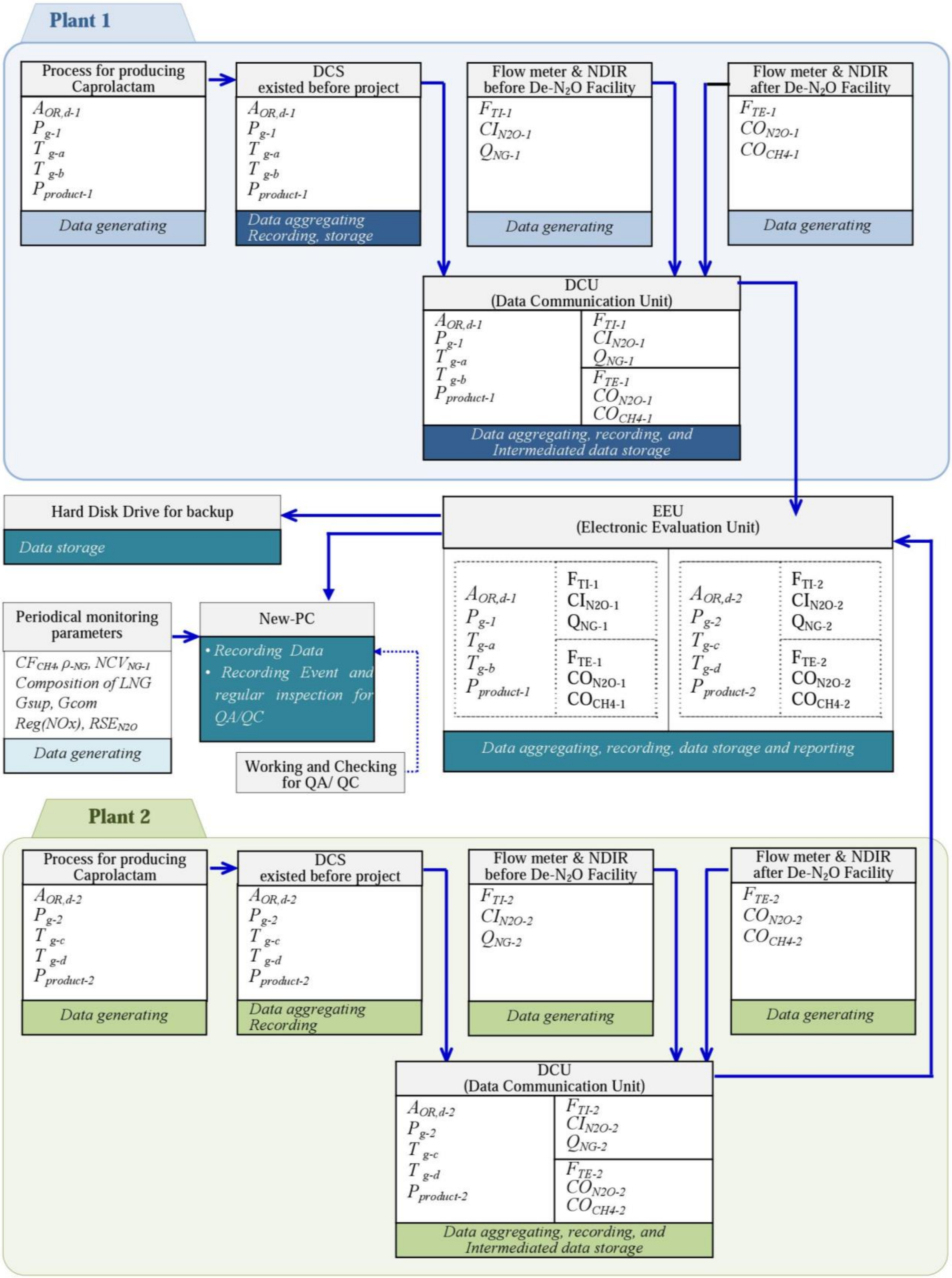

Figure C.3 Data Collecting Flow

(c) Organizational structure, roles and responsibilities of personnel

(1) Organization Structure

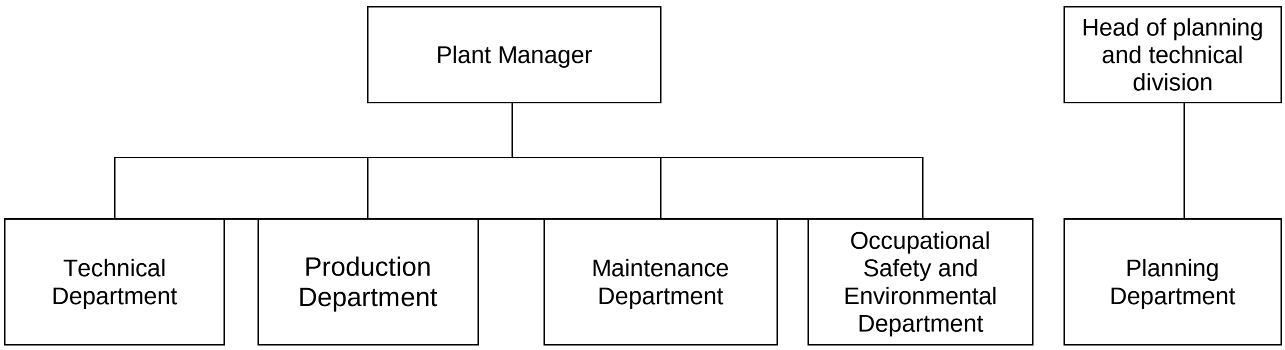

Figure C.4 The scheme of the operational and management structure

(2) Roles and responsibilities of personnel

Plant Manager

The Plant Manager takes overall responsibility for the operation and maintenance of the N_2O 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_2O 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_2O 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_2O concentration or flow rate at the monitoring points of inlet and outlet of N_2O 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_2O concentration of inlet is replaced with the lowest number, and that of outlet is with highest one.

