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Carbon dioxide capture

Part 2: Evaluation procedure to assure and maintain stable performance of post-combustion CO_2 capture plant integrated with a power plant

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National foreword

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Carbon dioxide capture —

Part 2: Evaluation procedure to assure and maintain stable performance of post-combustion CO_2 capture plant integrated with a power plant

Captage du dioxyde de carbone —

Partie 2: Mode opératoire d'évaluation pour assurer et maintenir une performance stable du captage du CO_2 post-combustion intégré à une centrale thermique

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 265, *Carbon dioxide capture, transportation, and geological storage*.

A list of all parts in the ISO 27919 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

Atmospheric carbon dioxide (CO_2) emissions must be reduced to meet climate change mitigation targets. Including carbon dioxide capture and storage (CCS) in current emission reduction approaches increases the probability of meeting these targets at the lowest cost to the global economy. CO_2 capture from gases produced by combustion of carbonaceous fuels is the only technology capable of dealing directly with emissions from power plants and other industrial sectors, such as cement manufacture and fertilizer production.

This document is the second in a series of standards for post-combustion CO_2 capture (PCC) from a power plant using a liquid-based chemical absorption process. Building on ISO 27919-1 on evaluation of key performance indicators (KPIs), this document provides an evaluation procedure to assure and maintain reliable performance of a PCC plant integrated with a power plant. New or revised standards focusing on other CO_2 capture technologies and approaches will be developed later.

PCC is applicable to all combustion-based thermal power plants. A simplified block diagram illustrating the PCC process is shown in Figure 1.

