Eskom	Guideline	Technology

Title: **Coal Fired Power Station's Common Plant Siemens S5 PLC Migration Guideline**

Unique Identifier:	**240-129144507**
Alternative Reference Number:	**N/A**
Area of Applicability:	**Engineering**
Documentation Type:	**Guideline**
Revision:	**1**
Total Pages:	**15**
Next Review Date:	**June 2023**
Disclosure Classification:	**CONTROLLED DISCLOSURE**

APPROVED FOR AUTHORISATION
TECHNOLOGY ENGINEERING
DOCUMENT CENTRE X4962

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PCM Reference: **240-56355828**

SCOT Study Committee Number/Name: **SC08-03-C00-2**

CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

A number of Eskom coal-fired power stations make use of the Siemens S5 PLC technology in the Common Plant. Although various Power Stations also employ S5 PLCs on the Power Island for Unit and Electrical Reticulation control systems, a separate document will be compiled that will address the migration and upgrade strategy of these systems. The S5 PLC was declared obsolete in 2015 by the OEM, Siemens. This has resulted in the unavailability of spares and technology support by the OEM. Power plant operations have been left at risk due to the increasing amount of S5 technology failures. The control equipment obsolescence and the subsequent production risks on the Common Plant can be mitigated in several ways and this guideline serves to provide the recommended strategy.

Two fundamentally different strategies were considered in this guideline to address the obsolescence risk. Both have their advantages and disadvantages which are tabled as part of this guideline, and the conclusion was drawn that either one could be the recommended solution, depending on the specific station scenario:

- For common plants employing S5 technology, a full DCS replacement solution is recommended, the benefits with regards to redundancy, fault tolerance, availability, Forward documentation, Management of Cybersecurity and centralisation are valuable improvements. These projects should be well planned in advance and follow the full Project Life Cycle Model from design, execution to handover.
- As mitigation against random S5 equipment failures, until a DCS solution can be implemented and executed, the S5 PLCs should be replaced with S7 PLC technology on an ad-hoc and a one to one basis. A scope of work for ad-hoc implementation should be compiled by each site to allow for fast project execution to minimize any plant availability risks. This assumes that the number of completed S5 to S7 replacements are a small percentage of the total PLC installation (<20%) on the Common Plant. Should the number of S7 replacements exceed 20%, it is recommended that the remainder of the S5 PLC installation should continue with the migration to S7 PLC and a DCS replacement project should not be initiated. However, the 20% installed base threshold is a recommendation and each project should be reviewed on a case by case scenario.
- It should be noted that an S5 to S7 migration also requires an upgrade on the current SCADA / HMI, since the S7 PLC can't communicate with the S5 Supervisory system.
- Even though the S5 IO cards and Controllers do not need to be replaced simultaneously and in one go for the Control System to function, it is recommended to replace both S5 IO cards and controllers in a single project, since both are obsolete. The execution strategy within the project may follow a phased approach with controllers replaced first and IO cards afterwards.
- It is further recommended that all C&I equipment is housed in environmentally suitable conditions as per Environmental Conditions for Process Control Equipment Used at Power Stations [3] standard.

1. INTRODUCTION

A number of Eskom coal-fired power stations employ the Siemens S5 PLC technology in the Common Plant. Although various Power Stations also employ S5 PLCs on the Power Island for Unit and Electrical Reticulation control systems, a separate document will be compiled that will address migration and upgrade strategy of these systems. The S5 PLC was declared obsolete in 2015 by the OEM, Siemens.

This has resulted in the unavailability of spares and technology support by the OEM. Power plant operations have been left at risk due to the increasing amount of S5 technology failures. The obsolescence and subsequent production risks posed by S5 controllers on the Common Plant can be mitigated in several ways which this guideline will address. A number of projects are earmarked to replace their S5 technology on the Common Plant within the Eskom fleet and this necessitated a guideline to streamline the approach and direction for replacement projects.

2. SUPPORTING CLAUSES

2.1 SCOPE

This guideline focuses only on the S5 Technology employed in the Common Plant of power stations and excludes the power islands. The recommendations and proposals made are only applicable to the Common Plant and S5 PLCs, although similar conclusions could be made with Common Plants employing obsolete PLC Technology from another OEM.

This document excludes the migration or upgrade options for the Siemens T2000 DCS which is also based on the Simatic S5 Technology.