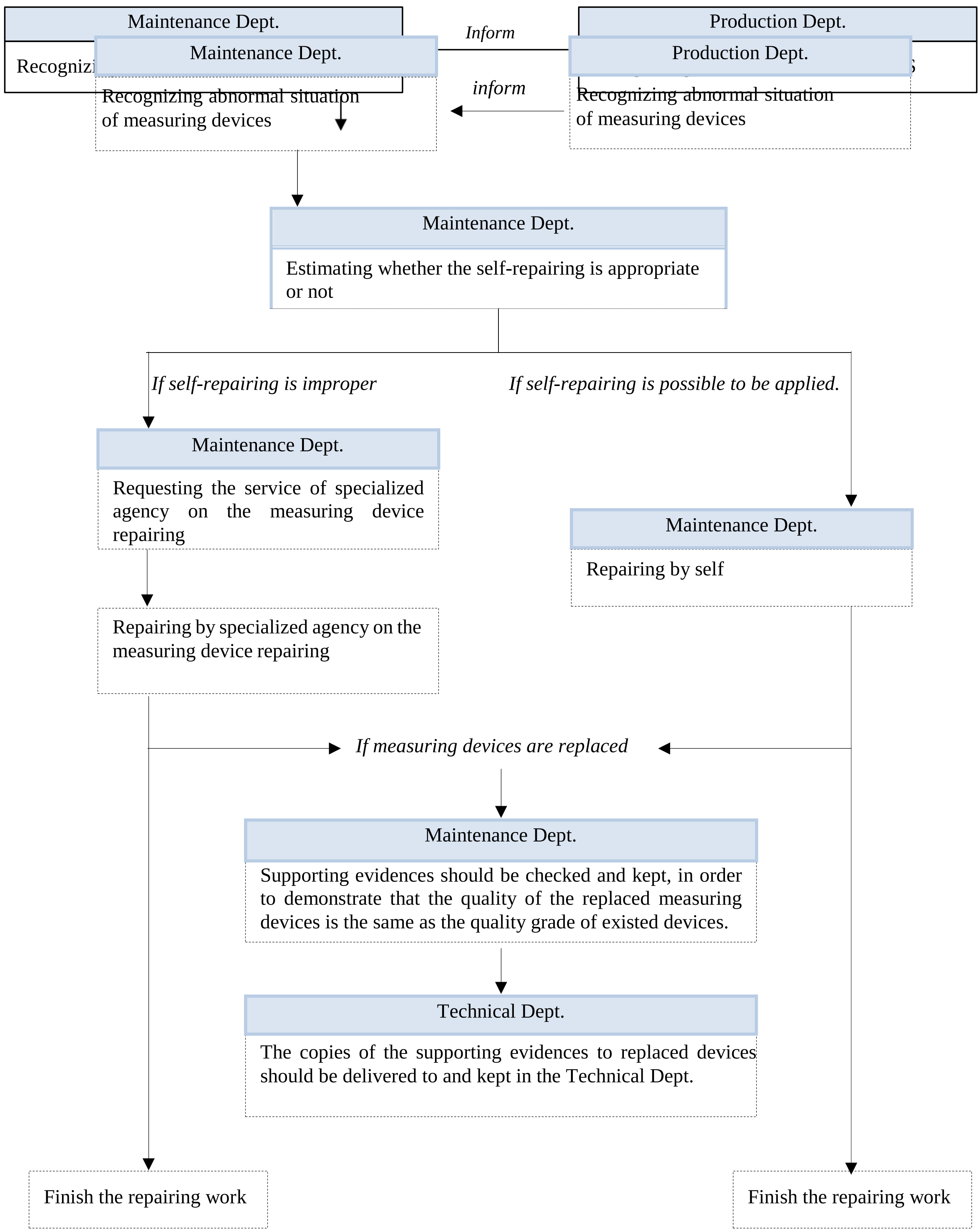

Figure C.5 Emergency Procedures for malfunctions of measuring devices in general

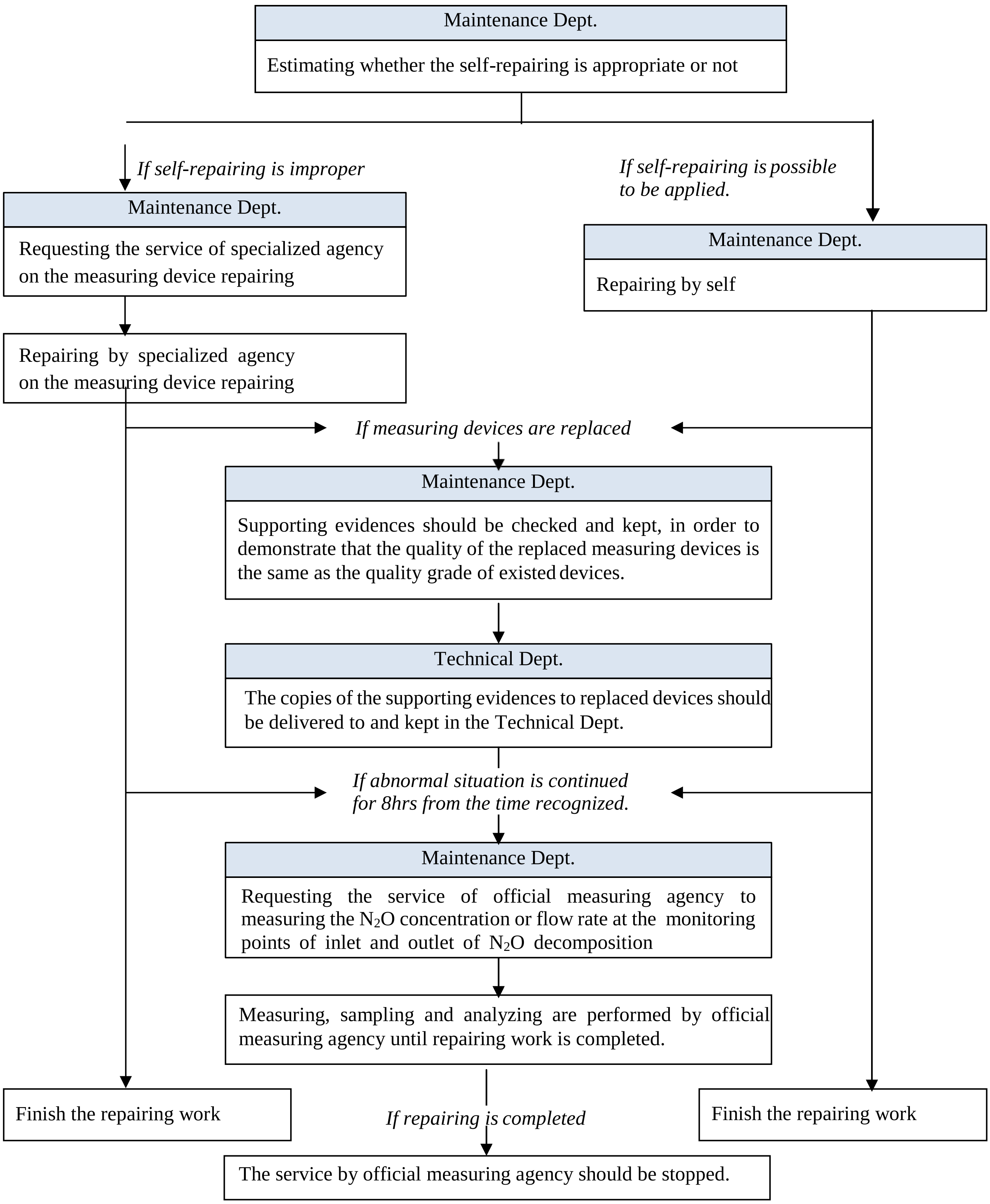

Figure C.6 Emergency Procedures for malfunction of AMS

(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_2O 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 NOx and N_2O are checked by monthly report too.