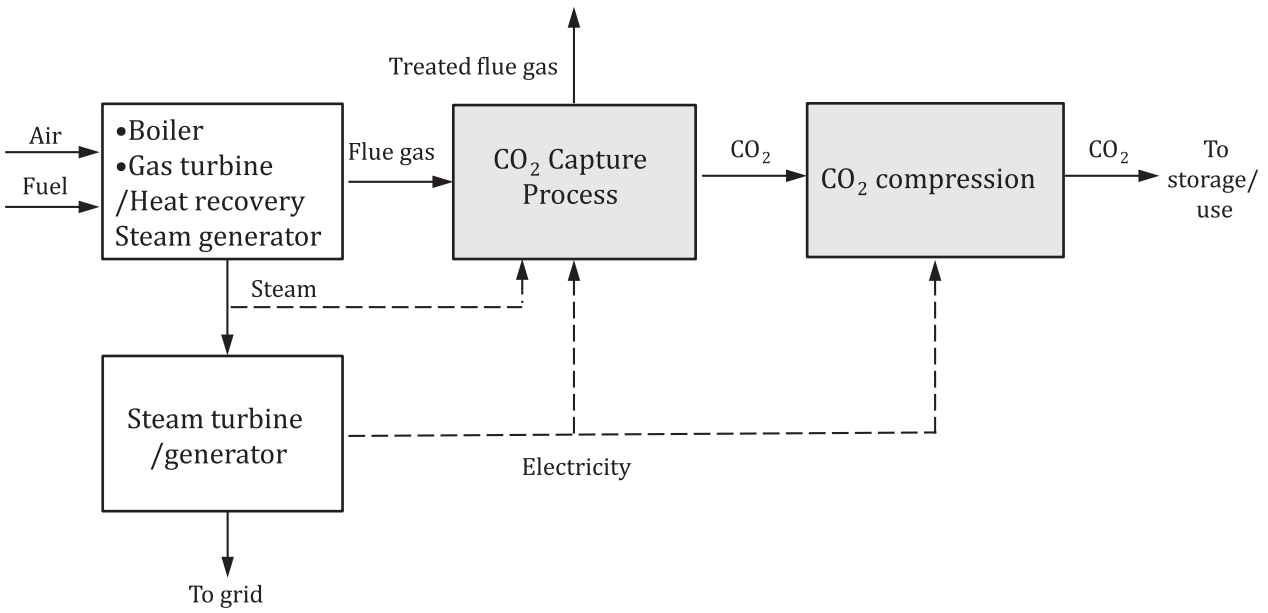

Figure 1 — Simplified block diagram of PCC

In a typical power generation facility, carbonaceous fuel (e.g. coal, oil, gas, biomass) is combusted with air in a boiler to raise steam. The steam drives a turbine or generator to produce power. In a gas-turbine combined-cycle system, the combustion in the gas turbine drives power generation, while steam generated through a heat-recovery steam generator produces additional power. Flue gas from the boiler or gas turbine consists mostly of N_2, CO_2, H_2O and O_2, with smaller amounts of other compounds depending on the fuel used. The PCC process is located downstream of conventional pollutant controls. Chemical-absorption-based PCC usually requires steam to be extracted from the power plant's steam cycle or the use of lower-grade heat sources for absorption liquid regeneration, depending on the absorption liquid and process employed.

The economic and environmental value of a PCC plant is determined by its technical performance, as well as its ability to achieve and maintain stable operation as required by its owners/stakeholders, as follows:

— The owner of the flue gas source has an interest in sustained CO_2-emission reductions.

— The owner of the CO_2-product has an interest being able to supply CO_2 at the desired rate regardless of external conditions.

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The CO_2 receiver has an interest in CO_2-product availability for its own operations.

Thus, this document describes a procedure that combines technology item evaluation procedure with reliability, availability, and in some cases maintainability evaluation methods.

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Carbon dioxide capture —

Part 2: Evaluation procedure to assure and maintain stable performance of post-combustion CO_2 capture plant integrated with a power plant

1 Scope

This document provides definitions, guidelines and supporting information for evaluating and reporting (with respect to the basic design items ongoing, and the operational results of a reference plant or unit as feedback) to ensure the (designed) performance of a PCC plant integrated with a host power plant. The PCC plant separates CO_2 from the power plant flue gas in preparation for subsequent transportation and geological storage. The physical system being addressed is a single power plant, with an optional auxiliary unit to provide thermal energy required for the PCC plant, and a single PCC plant as described in ISO 27919-1.

The formulas and methods to assure and maintain reliable performance, presented in this document, describe issues addressed during the design and construction phases and practices that document reliability and availability during routine operation. These practices would also guide ongoing maintenance programmes.

This document does not provide guidelines for benchmark, comparison or assessment studies for PCC plant operations using different capture technologies (i.e. absorbents), nor does it specify appropriate operating conditions such as temperature etc.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 27919-1, *Carbon dioxide capture — Part 1: Performance evaluation methods for post-combustion CO_2 capture integrated with a power plant*

3 Terms, definitions, abbreviated terms and symbols

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Terms and definitions

3.1.1
administrative delay
delay to maintenance incurred for administrative reasons

[SOURCE: IEC 60050-192 (192-7-12), modified — “maintenance action” was changed to “maintenance”]

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3.1.2
availability
ability of a *PCC plant* (3.1.20) integrated with the power plant to be in a state to perform as required under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided

3.1.3
corrective maintenance
maintenance carried out after fault detection to effect restoration

Note 1 to entry: Corrective maintenance of items disrupts the plant availability.

3.1.4
derated
derating
difference between the maximum and the dependable one, or such a condition

Note 1 to entry: For derated hours, it means operating time with the rated output lowered.

3.1.5
downtime
time interval for which the *item* (3.1.9) is in a state of being unable to perform as required due to internal faults, or *preventive maintenance* (3.1.24)

Note 1 to entry: unavailable time

3.1.6
emergency operation
type of sudden *shut-down* (3.1.36) operation to protect hardware from damage

3.1.7
external influence
critical subjects occurring outside the *PCC plant* (3.1.21) evaluation boundary

3.1.8
failure mechanism
process that leads to failure

Note 1 to entry: The process may be physical, chemical, logical, or a combination thereof.

[SOURCE: IEC 60050-192:2015, 192-03-12]

3.1.9
item
subject being considered

Note 1 to entry: An item may be an individual part, component, device, functional or process unit, equipment, subsystem, or system, related with technology.

Note 2 to entry: An item may consist of hardware, software, people or any combination thereof.

[SOURCE: IEC 60050-192:2015, 192-01-01, modified — “functional unit” was changed to “functional or process unit” and “system” was changed to “related with technology” in Note 1. Note 3 to Note 5 were deleted.]