2.1.1 Purpose

A number of S5 replacement or migration projects are currently underway or are planned to address the S5 obsolescence risks. S5 PLC Technology is installed at 6 Common Plants within the Eskom coal-fired fleet and due to the number of projects planned to be executed in parallel at various sites, it necessitated a streamlined approach and Technology direction of the replacement projects.

2.1.2 Applicability

This document applies to all Eskom coal-fired power stations that make use of S5 Technology in the Common Plant.

2.2 NORMATIVE/INFORMATIVE REFERENCES

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] ISO 9001 Quality Management Systems.

[2] 474-11242 Control and Instrumentation Group Technology Strategic report for 2017

[3] 240-56355731 Environmental Conditions for Process Control Equipment Used at Power Stations Standard

2.2.2 Informative

[4] 240-48197042 Procedure for the Management of Technology Obsolescence

2.3 DEFINITIONS

Definition	Description
Control Equipment	This is a collective term describing all the relevant control system equipment and components: e.g. DCS/ PLC, Servers, HMIs, networks and engineering/diagnostic stations etc.
Instrumentation Equipment	All associated field devices and infrastructure: e.g. Instruments, manifolds, cabling, racking, junction boxes, marshalling cubicles, etc.)
Migration	Phased process which replaces software to a new revision with the same technology and the same OEM (Control Systems). Change limited to system software components for clients, servers and processors. The continuous changes to software ensure supportability by the OEM and reduce cost on the product when an upgrade with same OEM is done. See Refurbishment, Software Components and Upgrade for related definitions.
Obsolete	No longer supported, having been replaced by something newer and better or more cost effective or profitable. Product reached the end of its useful life or end of active support from the OEM.
Obsolescence	Obsolescence is the identification and phasing out of power generation and power delivery control equipment assets, to maintain the integrity of the design base.
Refurbishment	Complete replacement of C&I HMI or C&I (Control and Instrumentation) equipment which includes changes to supporting infrastructure such as clients, servers, networks, cabinets, power supplies, cabling and software components. See Migration, Upgrade and Software Components for related definitions.
Upgrade	The replacement of hardware and software (Change limited to system hardware and/or software components such as clients and servers) based on the newest OEM technology, typically every five to six years for HMI equipment. The intent is to do minimal engineering but to carry over the intellectual property into the newer platform. See Refurbishment, Software Components and Migration for related definitions
Software Components	Software components may be a combination of Project Data, Application Software, Operating Systems and Firmware on Servers. See Refurbishment, Migration and Upgrade for related Definitions.

The terms *migration* and *upgrade* are defined in the above table. Since the change from S5 to S7 or from S5 to a DCS platform includes both hardware and software changes, the change will be referred to “S5 to S7 migration upgrade project” or only “migration” going forward in the document.

2.3.1 Disclosure Classification

Controlled Disclosure: Controlled Disclosure to external parties (either enforced by law, or discretionary).

2.4 ABBREVIATIONS

Abbreviation	Description
C&I	Control and Instrumentation
CoE	Centre of Excellence
CP	Communication Processor
CPU	Central Processing Unit
DCS	Distributed Control System
Gx	Generation
HMI	Human Machine Interface
HVAC	Heating Ventilation Air Conditioning
IO	Input / Output
IP	Intellectual Property
OEM	Original Equipment Manufacturer
PEI	Production Engineering Integration
PLC	Programmable Logic Controller
LPS	Low Pressure Services
SCADA	Supervisory Control And Data Acquisition
WTP	Water Treatment Plant

2.5 ROLES AND RESPONSIBILITIES

C&I CoE: Responsible to determine the technology requirements for the replacement of control systems. The C&I CoE is responsible, and maintains standards and guidelines relating to control systems in Gx. The CoE is further responsible for the development of the Gx control system standards, guidelines, designs, technologies, concepts and specifications, control system strategies for control system migrations, upgrades and refurbishments projects. These responsibilities are applicable during the design, engineering, commissioning and the de-commissioning phases. The CoE provides design assurance throughout the project life cycle model for C&I projects.

PEI C&I: Responsible for the fleet-wide technology strategy and recommendations in support of implementation in the life cycle plans.

Power Station C&I: Responsible to compile the project work request related to obsolete systems.

2.6 PROCESS FOR MONITORING

The document shall be updated in accordance with the Eskom document review process or as business needs change.