- **Annual report** is a bunch of monthly report files.

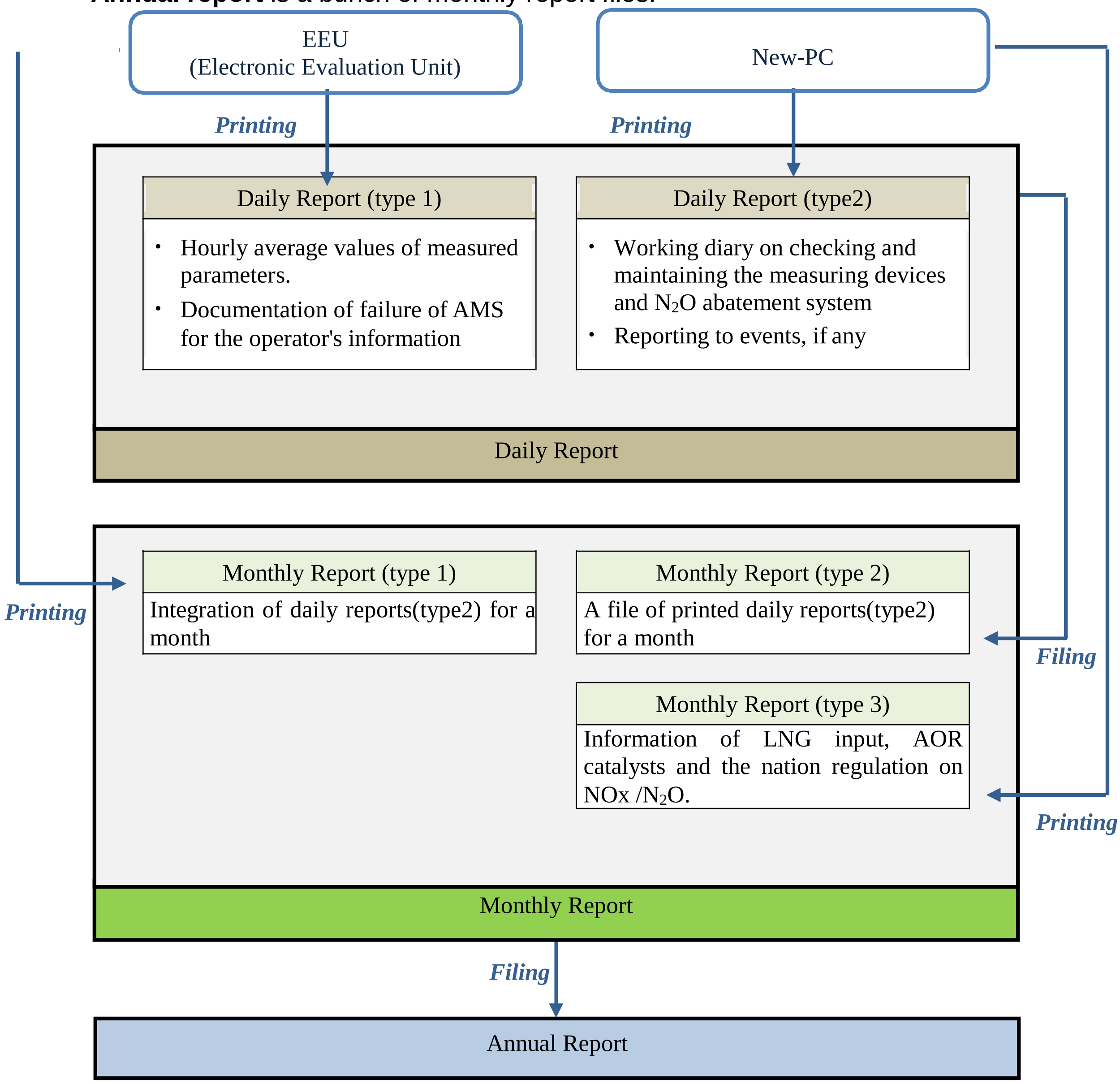

Figure C.7 The consists of the periodical reports

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

AMS(Automated measuring system) has been applied to measure the amount of N_2O emission at the two monitoring points of the inlet and outlet of N_2O destruction facility of each plant involved in this project. By AMS, the concentration of N_2O and the volume flow rate of tail gas are measured simultaneously(F_{Ti}, CI_{N2O}, and F_{TE}, CO_{N2O}) 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_2O 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
F_{TI-1}	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	
CI_{N2O-1}	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	
F_{TE-1}	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	
CO_{N2O-1}	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 expolosion 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	
CI_{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 expolosion 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 (25/07/2016~28/07/2016) 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:

(a) Section of the location of measurement

(b) Duly installation of the monitoring equipment

(c) Correct choice of measurement range

(d) Calibration of AMS using the standard-Reference-Method(SRM) as guidance

(e) Calibration curve either as linear regression or as straight line from absolute zero to centre of a scatter-plot

(f) 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)

Annual Surveillance test has been carried out in July of 2018 (18/07/2018 ~ 19/07/2018)

(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.

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

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)
$Q_{NG\ combustion\ gas}$	: Combustion gas of natural gas (Nm^3/h)
VEF	: Volumetric Expansion Factor

For monitoring, the gas generated by combusting natural gas($Q_{NG\ combustion\ gas}$) 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-NOx and/or De-N_2O 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_2O abatement catalysts supplier. This value of VEF is applied as a fixed official value.

(h) <u>Training</u>

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-N2O 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

(Copy this table for each data or parameter.)

Data/Parameter	**GWP_{N2O}**
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_2O is defined in the 2nd commitment period (starting 01/01/2013) as 298 tCO_2/tN_2O.
Purpose of data/parameter	Baseline Emission / Project Emission Calculation
Additional comments	Not applicable

Data/parameter:	***GWP_{CH4}***
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_4 is defined in the 2nd commitment period (starting 01/01/2013) as 25 tCO_2/tCH_4.
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.
Purpose of data	Baseline Emission / Project Emission Calculation
Additional comments	Not applicable

	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

Data/parameter:	$A_{OR,hist}$
Unit	tNH3/day
Description	Maximum of historical ammonia flow rate of the ammonia oxidation reactor (AOR)
Source of data	PDD
Value(s) applied)	$A_{OR,hist-1}$: 42.250tNH_3/d (total flow rate for AOR-a and AOR-b in Plant I) $A_{OR,hist-2}$: 44.557tNH_3/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 (1st Jan.2007 - 31st 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