3.1.10
logistic delay
delay, excluding *administrative delay* (3.1.1), incurred for the provision of resources needed for a *maintenance* (3.1.12) action to proceed or continue

[SOURCE: ISO 20815:2018, 3.1.24]

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3.1.11
maintainability
ability to be retained in, or restored to, a state in which the required function can be performed under given conditions

3.1.12
maintenance
combination of all technical and management actions intended to retain an *item* (3.1.9) in, or restore it to, a state in which it can perform as required

Note 1 to entry: Management is assumed to include supervision activities.

[SOURCE: IEC 60050-192:2015, 192-06-01]

3.1.13
mean downtime
MDT
average of the *downtime* (3.1.5)

[SOURCE: IEC 60050-192:2015, 192-08-10]

3.1.14
mean time between failures
MTBF
average time between failures that initiate a forced *outage* (3.1.20), i.e. the quotient of attempted operating hours to the number of forced *outages* (3.1.20)

3.1.15
meantime between maintenance
MTBM
average time between *maintenance* (3.1.12), i.e. the quotient of attempted operating hours to the number of *maintenance* (3.1.12)

3.1.16
mission time
duration of the mission

Note 1 to entry: Mission is the state that the equipment or system is 100 % operational.

[SOURCE: ISO 10438-1:2007, 3.1.19]

3.1.17
nominal product CO_2 capacity
NC
highest continuous flow rate of delivering captured CO_2 under typical representative conditions defined by the plant operator

3.1.18
normal operation
operation where the product CO_2 is exported to the transporting system maintaining the required performance based on ISO 27919-1

3.1.19
on-stream factor
OSF
ratio of the summation of all on-stream time to the *reference period* (3.1.31), with both expressed as hours

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3.1.20
outage
time interval for which the *item* (3.1.9) is in a state of being unable to perform as required, for any reason

[SOURCE: IEC 60050-192:2015, 192-02-19, modified — “a disabled state” was changed to “a state of being unable to perform as required, for any reason”]

3.1.21
PCC plant
process and associated equipment that produces a CO_2 stream from combustion gases

[SOURCE: ISO 27919-1:2018, 3.1.26]

3.1.22
PCC plant capacity availability
PCA
availability (3.1.2) of *PCC plant* (3.1.21) from a perspective of *product CO_2 amount* (3.1.26) during a *reference period* (3.1.31)

Note 1 to entry: It is mathematically defined by Formula (3).

3.1.23
PCC plant load
ratio of the *product CO_2 capacity* (3.1.27) in operation to the *‘nominal product CO_2 capacity’* (3.1.17)

3.1.24
preventive maintenance
maintenance (3.1.12) carried out in accordance with an established time schedule and performed according to a prescribed criterion

Note 1 to entry: See also condition-based maintenance (IEC 60050-192:2015, 192-06-07), and scheduled maintenance (IEC 60050-192:2015, 192-06-12).

[SOURCE: ISO 23815-1:2007, modified — "criteria" was changed to "criterion". The Note and the following text were deleted "in order to reduce the probability of failure or the degradation of the functioning of a crane"].

3.1.25
project cycle
series of phases of which a project consists, e.g. basic design, engineering, manufacturing, commissioning and operation

3.1.26
product CO_2 amount
volume, moles or mass of CO_2 resulting from the PCC process

3.1.27
product CO_2 capacity
total flow rate of the captured CO_2 exported

Note 1 to entry: It is generally expressed as product CO_2 amount per hour.

3.1.28
product CO_2 producibility
PCPB
ratio of the *product CO_2 amount* (3.1.26) produced to the *nominal product CO_2 capacity* (3.1.17) accumulated during the *reference period* (3.1.31)

3.1.29
proven technology element
element with low or acceptable uncertainty levels

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3.1.30
redundancy
item (3.1.9) where an equivalent unit can be put online to provide the same function if the *item* (3.1.9) fail to provide the service

Note 1 to entry: Redundancy is related to a strategy of design, where a spare system or component is provided so that, even if one item fails, the spare system or component will operate in place of the deficient item such that plant performance is not affected.

3.1.31
reference period
RP
period of time between an initial time and an end time over which all historical or projected performance metrics are measured or projected

Note 1 to entry: Reference period is equivalent to period hours.