2.7 RELATED/SUPPORTING DOCUMENTS

Refer to Normative (2.2.1) and Informative (2.2.2) sections in this document.

3. S5 PLC TECHNOLOGY IN CONTEXT AND REPLACEMENT STRATEGY

3.1 S5 PLC TECHNOLOGY INSTALLED BASE

The S5 PLC technology is installed at numerous coal-fired common plants in the Eskom fleet.

3.1.1 Installed Based for the S5 PLC in the Common Plants

According to [2] the S5 Siemens PLC is installed at the following coal-fired power stations Common plant areas:

Table 1: S5 Installed Base

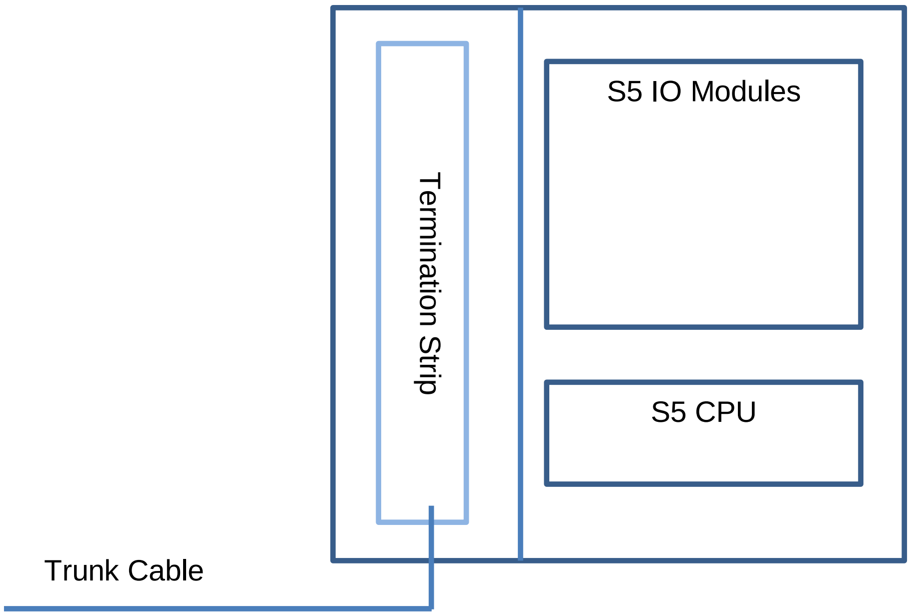
No	Power Station	Plant Area on Common Plant
1	Duvha	LPS
2	Hendrina	Fuel Oil, Other Common Plant areas
3	Kendal	Common Plant
4	Kriel	WTP, Ash Plant
5	Matla	WTP, Ash & Slurry Plant
6	Tutuka	WTP

Some of the above stations in Table 1 have already initiated or are in the early design stages to execute projects to address the S5 PLC obsolescence risks.

3.1.2 S5 PLC Technology Architecture

The S5 hardware comprises of IO Card Modules, CPUs, Memory Modules and Communication Processors. Only the main components of IO modules and CPUs, as illustrated in Figure 1 below, will be referred to going forward in this document, but their referral is encompassing the other S5 auxiliary equipment such as Memory and CP modules:

Figure 1: S5 PLC Technology and Equipment



Both the IO Card modules and controllers are obsolete. It should be noted that different models of S5 equipment is used at various stations. Models typically found in the Eskom fleet include the S5 100U, 115U, 130A, 135U and 150A controllers. The various models cannot be used interchangeably as they have different capabilities and functionalities in terms of:

- Functional Capabilities (Binary logic operations, comparison, arithmetic, digital and closed-loop functions)
- Application (Open-loop, closed-loop, arithmetic & comparison functions)
- Memory capacity and memory Types (EPROM and RAM)
- Cycle times (200-5ms)
- Expansion capabilities for Digital & Analog inputs and outputs (128 to 1024 IOs)
- Interface options to networks (computer, typewriter, VDU etc.)
- Programming methods (linear or structured)
- Power Supply compatibility (PU610, 630, 670 and 690)
- Data link lengths limits (3 to 1000m)
- Program input and outputs

In addition to having different capabilities, the various S5 models were released with different firmware versions over time, complicating the interoperability and changeability of controllers further, even if they are of the same model range.