Data/parameter:	$T_{g,hist}$
Unit	°C
Description	Historical operating temperature range of the ammonia oxidation reactor
Source of data	PDD
Value(s) applied)	$T_{g,hist-a}$: 656.57− 731.66°C (for AOR-a in Plant I) $T_{g,hist-b}$: 662.08−743.92 °C (for AOR-b in Plant I) $T_{g,hist-c}$: 738.95− 774.85°C (for AOR-c in Plant II) $T_{g,hist-d}$: 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 (1st Jan.2007 - 31st Dec.2009).
Purpose of data	Baseline Emission Calculation
Additional comments	Not applicable

Data/parameter:	$P_{g,hist}$
Unit	*Pa gauge*
Description	Historical operating pressure range of the ammonia oxidation reactor
Source of data	PDD
Value(s) applied)	$P_{g,hist\_1}$: 43,320 − 98,564 Pa gauge (for AOR-a and AOR-b in Plant I) $P_{g,hist\_2}$: 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 (1st Jan.2007 - 31st Dec.2009).
Purpose of data	Baseline Emission Calculation
Additional comments	Not applicable

Data/parameter:	$G_{sup,hist}$
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

Data/parameter:	$G_{com,hist}$
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

Data/parameter:	$OXID_{HC}$
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

Data/parameter:	EF_{CH4}
Unit	tCO_2/tCH_4
Description	Emission factor of methane
Source of data	PDD
Value(s) applied)	2.75(tCO_2/tCH_4)
Choice of data or measurement methods and procedures	This value is theoretically calculated as follows; 44 gCO_2/16gCH_4

Purpose of data	Project Emission Calculation
Additional comments	Not applicable

Data/parameter:	ρ_{CH4}
Unit	t/m^3
Description	Density of methane
Source of data	Tool to determine project emissions from flaring gases containing methane
Value(s) applied)	0.000716 t/m_3 (0_oC, 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

Data/parameter:	M_i
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_2O concentrations at N_2O destruction facility inlet and outlet.
Purpose of data	Baseline Emission Calculation / Project Emission Calculation
Additional comments	Not applicable

Data/parameter:	Reg_{NOx}
Unit	tNO_X/Nm^3
Description	National regulation on NO_X emissions
Source of data	The “Clean Air Conservation Act”, one of the National environmental legislation, Ministry of Environment
Value(s) applied)	4.10714×10^{-7} tNOx/Nm³ (as a NO_2 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 NOx emission is 200 ppm(v) as a NO_2 concentration level. The unit of ($tNOx/Nm_3$) is adjusted from the ppm(v) unit by following equation : 4.10714×10^{-7} [$tNOx/Nm^3$] = 200 ppm(v) $\times 10^{-6} \times$ 46/22.4/1,000
Purpose of data	Not applicable
Additional comments	Not applicable

D.2. Data and parameters monitored

(Copy this table for each data or parameter.)

Data/Parameter	$F_{TI,i}$
Unit	Nm^3/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_{TI} <table><tr><th></th><th>Plant I</th><th>Plant II</th></tr><tr><td>**F_{TI}** (Nm³/hr) average</td><td>N/A</td><td>43,331.11</td></tr></table>
Monitoring equipment	<table><tr><th></th><th>Plant I</th><th>Plant II</th></tr><tr><td>Type</td><td>Ultrasonic flow meter</td><td>Ultrasonic flow meter</td></tr><tr><td>Accuracy class</td><td>< 2%</td><td>< 2%</td></tr><tr><td>Serial No.</td><td>N/A</td><td>HEAD A : 1217011 HEAD B : 1217012 Evaluation Unit : 1216866 Case of Evaluation : 1217002</td></tr><tr><td>Calibration frequency</td><td>Every day by Auto calibration manner</td><td>Every day by Auto calibration manner</td></tr><tr><td>Date of last calibration</td><td>N/A</td><td>30/04/2019</td></tr><tr><td>Validity</td><td>N/A</td><td>Yes</td></tr></table>
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	Nm³/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} <table><tr><th></th><th>Plant I</th><th>Plant II</th></tr><tr><td>**F_{TE}** (Nm³/hr) average</td><td>N/A</td><td>46,007.34</td></tr></table>
Monitoring equipment	<table><tr><th></th><th>Plant I</th><th>Plant II</th></tr><tr><td>Type</td><td>Ultrasonic flow meter</td><td>Ultrasonic flow meter</td></tr><tr><td>Accuracy class</td><td>< 2%</td><td>< 2%</td></tr><tr><td>Serial No.</td><td>N/A</td><td>HEAD A : 1217013 HEAD B : 1217014 Evaluation Unit : 1216867 Case of Evaluation : 1217003</td></tr><tr><td>Calibration frequency</td><td>Every day by Auto calibration manner</td><td>Every day by Auto calibration manner</td></tr><tr><td>Date of last calibration</td><td>N/A</td><td>30/04/2019</td></tr><tr><td>Validity</td><td>N/A</td><td>Yes</td></tr></table>
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:	***$CI_{N2O,i}$***
Unit	N_2O/Nm^3
Description	N_2O 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 *CI_{N2O}* Average value / Plant I / Plant II: *$CI_{N2O,I}$* as tN_2O/Nm^3 / N/A / 3.62932×10^{-6}
Monitoring equipment	Type: Plant I NDIR; Plant II NDIR Accuracy class (repeatability): Plant I > 95%; Plant II > 95% Serial No.: Plant I N/A; Plant II AO-749 Calibration frequency: Plant I Every 2 weeks; Plant II Every 2 weeks Date of last calibration: Plant I N/A; Plant II 25/04/2019 Validity: Plant I N/A; Plant II 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:	***$CO_{N2O,i}$***
Unit	N_2O/Nm^3
Description	N_2O 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 *CI_{N2O}* Average value / Plant I / Plant II: *$CO_{N2O,I}$* (tN_2O/Nm^3) / N/A / 5.6801×10^{-7}
Monitoring equipment	Type: Plant I NDIR; Plant II NDIR Accuracy class (repeatability): Plant I > 95%; Plant II > 95% Serial No.: Plant I N/A; Plant II AO-751 Calibration frequency: Plant I Every 2 weeks; Plant II Every 2 weeks Date of last calibration: Plant I N/A; Plant II 25/04/2019 Validity: Plant I N/A; Plant II 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:	***$P_{product,y}$***
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	<table><tr><th></th><th>Plant I</th><th>Plant II</th></tr><tr><td>$P_{product,\ period}$ (ton/period)</td><td>N/A</td><td>31,816.88</td></tr></table>
Monitoring equipment	<table><tr><th>Plant II</th><th>Plant I</th><th>Plant II</th></tr><tr><td>Type</td><td>Mass flow meter</td><td>Mass flow meter</td></tr><tr><td>Accuracy class (repeatability)</td><td>Within ± 0.1%</td><td>Within ± 0.15%</td></tr><tr><td>Serial No.</td><td>N/A</td><td>28 529138</td></tr><tr><td>Calibration frequency</td><td>Every 2 years</td><td>Every 2 years</td></tr><tr><td>Date of last calibration</td><td>N/A</td><td>27/04/2017 11/05/2018</td></tr><tr><td>Validity</td><td>N/A</td><td>Yes</td></tr></table>
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