3.1.32
reliability
measure of the probability of success for an operation and, the ability of each *item* (3.1.9) to perform its intended function as needed in an assembled *PCC plant* (3.1.20) during a given time interval within the designed conditions without failure

3.1.33
reliable performance
ability of a *PCC plant* (3.1.21) to function reliably as required

3.1.34
schedule compliance
SC
ratio of the *product CO_2 amount* (3.1.26) produced to the scheduled CO_2 product amount requirement met (historical) or to be met (projected) by the *PCC plant* (3.1.21) within a given time period

3.1.35
service hours
accumulated period of time during stand-by and *normal operation* (3.1.18) including *start-up* (3.1.39) and *shut-down* (3.1.36) in between[SOURCE: ISO 3977-9:1999, 3.98, modified — "from main flame ignition through to flame extinction" was replaced by " during stand-by and normal operation including start-up and shut-down in between"].

3.1.36
shut-down
event during which all required function of a *PCC plant* (3.1.21), and its equipment, is brought from an operating state to a stoppage state under the control of a programmed sequence

3.1.37
stand-by state
non-operating up state ready to start

3.1.38
starting reliability
SR
probability of successful *start-up* (3.1.39) when the *PCC plant* (3.1.21) is on stream within a specified period

3.1.39
start-up
act of getting a *PCC plant* (3.1.21) and its equipment from a stoppage state ready to activate its *items* (3.1.9) to an operating state

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3.1.40
technical delay
accumulated time necessary to perform auxiliary technical actions associated with the *maintenance* (3.1.12) action itself

3.1.41
time availability
TA
ratio of the subtraction of the summation of each element of the *PCC plant* (3.1.21) unavailable time from the *reference period* (3.1.31) to the *reference period* (3.1.31)

Note 1 to entry: Available time is calculated by subtraction of the unavailable time from reference period.

3.1.42
time reliability
TR
ratio of the subtraction of *PCC plant* (3.1.21) unavailable time from the time between preventative *maintenance* (3.1.12) to the time between preventative *maintenance* (3.1.12)

3.1.43
unavailability
PCC plant (3.1.21) is not in a state to perform as required due to an internal faults or *preventive maintenance* (3.1.24)

3.1.44
uptime
time interval during which a *PCC plant* (3.1.21) is in a state of being able to perform as required

Note 1 to entry: Absence of necessary external resources may prevent operation but does not affect.

Note 2 to entry: Available time.

3.2 Abbreviated terms

CCS	carbon dioxide capture and storage
DSS	daily start-up and stop
EHS	environment, health and safety
KPIs	key performance indicators
MAD	mean administrative delay
MDT	mean downtime
MLD	mean logistic delay
MR	mission reliability
MTBF	mean time between failure
MTPM	mean time to preventive maintenance
MTTR	mean time to repair
NC	nominal product CO_2 capacity
NPC	nominal product CO_2

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OSF	on-stream factor
OST	summation of each element of on-stream time
PCA	PCC plant capacity availability
PCC	post-combustion CO_2 capture
PCP	product CO_2 produced
PCPB	product CO_2 producibility
PCNP	product CO_2 not produced
RAM	reliability, availability and maintainability
RP	reference period
SC	schedule compliance
SPC	scheduled product CO_2
SR	starting reliability
TA	time availability
TBPM	time between preventative maintenance
TQ	technology qualification
TR	time reliability
UT	unavailable time

3.3 Symbols

n_{FO}	number of forced outages
n_{FS}	number of failures to start-up
n_{SA}	number of starting attempts
n_{SS}	number of successful start-ups
$PC_{nominal}$	nominal product CO_2 capacity [t/h]
PR_{BSPC}	bonus production in excess of the planned capacity to make up the shortage of product CO_2 production compared with SPC [t]
PR_{NPC}	amount [t] of NPC accumulated during the RP [t], calculated using Formula (4)
PR_{PCP}	product CO_2 amount produced [t]
PR_{PCU}	accumulation of the amount [t] of PCNP due to PCC plant capacity unavailability (excluding external influences) during the RP [t], calculated using Formula (5)
PR_{SPC}	scheduled product CO_2 amount [t]
PR_{SSPC}	shortage in product CO_2 amount compared to the scheduled during the RP [t]
t	mission time in hours [h]

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$t_{preventive}$ time period for preventive maintenance (planned) [h]

t_{repair} time period for repair as corrective maintenance (unplanned) [h]

T_{EPDH} equivalent planned derated hours [h], defined as the product of planned derated hours [h] and the size of the reduced capacity[t/h], divided by the NC [t/h] accumulated during the RP [h]; EPDH may be caused by planned outages or capacity reduction resulting from planned maintenance.