3.1.3 S5 PLC Obsolescence Risks, Controls & Mitigation

Power Stations employing S5 PLC technology in their common plants are at risk due to the OEM having discontinued the production and support of the product. The current worsening environmental conditions at many substations and equipment rooms, which house the S5 PLCs, are contributing to accelerated electronics failure and performance. The following controls or mitigations and are practiced at most sites to extent or prolong the life of the S5 PLCs:

Table 2: Risk Control and Effectiveness

No	Mitigation & Controls	Control Effectiveness
1	Repairing of failed electronic modules	This is a highly specialised field and only limited service providers are available. Many failures are also beyond repair and limited warranty on workmanship is provided.
2	Cleaning of existing S5 modules	Running/working PLCs and S5 module are cleaned by vacuuming the dust from the equipment directly. Blowing is to be avoided as this lodges dust into the equipment slots and contributes to further degradation of performance. Adequate care should be taken to limit the effects of static electricity on the sensitive electronic equipment while cleaning of the modules. As a last resort only, running/working PLCs and S5 modules are sent away to undergo a specialised cleaning process. This should only be limited to IO cards and not CPU or CP

		modules, due to the increased level of component sensitivity of the insert and removal process. Any activity on the S5 CPU and memory modules should generally be limited to fault finding only. Cleaned modules are then swopped out and a next batch of dust-contaminated modules are sent away for cleaning. The rotation of modules is done continuously until the process is exhausted. This mitigation has proven to achieve a degree of success on the Common Plant control system at Kendal Power Station.
3	Sourcing S5 modules from already refurbished plants or units and also from the Eskom fleet	A number of S5 replacement or upgrade projects are currently in progress across the Eskom fleet and potential spares are released and made available. However, in general, the condition of the S5 electronics is poor which is limiting the benefits of this mitigation. Age (up to 3 decades old) and operating in an unfavourable and non-conducive environment (high dust and temperature exposure) leaves this mitigation option as a temporary solution only. Due to different capabilities and firmware versions of S5 models, it is to be noted that different models of S5 equipment cannot be used interchangeably as spare equipment, refer to Section 3.1.2 S5 modules earmarked for further use at other stations require specialised storage and transport environmental conditions to limit further exposure to damage of the S5 modules as described in [3]. All replaced electronic equipment that is to be retained for re-use will need to be cleaned, vacuum packed and stored in a suitable location.
4	Improving the environmental condition of equipment rooms	Some stations have initiated HVAC refurbishment projects to improve the environmental conditions that house the S5 equipment and modules, although in most cases this has come too late. Exposure to high temperature and high amounts of dust has left the S5 electronics with irreversible damage. Providing adequate [3] HVAC to the S5 housed equipment rooms will extend the lifespan of the S5 modules on a short-term basis only.

Although the obsolescence control measures and mitigation efforts have been effective to some degree, and definitely prolonged failures, the S5 PLCs need to be replaced. Upgrade and migration projects need to be executed as high priority projects, in order to mitigate the plant availability and reliability risks of the Eskom fleet.

3.2 S5 REPLACEMENT STRATEGY

The replacement of the S5 Technology on the Common Plant can follow several technical strategies, each with their own advantages and disadvantages. The following strategies are considered for replacement projects on the Common Plant:

3.2.1.1 One on One S5 with S7 PLC replacement

This strategy involves replacement of the existing S5 Control system components (PLC and IO modules) with newer S7 based equipment, including PLC and IO modules, on a one to one basis. This strategy has the following advantages and disadvantages:

Table 3: Advantages and Disadvantages of a One on One S5 with S7 PLC replacement strategy

No	Advantages	Disadvantages
1	Relatively short engineering time, existing S5 logics are converted to S7 logics using OEM procedures or via a specialised intermediate module or controller that can run both S5 and S7 logics at the same time. If the S5 program does not have programing comments or plant operating and control philosophies are not available, the engineering time is considerably increased and this advantage lost. This became evident on the Kriel S5 to S7 upgrade project, where programs without comments and/or systems without detailed philosophies took much longer to verify and complete. The upgrade from the S5 to S7 platforms has been completed successfully at Kriel Power Station (during 2017-2018). The code conversion process itself from S5 to S7 was completed without major challenges.	Some S5 installations on the Common Plant are configured redundantly, but the majority is not. Therefore a S5 to S7 migration, in most cases, remains a simplistic solution, with no improvement in terms of redundancy and fault tolerance.
2	Existing cabinets can be re-used if space allows for it.	Cyber Security advances are not realised. DCS technology is at the forefront of Cyber Security research, implementation and certification.
3	Implementation can be done by OEM and numerous system integrators that are available locally. Care should be taken regarding OEM IP when submitting S5 programs or documentation to an open market or as part of an enquiry. Should a contract be placed with a non-OEM supplier or system integrator, legal terms and conditions should be included as part of the contract, specifying the non-disclosure and limitations, as applicable, of the OEM IP.	