Data/parameter:	***$A_{OR,d}$***
Unit	tNH_3/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_3/day) of AOR in this period<table><tr><th></th><th>Plant I</th><th>Plant II</th></tr><tr><td>$A_{OR,d}$ (tNH_3/day)</td><td>N/A</td><td>42.063</td></tr></table>
Monitoring equipment	<table><tr><th></th><th>Plant I</th><th>Plant II</th></tr><tr><td>Type</td><td>Differential Pressure</td><td>Differential Pressure</td></tr><tr><td>Accuracy class (repeatability)</td><td>Within ± 0.1%</td><td>Within ± 0.1%</td></tr><tr><td>Serial No.</td><td>N/A</td><td>121080055040028</td></tr><tr><td>Calibration frequency</td><td>Every 2 years</td><td>Every 2 years</td></tr><tr><td>Date of last calibration</td><td>N/A</td><td>26/04/2017 17/05/2018</td></tr><tr><td>Validity</td><td>N/A</td><td>Yes</td></tr></table>
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

<table>
<tr><th>Data/parameter:</th><th>$T_{g,d}$</th></tr>
<tr><td>Unit</td><td>°C</td></tr>
<tr><td>Description</td><td>Actual daily (d) operating temperature of the ammonia oxidation reactor</td></tr>
<tr><td>Measured/calculated/default</td><td>Measured</td></tr>
<tr><td>Source of data</td><td>Thermocouple</td></tr>
<tr><td>Value(s) of monitored parameter</td><td>Average daily temperature (°C) of AOR in this period
<table>
<tr><th colspan="2">Plant I</th><th colspan="2">Plant II</th></tr>
<tr><td>$T_{g,a}$ (°C)</td><td>$T_{g,b}$ (°C)</td><td>$T_{g,c}$ (°C)</td><td>$T_{g,d}$ (°C)</td></tr>
<tr><td colspan="2">N/A</td><td>751.98</td><td>750.50</td></tr>
</table></td></tr>
<tr><td>Monitoring equipment</td><td>Before 21/05/2018
<table>
<tr><th>Plant II</th><th colspan="2">T_{g-c}</th><th colspan="2">T_{g-d}</th></tr>
<tr><td>Type</td><td colspan="2">Thermocouple K</td><td colspan="2">Thermocouple K</td></tr>
<tr><td rowspan="3">Accuracy class (Maximum error)</td><td>300°C</td><td>+1.27°C</td><td>300°C</td><td>+1.27°C</td></tr>
<tr><td>500°C</td><td>+1.74°C</td><td>500°C</td><td>+1.74°C</td></tr>
<tr><td>700°C</td><td>+2.05°C</td><td>700°C</td><td>+2.05°C</td></tr>
<tr><td>Serial No.</td><td colspan="2">2879576</td><td colspan="2">2879575</td></tr>
<tr><td>Calibration frequency</td><td colspan="2">Every 2 years</td><td colspan="2">Every 2 years</td></tr>
<tr><td>Date of last calibration</td><td colspan="2">26/04/2017</td><td colspan="2">26/04/2017</td></tr>
<tr><td>Validity</td><td colspan="2">Yes</td><td colspan="2">Yes</td></tr>
</table>
After 21/05/2018
<table>
<tr><th>PlantII</th><th colspan="2">T_{g-c}</th><th colspan="2">T_{g-d}</th></tr>
<tr><td>Type</td><td colspan="2">Thermocouple K</td><td colspan="2">Thermocouple K</td></tr>
<tr><td rowspan="3">Accuracy class (Maximum error)</td><td>300°C</td><td>-0.1°C</td><td>300°C</td><td>-0.1°C</td></tr>
<tr><td>500°C</td><td>-0.8°C</td><td>500°C</td><td>-1.0°C</td></tr>
<tr><td>700°C</td><td>-1.2°C</td><td>700°C</td><td>-1.4°C</td></tr>
<tr><td>Serial No.</td><td colspan="2">4100472</td><td colspan="2">4100474</td></tr>
<tr><td>Calibration frequency</td><td colspan="2">Every 2 years</td><td colspan="2">Every 2 years</td></tr>
<tr><td>Date of last calibration</td><td colspan="2">11/05/2018</td><td colspan="2">11/05/2018</td></tr>
<tr><td>Validity</td><td colspan="2">Yes</td><td colspan="2">Yes</td></tr>
</table></td></tr>
<tr><td>Measuring/reading/recording frequency:</td><td>•Measuring period : Continuously
•Recording frequency : Hourly</td></tr>
<tr><td>Calculation method (if applicable):</td><td>Not applicable</td></tr>
<tr><td>QA/QC procedures:</td><td>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.</td></tr>
<tr><td>Purpose of data:</td><td>Baseline emission Calculation</td></tr>
<tr><td>Additional comments:</td><td>Not applicable</td></tr>
</table>

<table>
<tr><th>Data/parameter:</th><th>$P_{g,d}$</th></tr>
<tr><td>Unit</td><td>Pa gauge</td></tr>
<tr><td>Description</td><td>Actual operating pressure of the ammonia oxidation reactor on day d</td></tr>
<tr><td>Measured/calculated/default</td><td>Measured</td></tr>
<tr><td>Source of data</td><td>Pressure gauge</td></tr>
<tr><td>Value(s) of monitored parameter</td><td>Average daily Pressure (Pa/day) of AOR in this period
<table>
<tr><th></th><th>Plant I</th><th>Plant II</th></tr>
<tr><td>$P_{g,d}$ (Pa/day)</td><td>N/A</td><td>91,429</td></tr>
</table></td></tr>
</table>

<table>
<tr><td>Monitoring equipment</td><td>
<table>
<tr><td></td><td>Plant I</td><td>Plant II</td></tr>
<tr><td>Type</td><td>Gauge Pressure</td><td>Gauge Pressure</td></tr>
<tr><td>Accuracy class</td><td>Within ± 0.1%</td><td>Within ± 0.1%</td></tr>
<tr><td>Serial No.</td><td>N/A</td><td>1211 80055040030</td></tr>
<tr><td>Calibration frequency</td><td>Every 2 years</td><td>Every 2 years</td></tr>
<tr><td>Date of last calibration</td><td>N/A</td><td>26/04/2017
15/05/2018</td></tr>
<tr><td>Validity</td><td>N/A</td><td>Yes</td></tr>
</table>
</td></tr>
<tr><td>Measuring/reading/recording frequency:</td><td>•Measuring period : Continuously
•Recording frequency : Hourly</td></tr>
<tr><td>Calculation method (if applicable):</td><td>Not applicable</td></tr>
<tr><td>QA/QC procedures:</td><td>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.</td></tr>
<tr><td>Purpose of data:</td><td>Baseline emission Calculation</td></tr>
<tr><td>Additional comments:</td><td>Not applicable</td></tr>
</table>