T_{ESEDH} equivalent seasonal derated hours [h], defined as the product of the NC [t/h] minus the net dependable capacity [t/h] and the available hours [h], divided by the NC [t/h] accumulated during the RP [h]; ESEDH may be caused by seasonal weather conditions.

T_{EUDH} equivalent unplanned derated hours [h], defined as the product of the unplanned reduced capacity hours [h] and the size of the reduced capacity[t/h], divided by the NC [t/h] accumulated during the RP[h]; EUDH may be caused by forced outages or capacity reduction resulting from unplanned repairs.

T_{FOH} forced outage hours [h]

T_{MDT} MDT comprises of T_{MTTR}, T_{MTPM}, T_{MAD} and T_{MLD} in the case of long-term operation [h].

T_{MTBM} meantime between maintenance [h]

T_{OST} summation of each element of on-stream time [h]

T_{PH} period hours [h]

T_{POH} planned outage hours [h]

T_{RP} reference period [h]

T_{RSH} reserve shut-down or service hours [h]

T_{SH} service hours [h]

T_{TBPM} time [h] between preventative maintenance (TBPM), specifically the period of continuous operation between the shut-down overhaul-based maintenance and the next

T_{UTRP} accumulation of the PCC plant UT (i.e. downtime) during the RP [h] calculated using Formula (2)

T_{UTTBPM} accumulation of PCC plant UT [h] during TBPM (excluding the time period for preventive maintenance)

e base of the natural logarithm

λ failure rate in events per hour

4 Principles

4.1 General

This document describes technology item evaluation procedure with reliability, availability, and in some cases maintainability evaluation methods.

The evaluation procedure in this document assumes the following:

a) A PCC plant shall be designed, manufactured and constructed in line with proven and established engineering practices during the whole project cycle.

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b) A PCC plant design may be a combination of proven technology items with some novel items that can contribute to improving the performance and/or economy of construction or operation. The level of novelty is related to the technological readiness of the applied technology items.

c) A shut-down of the PCC plant does not cause immediate stoppage of the upstream power plant.

d) A PCC plant is a maintainable system and availability may be improved if maintainability as well as reliability of each technology item is improved through feedback of operational results, etc.

This document focuses only on critical items and parameters in terms of impact of reliability/availability/maintainability. Noncritical items and noncritical parameters will not be covered.

4.2 Reliable performance

Reliable performance depends on having a PCC plant that performs as required.

Reliable performance has two aspects:

a) that the required performance is satisfied at the initial conditions;

b) that it is maintained during a defined period.

4.3 Ensuring and maintaining reliable performance

For a PCC plant to perform as required over the project cycle the following should be addressed:

a) basic concepts of availability, reliability and maintainability – refer to Clause 5;

b) guidelines for ensuring reliable performance at delivery in terms of design – refer to Clause 6;

c) guidelines for adequate monitoring and for evaluating reliable performance in terms of operation and maintenance – refer to Clause 7 and Clause 8;

d) guidelines for reporting availability – refer to Clause 9 based on Clause 6, Clause 7 and Clause 8.

4.4 Procedure outline

4.4.1 Outline of procedure flow

The evaluation procedure consists of process steps 1 to 6 crossing through actions in the related project cycle phases and the block flow diagram in Figure 2 should be referred to. Process steps 1 to 3 are categorized as normative and outlined with each reference clause. Process step 2 (Details) and 4 to 6 are categorized as informative and also outlined similarly.