4	Most Eskom sites employ S7 technology already. In these installations, the S7 platform is well known by engineering, operating and maintenance staff. The training period can be reduced considerable or totally omitted depending on specific site capability.	
5	Most sites have done a S5 to S7 migration already, the process and procedure is understood and the engineering and maintenance staff gained valuable experience. The risks in terms of timelines and technicalities of a migration have been experienced.	
6	S5 to S7 replacement projects can be done on a plant by plant basis. This has the benefit of smaller projects that can be implemented at a given time with lower budgets and a reduced project and contracts management effort.	

3.2.1.2 S5 PLCs with DCS replacement (T3000 or other OEM)

This strategy involves replacement of the existing S5 Control system components (PLC and IO modules) with a DCS solution. The DCS solution can either be from the same OEM as the S5 (i.e. migrating to the Siemens T3000 platform) or from another OEM. This strategy has the following advantages and disadvantages:

Table 4: Advantages and Disadvantages of a S5 with DCS replacement strategy

No	Advantages	Disadvantages
1	Existing cabinets can be re-used if space allows for it. In such a case the cabinet backplane is replaced with a DCS installation and the cable terminations remain intact.	Implementation can usually only be done by the DCS OEM. This limits competition and the OEM may charge higher rates for support and maintenance after project execution.
2	Latest DCS advances, benefits and systems are available, such as: Large scale distributed control, central engineering, forward documentation, network management, back-up automation, user management and integrated Cybersecurity management system. Cyber security advances include Secure remote access, malware protection, network hardening, account management, security patch management and network intrusion detection. From a hardware perspective, DCS equipment has more of security features which makes it more resistant and hardened to cyber threats.	Some sites may not be familiar with the DCS technology and this will require extensive training for operating, engineering and maintenance departments. The DCS control system solution complexity is much higher than a simplex PLC solution.
3	Cyber Security advances are realised. DCS technology it at the forefront of Cyber Security research, implementation and certification.	Engineering time is typically longer and benefits are realised only if the DCS is implemented on multiple plant areas. Single

	Secure OEM "hot-line" benefits are available to DCS solutions to allow easier patch management, compared to PLC configurations that make use of a modem connection, which is a far greater risk to cyber threats.	plant subsystem upgrades are not recommended. This requires larger Capex budgets to implement since most / entire plant is replaced within one project, resulting in complex project and contracts management.
4	The process control can be reviewed to optimise redundancy and fault tolerance. Typically a redundant set of CPUs are used per Automation Server instead of a simplistic solution of the S5 to S7 PLC upgrade. A simplistic solution on the Common Plant may be adequate for some plant areas but in general a redundant solution is preferred.	
5	Recent Tenders received for DCS replacement versus PLC upgrades with similar scope and requirements have indicated that the costs for DCS solutions have reduced significantly in recent time, and they compare competitively with PLC based solutions.	

3.2.1.3 Planning for migration or replacement

The current common plant sites that make use of S5 Technology should ensure the current plant design baselines are available to ensure streamlined engineering by the OEMs and Contractors. As a minimum, the following should form part of the baseline documentation:

- Loop wiring diagrams
- Cable Schedules & Termination details
- S5 Logics and process plant operating and control philosophy
- Cubicles layout drawings
- Network diagrams
- Control System Architecture

Extended outage periods on the Common Plant systems (Ash, Coal, Water Treatment and LPS) are typically not available. As a result, detailed and meticulous planning is required by both the Contractor and Eskom, involving all stakeholders:

- Engineering (Process and C&I), from CoE, PEI and Site
- Maintenance
- Operating
- Production
- Contractor

In order to minimize any possible impacts on plant production, due to unforeseen migration problems, a phased approach is recommended. This entails dividing the common plant into functional areas and allows sectional and phased completion. Any changes to the field (instrumentation, final control element) or philosophy optimization should only be done once the IO and Controllers have been replaced.