Data/parameter:	G_{sup}
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

Data/parameter:	G_{com}
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

Data/parameter:	***$Type_{HC}$***
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_{CH4}***
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	(see table below)
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

	Plant I	Plant II
Nov. 2018	N/A	0.9326
Dec. 2018		0.9319
Jan. 2018		0.9339
Feb. 2018		0.9277
Mar. 2018		0.9333
Apr. 2018		0.9260
Period 10		0.9309

Data/parameter:	***$Q_{NG,y}$***
Unit	Nm^3
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	<table><tr><th></th><th>Plant I</th><th>Plant II</th></tr><tr><td>Q_{NG} (Nm³/day)</td><td>N/A</td><td>1,245.59</td></tr></table>
Monitoring equipment	<table><tr><th></th><th>Plant I</th><th>Plant II</th></tr><tr><td>Type</td><td>Orifice</td><td>Orifice</td></tr><tr><td>Accuracy class</td><td>±0.90%</td><td>±0.90%</td></tr><tr><td>Serial No.</td><td>N/A</td><td>02319623</td></tr><tr><td>Calibration frequency</td><td>Every 2 years</td><td>Every 2 years</td></tr><tr><td>Date of last calibration</td><td>N/A</td><td>26/10/2016 16/05/2018</td></tr><tr><td>Validity</td><td>N/A</td><td>Yes</td></tr></table>
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

Data/parameter:	$Q_{CH4,y}$
Unit	Nm^3/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<table><tr><th></th><th>Plant I</th><th>Plant II</th></tr><tr><td>Q_{CH4} (Nm³/day)</td><td>N/A</td><td>1,156.2414</td></tr></table>
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

Data/parameter:	$Q_{HC,y}$
Unit	Nm^3/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<table><tr><th></th><th>Plant I</th><th>Plant II</th></tr><tr><td>Q_{HC} (Nm³/day)</td><td>N/A</td><td>87.3459</td></tr></table>
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

<table>
<tr><td>Data/parameter:</td><td>ρ_{NG}</td></tr>
<tr><td>Unit</td><td>t/Nm^3</td></tr>
<tr><td>Description</td><td>Density of the natural gas</td></tr>
<tr><td>Measured/calculated/default</td><td>Not applicable</td></tr>
<tr><td>Source of data</td><td>Monthly report provided by the fuel supplier</td></tr>
<tr><td>Value(s) of monitored parameter</td><td>
<table>
<tr><th></th><th>Plant I</th><th>Plant II</th></tr>
<tr><td>Nov 2018</td><td rowspan="7">N/A</td><td>0.7734×10^{-3}</td></tr>
<tr><td>Dec 2018</td><td>0.7766×10^{-3}</td></tr>
<tr><td>Jan 2019</td><td>0.7743×10^{-3}</td></tr>
<tr><td>Feb 2019</td><td>0.7781×10^{-3}</td></tr>
<tr><td>Mar 2019</td><td>0.7757×10^{-3}</td></tr>
<tr><td>Apr 2019</td><td>0.7783×10^{-3}</td></tr>
<tr><td>Period 11</td><td>0.7761×10^{-3}</td></tr>
</table>
</td></tr>
<tr><td>Monitoring equipment</td><td>Not applicable</td></tr>
<tr><td>Measuring/reading/recording frequency:</td><td>Recording frequency : Monthly</td></tr>
<tr><td>Calculation method (if applicable):</td><td>Not applicable</td></tr>
<tr><td>QA/QC procedures:</td><td>Not applicable</td></tr>
<tr><td>Purpose of data:</td><td>Project Emission Calculation</td></tr>
<tr><td>Additional comments:</td><td>Not applicable</td></tr>
</table>

<table>
<tr><td>Data/parameter:</td><td>ρ_{HC}</td></tr>
<tr><td>Unit</td><td>t/m^3</td></tr>
<tr><td>Description</td><td>Density of the hydrocarbon with two or more molecules of carbon in natural gas</td></tr>
<tr><td>Measured/calculated/default</td><td>Calculated</td></tr>
<tr><td>Source of data</td><td>Information provided by the natural gas supplier</td></tr>
<tr><td>Value(s) of monitored parameter</td><td>
<table>
<tr><th></th><th>Plant I</th><th>Plant II</th></tr>
<tr><td>Nov 2018</td><td rowspan="7">N/A</td><td>1.5676×10^{-3}</td></tr>
<tr><td>Dec 2018</td><td>1.6059×10^{-3}</td></tr>
<tr><td>Jan 2019</td><td>1.5980×10^{-3}</td></tr>
<tr><td>Feb 2019</td><td>1.5749×10^{-3}</td></tr>
<tr><td>Mar 2019</td><td>1.6111×10^{-3}</td></tr>
<tr><td>Apr 2019</td><td>1.5579×10^{-3}</td></tr>
<tr><td>Period 11</td><td>1.5859×10^{-3}</td></tr>
</table>
</td></tr>
<tr><td>Monitoring equipment</td><td>Not applicable</td></tr>
<tr><td>Measuring/reading/recording frequency:</td><td>Not applicable</td></tr>
<tr><td>Calculation method (if applicable):</td><td>$\rho_{HC} = (\rho_{NG} - \rho_{CH4} \times CF_{CH4}) / (1-CF_{CH4})$</td></tr>
<tr><td>QA/QC procedures:</td><td>Not applicable</td></tr>
<tr><td>Purpose of data:</td><td>Project Emission Calculation</td></tr>
<tr><td>Additional comments:</td><td>Not applicable</td></tr>
</table>

Data/parameter:	EF_{NG}
Unit	tCO_2/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	<table><tr><th></th><th>Plant I</th><th>Plant II</th></tr><tr><td>Nov 2018</td><td rowspan="7">N/A</td><td>2.7750</td></tr><tr><td>Dec 2018</td><td>2.7764</td></tr><tr><td>Jan 2019</td><td>2.7766</td></tr><tr><td>Feb 2019</td><td>2.7760</td></tr><tr><td>Mar 2019</td><td>2.7762</td></tr><tr><td>Apr 2019</td><td>2.7724</td></tr><tr><td>**Period 11**</td><td>2.7754</td></tr></table>
Monitoring equipment	Not applicable
Measuring/reading/recording frequency:	Not applicable
Calculation method (if applicable):	$EF_{NG} = COEF_{NG} \times NCV_{NG}/\rho_{NG} \times 44/12$ Where $COEF_{NG}$: 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_{NG} : Net calorific value of the natural gas [TJ/Nm^3] For this project, NCV_{NG} is offered by KOGAS. ρ_{NG} : Density of the natural gas[t/Nm^3] 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