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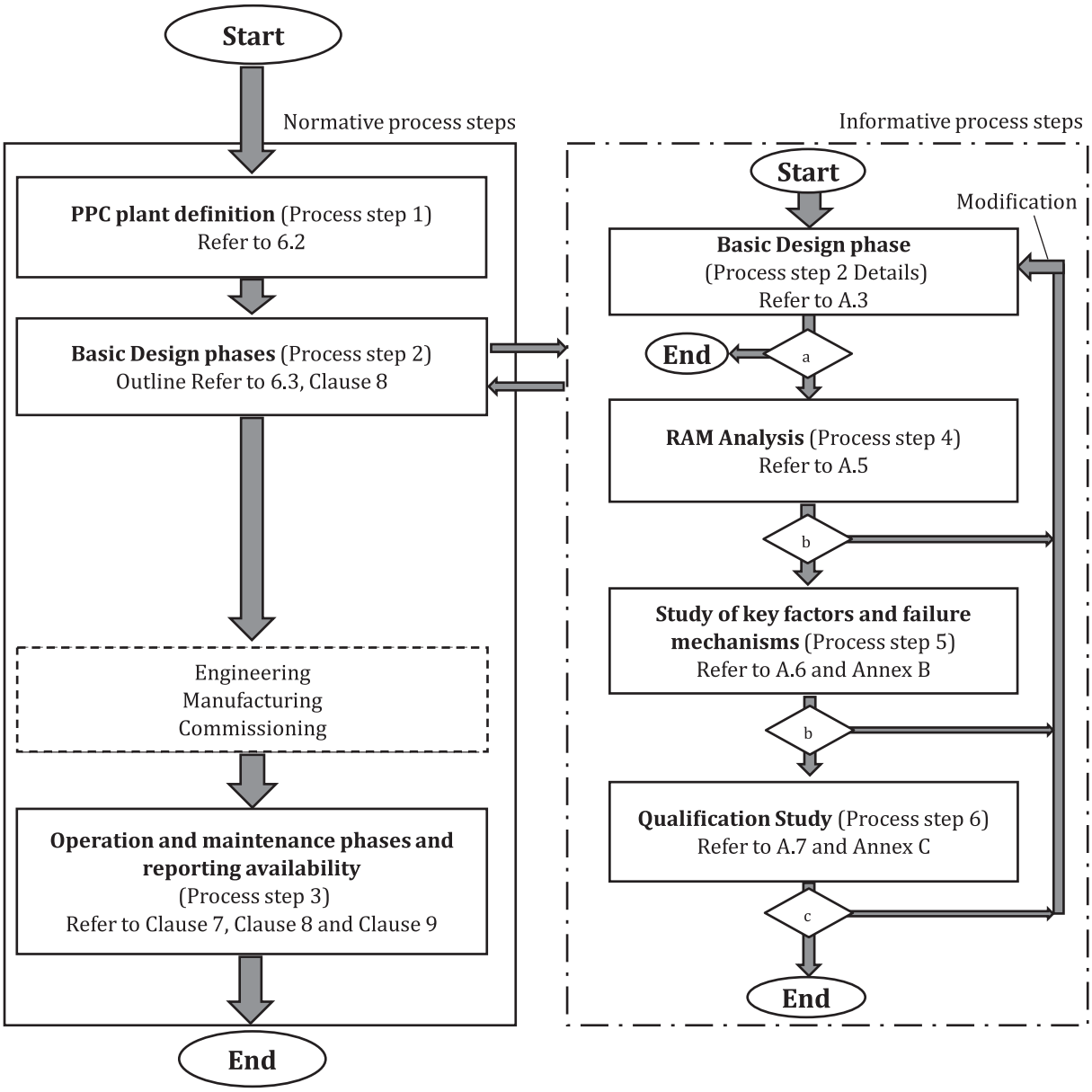

a If novel items do not exist, go to End and otherwise go down.

b If novel items become managed or can be treated in the next process step, go down and otherwise return to process step 2 (Details) for modification.

c If novel items, related to the above process steps become managed, go to End and otherwise return to process step 2 (Details) for modification including abandonment of applied design.

NOTE Novel item means novel technology items.

Figure 2 — Block flow diagram of evaluation procedure

4.4.2 Process step 1 to 3 outline — Main part

a) Process step 1 – PCC plant definition

The PCC plant definition sets the basis for the evaluation. The basic design requirement data for a PCC plant should be referred to in 6.2.

NOTE 1 These data are normally provided by the operator side except some performance values, when they are proposed by the supplier.