This is done in order to minimize the effort required, should a plant's control system need to be returned to the previous configuration on S5 technology, due to problems on the new platform. Restrictions on execution timelines (plant shutdown periods) will need to be defined by process engineering together with the site operating and production department, prior to Contract award, and confirmed prior to detailed execution planning.

The upgrade project execution plan by the Contractor must define the detailed steps planned to be undertaken in the migration or replacement process. The execution and change-over plan must be adequately detailed and compliment the already submitted concept change-over plan (submitted by the Contractor earlier in the Contract's execution) to also highlight any upfront engineering work that needs to take place, prior to the change-over.

Lessons learnt from Tutuka indicate that smaller plant portions should be changed-over at a time, limiting the required down-time of the various process plants. It is important to realise that changes to the existing S5 programs and logics are expected in a migration project. This is to allow for adequate process interlocking of various process plants running on both the S5 and newly installed equipment.

The execution plan must include a recovery strategy and plan, should the change-over process not go according to plan, taking the allowed time restrictions into account for the applicable plant area. If the recovery plan does not go according to plan, an operational intervention may be required, even running the process plant on manual. It must be noted however, that this should be documented in the recovery plan and a detailed risk assessment is to be undertaken prior to acceptance of such a plan or strategy. Manual operating of complex process plant should be avoided (WTP) but may be considered for simpler process control areas (Coal plant).

3.2.1.4 Process Control Improvements and Operational Considerations

The opportunity to improve the process control presents itself with the migration or replacement project. It is however recommended to only incorporate new philosophies and optimization after the migration to a new technology has been undertaken and not within one go. Reason being, that a recovery plan will be easier to compile and execute, and fall-back to the old technology greatly simplified should the migration experience any problems.

Process control improvements and optimization should therefore also follow phased approach as the main objective for migration is obsolescence and not plant improvements, although the opportunity does exists.

Training for engineering, operating and maintenance staff needs to be included as part of the Contractor's scope if the platform does not exist at the station already. Correct scheduling of training is vital for a smooth plant take-over, and training should not only be done once the execution has been completed. All departments, including engineering, operating and maintenance, should be part of the upgrade project processes, already from project initiation.

3.2.1.5 Recommended Strategy

Based on findings in section 3.1.4.2 and 3.1.4.3, the following recommendation is made for S5 PLC replacement on Common plants:

- For common plants employing S5 technology, a full DCS replacement solution is recommended, the benefits with regards to redundancy, availability, fault tolerance, Cybersecurity management, Forward documentation and centralisation are valuable improvements. These projects should be well planned in advance and follow the full Project Life Cycle Model from design, execution to handover.

- As mitigation against random S5 equipment failures, until a DCS solution can be implemented and executed, the S5 PLCs should be replaced with S7 PLC technology on an ad-hoc and a one to one basis. A scope of work for ad-hoc implementation should be compiled by each site to allow for fast project execution to minimize any plant availability risks. This assumes that the number of completed S5 to S7 replacements are a small percentage of the total PLC installation (<20%) on the Common Plant. Should the number of S7 replacements exceed 20%, the remainder of the S5 PLC installation should continue with the migration to S7 and a DCS replacement project should not be initiated. However, the 20% installed base threshold is a recommendation and each project should be reviewed on a case by case scenario.
- It should be noted that an S5 to S7 migration also requires an upgrade on the current SCADA / HMI, since the S7 PLC can't communicate with the S5 Supervisory system.
- Even though the S5 IO cards and Controllers do not need to be replaced simultaneously and in one go for the Control System to function, it is recommended to replace both S5 IO cards and controllers in a single project, since both are obsolete. The execution strategy within the project may follow a phased approach with controllers replaced first and IO cards afterwards.
- It is recommended that all C&I equipment is housed in environmentally suitable conditions as per Environmental Conditions for Process Control Equipment Used at Power Stations Standard [3].

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5. REVISIONS

Date	Rev.	Compiler	Remarks
May 2018	0.1	CW Kohlmeyer	First Draft Document for SC Review
June 2018	0.2	CW Kohlmeyer	Final Draft After SC Review Process
June 2018	1	CW Kohlmeyer	Final Document for Authorisation and Publication

6. DEVELOPMENT TEAM

The following people were involved in the development of this document:

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7. ACKNOWLEDGEMENTS

- None