Data/parameter:	EF_{HC}
Unit	tCO_2/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	<table><tr><th></th><th>Plant I</th><th>Plant II</th></tr><tr><td>Nov 2018</td><td rowspan="7">N/A</td><td>2.9332</td></tr><tr><td>Dec 2018</td><td>2.9374</td></tr><tr><td>Jan 2019</td><td>2.9452</td></tr><tr><td>Feb 2019</td><td>2.9278</td></tr><tr><td>Mar 2019</td><td>2.9389</td></tr><tr><td>Apr 2019</td><td>2.9009</td></tr><tr><td>**Period 11**</td><td>2.9306</td></tr></table>
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_2 emission factor of NG (tCO_2/tNG) ρ_{NG} : Density of natural gas (tNG/m_3) EF_{CH4} : CO_2 emission factor of CH_4 (tCO_2/tCH_4). ρ_{CH4} : Density of methane (tCH_4/ m_3). 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_{N2O}***
Unit	kgN_2O/tCaprolactam
Description	N_2O 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_{N2O} is for this period. <table><tr><th></th><th>Plant I</th><th>Plant II</th></tr><tr><td>SE_{N2O} (kgN_2O/tCaprolactam)</td><td>N/A</td><td>21.10</td></tr></table>
Monitoring equipment	Not applicable
Measuring/reading/recording frequency:	Not applicable
Calculation method (if applicable):	$SE_{N2O,period} = QI_{N2O,period} / P_{product,period} \times 1000$ Where, $QI_{N2O,period}$ means the monitored quantity of N_2O emissions at the inlet of the destruction facility (t N_2O), and $P_{product,period}$ 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:	***$OXID_{CH4}$***
Unit	%
Description	Oxidation factor of CH_4 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 <table><tr><th></th><th>Plant I</th><th>Plant II</th></tr><tr><td>$OXID_{CH4}$</td><td>N/A</td><td>98.20</td></tr></table>
Monitoring equipment	Not applicable
Measuring/reading/recording frequency:	Not applicable
Calculation method (if applicable):	$OXID_{CH4} = \{Q_{CH4} - (\sum_{i}^{n} F_{TE,i} \times 10^{-6})\} / Q_{CH4} \times 100\}$
QA/QC procedures:	Not applicable
Purpose of data:	Project Emission Calculation
Additional comments:	Not applicable

Data/parameter:	***CO_{CH4}***
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 | | Plant I | Plant II | | CO_{CH4} (ppm(v)) | N/A | 19.14 |
Monitoring equipment	| | Plant I | Plant II | | 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 | 23/10/2018 | | 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

Data/parameter:	***Reg_{NOx}***
Unit	$tNOX/Nm^3$
Description	National regulation on NOX 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	4.10714×10^{-7} $tNOx/Nm^3$ (as a NO_2 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

Data/parameter:	***$RSE_{N2O,y}$***
Unit	tN_2O/tCaprolactam
Description	Regulatory limit of N_2O emissions per unit of outlet of caprolactam (tN_2O/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

>>
Not applicable

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 ($P_{product,actual}$) exceeds the design capacity ($P_{product,max}$), the emissions related to the production above $P_{product,max}$ will not be claimed for the baseline scenario. Therefore $P_{product,\ actual}$ of each plant should be monitored. However, it is not able to be decided whether the actual production of caprolactam exceeds $P_{product,max}$, or not, because those values ($P_{product,max}$ and $P_{product,actual}$) 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 , $P_{product,max}$ (ton/yr)	No. of Operating days In PDD	Daily output (ton/day)	Period total output $P_{product,period}$ (ton/period)	No. of Operating days	Daily output (ton/day)
Plant I	63,307	363	174.40	-	-	-
Plant II	64,965	355	183.00	31,816.88	181	175.78

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

$$BE_{period,\ within\ permit\ range} = \left(\sum_{i}^{n} F_{TI,i} \times CI_{N2O,i} \times M_i \right) \times GWP_{N2O}$$

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)
$CI_{N2O,i}$	: 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"($tonCO_2$/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_2O/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_2O/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 :

$$QI_{N2O,y} = \sum_{i}^{n} F_{TI,i} \times CI_{N2O,i} \times M_i$$

For this period, $SE_{N2O,y}$ and $QI_{N2O,y}$ should be converted as $SE_{N2O,period}$ and $QI_{N2O,\ period}$ as follows :

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

The both of $SE_{N2O,y}$ values(18.58 for plant II) for Plant II are calculated as higher than $EF_{N2O,IPCC}$, and thus the values of EF_{N2O} are decided as 5.4kgN_2O/tonne of caprolactam in order to calculate $BE_{period,\ out\ of\ permit range}$.

Table E1-2 $SE_{N2O,y}$ for this period (period 11)

	Plant I	Plant II
$QI_{N2O-Period}$ (ton N_2O/period)	N/A	671.41
$P_{product-Period}$ (ton Caprolactam/yr)		31,816.88
$SE_{N2O,period}$ (kgN_2O/tCaprolactam)		21.10

If the actual daily ammonia flow rate exceeds the (upper) limit on maximum historical daily permitted ammonia flow rate, the baseline N_2O 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) <u>Baseline emission of Plant II</u>

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 $CI_{N2O,i-2}$ are aggregated to the daily *BE*($BE_{,day-2}$), and total *BE* on the period ($BE_{,period-11}$) are estimate as sum of $BE_{,day-2}$. The total *BE* on the period 11 for Plant II ($BE_{,period-11}$) is 180,177.68 tonCO_2/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 5,159.40 tonCO_2/period depends on following equation.

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

(b) <u>The total *BE* of Period 11</u>

Eventually, Total *BE* in this period is about 185,337.08 tCO_2e/period as shown below table.

		$BE_{period-11}$ (tCO_2e/period)	
		$BE_{period-11}$ in Plant I	$BE_{period-11}$ in Plant II
BE_{period} on AOR condition	Within permitted range	N/A	180,177.68
	Outside permitted range		5,159.40
BE_{period} total	BE_{period} for each plant		185,337.08
	$BE_{period-total}$	185,337.08	

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.