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b) Process step 2 – Basic design phase in the project cycle

The outline should be referred to 6.3 and details should be referred to in A.3. Applied technology shall be completely described as the basis for evaluation.

The following points should be done through previous experience and research and development results:

— review and risk management of key items and parameters; and

NOTE 2 Key items and parameters are normally provided by the supplier.

— review and risk management of operational limits to the PCC design and process.

Refer to A.3.

c) Process step 3 – Operation and maintenance phase in the project cycle

Maintenance and monitoring of the PCC process shall occur to produce the evidence of reliable performance. Refer to Clause 7, Clause 8 and Clause 9.

4.4.3 Process step 4 to 6 outline — Evaluations of items peculiar to a PCC plant with some uncertainty

a) Process step 4 –RAM analysis including definitions of the reliability for each item

The effect of reliability of each item on the overall PCC plant availability should be analysed and quantified. If the availability target is not met, the design should be improved.

b) Process step 5 – Study of key factors and failure mechanisms

The uncertainties in items caused from the gap of the related parameters between experience and the applied design remaining in process step 2 (Details) (e.g. due to items peculiar to a PCC plant) should be qualitatively evaluated from the perspective of possible risk.

In case of significant gaps between PCC experience or research and development and the design requirement for key items and parameters, a study of key factors and failure mechanisms should be conducted.

c) Process step 6 – Qualification study or reporting

Qualification study can be used to manage the risk related to novel items remaining by providing evidence to reduce uncertainties. Refer to A.7 and Annex C.

4.5 Governing principles

The following principles shall govern the evaluation procedure in the above process steps:

a) An overall plan for the evaluation process shall be prepared at the basic design phase. The plan shall include technical considerations and reporting requirements considering all the operating conditions of a PCC plant defined in Clause 7. The plan shall support the management, data collection, control and reporting of the evaluation activities as described in Clause 6 to Clause 9.

b) A basis for the evaluation (i.e. complete design requirements and descriptions of applied design in various documents and drawings depending on importance of technical items and the project situation) shall be developed as described in Clause 6 (6.2: process step 1 and 6.3: process step 2). Additional information on evaluation basis is given in ISO/TR 27912 and ISO 27919-1.

c) Relevant acceptance criteria for reliability, availability and maintainability targets for both the novel technological items, if they exist, and overall PCC plant shall be specified in process step in 6.2. Before quantitative targets are set, the approximate impact of the costs of demonstrating compliance should be considered.

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d) Screening of the PCC plant technology items shall be evaluated and screened based on analysing the experience from a reference plant or similar plant and research and development results to classify items (components, interface conditions, etc.) into proven and novel items. Novelty suggests involvement of new technical items which include new component types or changes of critical sizing parameters, or may include the case when known items have not previously been used within required limits of operation (6.3: process step 2).

For proven technology items, one may refer to engineering practices.

For novel technology items, a preliminary assessment of the reliability may be performed using available data. If there is insufficient data, the novel technology items may be replaced by proven technology items.

e) All evidence shall be reported and updated with operational experience after plant commission (typically after one year of operation) for the purpose of review or to provide feedback with tangible evidence as instructed (Clause 7, Clause 8 and Clause 9).

The required functions of the PCC plant under given conditions should be evaluated to:

1) confirm that the plant reaches its expected reliable performance (calculated at the basic design phase);

2) make potential adjustments to operation;

3) optimize maintenance activities (Clause 7, 8 and 9: process step 3).

5 Availability, reliability and maintainability - basic concepts for a PCC plant

5.1 General

This clause provides basic concepts of availability, reliability and maintainability for reporting and evaluation of reliable performance applied to a PCC plant. It comprises:

— spatial, temporal and ambient condition evaluation boundary;

— evaluation and quantification of availability;

— evaluation and quantification of reliability;

— evaluation and quantification of maintainability;

— combined aspect of availability, reliability and maintainability;

— unavailability (three categories).

The performance index considered in this clause are:

a) for availability as KPI (refer to 5.3):

— time availability (TA);

— PCC plant capacity availability (PCA);

b) for reliability (refer to 5.4):

— mission reliability (MR);

— mean time between failures (MTBF);

— time reliability (TR);

— starting reliability (SR);

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