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

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)
ρ_{CH4}	: Density of methane (tCH_4/m^3) , (0.000716 : ex ante value)
ρ_{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) <u>The total *PE* of Period 11</u>

Total *PE* in this period is 33,766 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	33,766
PE for Period total, $PE_{period-11}$ (tCO_2/period)	33,766	

E.3. Calculation of leakage emissions

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The installation of the N_2O 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_2e)	Project GHG emissions or actual net GHG removals (t CO_2e)	Leakage GHG emissions (t CO_2e)	GHG emission reductions or net anthropogenic GHG removals (t CO_2e)		
				Before 01/01/2013	From 01/01/2013	Total amount
Total	185,337.08	33,765.85	0	-	151,571	151,571

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_2e)	Amount estimated ex ante for this monitoring period in the PDD (t CO_2e)
151,571	173,788[1]

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

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1. Ex-ante calculation of Baseline Emission, BE_{y-2}

Main assumptions applied for Ex-ante calculation are follows:
- The N2O decomposition efficiency is 90%.
- The number of operating day in a year is 363 and 355 of Plant I and Plant II respectively.
- The number of operating time in a day is 24hr.
- The N2O concentration and the flow rate of tail gas are continuously monitored.
- The value adopted as the quantity of N2O includes the combined uncertainty of the applied monitoring equipment at the inlet of the destruction facility.
- The Oxidation factor of methane, OXIDCH4, is established to be 99.5%, referred to B.7.1
- All of hydrocarbon with two or more molecules of carbon in the natural gas used for re-heating DF are oxidized, OXIDHC = 100%.

Ex-ante calculation of Baseline Emission, BEy-2
As described in the equation (14) of Section B.6.1, the baseline emission is given by

$$BE_y = \left(\sum_{i}^{n} F_{TI,i} \times CI_{N2O,i} \times M_i\right) \times GWP_{N20}$$

Following values for parameter are applied to the equation, and the baseline emission for Plant II (BE,y-2) is estimated to 381,323 tCO2/yr.

Parameter		Value	Unit
n	Number of intervals during the year	8520	$year^{-1}$
M_i	Length of Measuring Interval	1	hr
$F_{TI,i}$	Volume flow rate at the inlet of the DF during interval i	49000	Nm^3/hr
$CI_{N2O,i}$	N_2O concentration in the tail gas of the DF inlet during interval i	2.9464×10^{-6}	tN_2O/Nm^3
GWP_{N2O}	Global warming potential of the nitrous oxide	310	-
The baseline emission for Plant II ($BE_{,y-2}$) = 381,323 tCO_2/yr			

The value of parameter n in table above is calculated by following equation:
8,520 (year-1) = 355 operating day per year (day/yr) × 24(hr/day) / Mi (hr)

The unit of CIN2O,i is adjusted from the ppm(v) unit by following equation :
2.9464 10-6 [tN2O/ Nm3] = 1,500 ppm(v) 10-6 44/22.4/1,000

2. Ex-ante calculation of Project Emission, PE_{y-2}
As described in the equation (9) of Section B.6.1, the baseline emission is given by

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

Following values for parameter are applied to the equation, and the project emission for Plant II ($PE_{,y-2}$) is estimated to 40,467tCO2/yr.

Parameter		Value	Unit
n	Number of intervals during the year	8,520	$year^{-1}$
M_i	Length of Measuring Interval	1	hr
$F_{TE,i}$	Volume flow rate at the exit of the DF during interval *i*	49,980	Nm^3/hr
$CO_{N2O,i}$	N_2O concentration in the tail gas of the DF exit during interval *i*	2.9464×10^{-7}	tN_2O/m^3
GWP_{CH4}	Global warming potential of CH_4	21	
GWP_{N2O}	Global warming potential of the nitrous oxide	310	-
ρ_{CH4}	Density of methane	0.000716	tCH_4/m^3
ρ_{HC}	Density of HC	0.001640	tHC/m^3
EF_{CH4}	CO_2 emission factor of CH_4	2.75	tCO_2e/tCH_4
EF_{HC}	CO_2 emission factor of HC with two or more carbon molecule in natural gas	2.85	tCO_2e/tHC
$Q_{CH4,y}$	Methane used in year y	632,706	Nm^3/y
$Q_{HC,y}$	HC with two or more carbon molecule in natural gas used in year y	60,822	Nm^3/y
$OXID_{CH4}$	Oxidation factor of methane	99.5	%
$OXID_{HC}$	Oxidation factor of HC	100	%
The Project emission for Plant II ($PE_{,y-2}$) = 40,467 tCO_2/yr			

The value of parameter *n* in table above is calculated by following equation:
8,520 (year-1) = 355 operating day per year (day/yr) × 24(hr/day) / *Mi* (hr)
The unit of *CON2O,i* is adjusted from the ppm(v) unit by following equation:
2.9464 10-7 [tN2O/ Nm3] = 150 ppm(v*)* 10-6 44/22.4/1,000

3. Ex-ante calculation of Emission Reduction, $ER_{,y-2}$

$$ER_{y-2} = BE_{y-2} - PE_{y-2}$$
$$= (381,323 - 40,467)\ tCO_2/yr$$
$$= 340,856\ tCO_2/yr$$

Therefore the ex-ante emission reduction to Plant II is about 340,856 tCO2/yr.

E.6. Remarks on increase in achieved emission reductions

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N/A

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

>>
N/A

Document information

<table>
<tr><th>Version</th><th>Date</th><th>Description</th></tr>
<tr><td>07.0</td><td>31 May 2019</td><td>Revision to:
Ensure consistency with version 02.0 of the “CDM project standard for project activities” (CDM-EB93-A04-STAN);
Add a section on remarks on the observance of the scale limit of small-scale project activity during the crediting period;
Add "changes specific to afforestation or reforestation project activity" as a possible post-registration changes;
Clarify the reporting of net anthropogenic GHG removals for A/R project activities between two commitment periods;
Make editorial improvements.</td></tr>
<tr><td>06.0</td><td>7 June 2017</td><td>Revision to:
Ensure consistency with version 01.0 of the “CDM project standard for project activities” (CDM-EB93-A04-STAN);
Make editorial improvements.</td></tr>
<tr><td>05.1</td><td>4 May 2015</td><td>Editorial revision to correct version numbering.</td></tr>
<tr><td>05.0</td><td>1 April 2015</td><td>Revisions to:
Include provisions related to delayed submission of a monitoring plan;
Provisions related to the Host Party;
Remove reference to programme of activities;
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<tr><td>04.0</td><td>25 June 2014</td><td>Revisions to:
Include the Attachment: Instructions for filling out the monitoring report form (these instructions supersede the "Guideline: Completing the monitoring report form" (Version 04.0));
Include provisions related to standardized baselines;
Add contact information on a responsible person(s)/ entity(ies) for completing the CDM-MR-FORM in A.6 and Appendix 1;
Change the reference number from F-CDM-MR to CDM-MR-FORM;
Editorial improvement.</td></tr>
<tr><td>03.2</td><td>5 November 2013</td><td>Editorial revision to correct table in page 1.</td></tr>
<tr><td>03.1</td><td>2 January 2013</td><td>Editorial revision to correct table in section E.5.</td></tr>
<tr><td>03.0</td><td>3 December 2012</td><td>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).</td></tr>
<tr><td>02.0</td><td>13 March 2012</td><td>Revision required to ensure consistency with the "Guidelines for completing the monitoring report form" (EB 66, Annex 20).</td></tr>
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