Regain Services Pty Ltd

Capacity Increase at Tomago Spent Potlining Facility Hazard and Operability Study (HAZOP) Report 40,000 tpa Capacity Thermal Treatment Plant

DATE: 17 JANUARY 2020

REGAIN DOC NO.: 246R005

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DOCUMENT REVISION STATUS			
REV	**DESCRIPTION**	**AUTHOR**	**DATE**
A	Issued to Client for Review	M Wallace	9 Dec 2019
0	Issued for Use	M Wallace	17 Jan 2020

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ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
AS	Australian Standard
BMS	Burner Management System
BV	Bureau Veritas
CH_4	Methane
FS	Flow Switch
FT	Flow Transmitter
H_2	Hydrogen
Hazop	Hazard and Operability (Study)
LS	Level Switch
LT	Level Transmitter
P&ID	Piping and Instrumentation Diagram
PM	Preventative Maintenance
PT	Pressure Transmitter
Regain	Regain Services Pty Ltd
SPL	Spent Pot Liner
TIC	Temperature Indicating Controller
tpa	tonnes per annum
TT	Temperature Transmitter
TTP	Thermal Treatment Plant
TTP2	Stage 2 Thermal Treatment Plant

1 INTRODUCTION

1.1 Background

Regain Services Pty Ltd (Regain) is currently in the design phase of its second Thermal Treatment Plant (TTP2) at the Tomago Aluminium Smelter Spent Potlining (SPL) facility in New South Wales. The new TTP2 is in addition at the existing TTP in operation at the Tomago facility.

An Environmental Assessment which included a gap analysis of a previously performed Preliminary Hazard Analysis was submitted prior to the Project Approval: MP 06_0050 MOD 2 – Increase the processing capacity of SPL from 20,000 tonnes per year to 60,000 tonnes per year and the installation and operation of an additional thermal treatment plant (MOD 2). The consent conditions for MOD 2 required that the following study reports be submitted for approval:

- Hazard and Operability Study;
- Construction Safety Study;
- Emergency Plan; and
- Safety Management System documentation.

Bureau Veritas (BV) has been requested by Regain to facilitate and document a hazard an operability study (Hazop) based on the current design.

This report details the methodology, workshop attendance, findings and recommendations of the Hazop based on the current design of TTP2.

1.2 Description of the Facility

The main plant items of the facility are a rotary kiln and hydrolysis reactor with associated gas handling, dust filtration and materials handling equipment.

The process function of the TTP2 is to eliminate hazards in SPL being cyanide and the propensity of certain constituents of SPL to react with water and generate flammable gases. Crushed SPL is fed to the rotary kiln where it is heated to nominally 600 degrees Celsius to destroy cyanide. The kiln is heated with a natural gas burner system. The temperature of the material in the kiln is controlled with a temperature indicator and controller (TIC).

The heated SPL discharges from the rotary kiln to the hydrolysis reactor where the SPL is mixed with water. The water reacts with the SPL producing reaction gases of ammonia, hydrogen and methane. The hydrolysis reaction gas are immediately transferred to the rotary kiln burning zone where the hydrogen and methane are burned with the natural gas fuel in the kiln. A portion of the water is converted to steam as it cools the SPL to a safe temperature prior to discharge from the reactor. The steam is also transferred to the rotary kiln. The reactor operates near atmospheric pressure.

Gases of combustion and steam are drawn through the rotary kiln through a baghouse dust filtration and collection system by an induced draft fan. The temperature of the material in the baghouse is controlled with a temperature indicator and controller TIC that is linked through the plant control system to the tempering air inlet damper valve.

1.3 Scope

The scope of the Hazop was the first stage of the capacity expansion being the second thermal treatment plant, TTP2. The basis of the Hazop was the P&ID [1] for TTP2 (by Regain Services Pty Ltd). The scope of the Hazop included:

- Feed via conveyor and elevator to TTP2;
- TTP2 Main Gas and Combustion Air;
- TTP2 Kiln and Reactor including induced draft fan; and
- TTP2 treated material to stockpile and interface with the existing TTP.

Attachment 1 presents the Hazop node list, which describes in detail the Hazop basis for each system examined.

Other than the interface between the two plants and consideration of isolation of the plants separately, examination of the existing TTP was excluded from the scope of this Hazop. The existing TTP was the subject of a separate previous Hazop.

1.4 Objectives

The objectives of the Hazop were to:

- identify potential hazards associated with the proposed design; and
- identify potential operability issues that may result in other risk issues, including the potential to lead to process safety hazards.
- make recommendations to improve the design and/or operability of the plant, and to minimise the risk to personnel, assets and the environment to as low as reasonably practicable (ALARP).

2 STUDY TEAM

The Hazop was conducted on the 28 - 29 November 2019 at the Regain offices in Port Melbourne. Table 2.1 presents the study team attendance record. Attachment 2 provides a copy of the signed attendance sheet.

Table 2.1 Study Team Attendance Record

Name	Title	Company
Michelle Woolnough	Combustion Engineer	Intelligent Energy Services
Andrew Dinning	Mechanical Engineer	Dinning Engineering
Andrew Bongetti	Electrical Engineer	ElecEng Consulting
Peter Laing	Electrical Engineer	Electrique
Roy Elliott	Operations Manager	Regain
Bernie Cooper	Director	Regain
John Cooper	Operations Support	Regain
Matthew Wallace	Facilitator	Bureau Veritas

3 WORKSHOP DELIVERY

3.1 Hazop Methodology

Effective risk management requires a systematic approach to identify hazards and eliminate or minimise the risks associated with these hazards. Hazop is a systematic means of hazard identification and assessment to verify a process design. A Hazop study is generally conducted during the conceptual and detailed design phases of projects. It is also a technique used on existing plant facilities to improve the safety and operability of the plant.

The Hazop followed the approach outlined in Figure 3.1. The Hazop nodes were determined by BV prior to the Hazop workshop during a review of the Piping and Instrumentation Diagram (PID) – Regain drawing number 246TD002 Revision H [1]. Additional nodes were identified during the workshop as required. Each node was assessed in detail by systematically considering deviations from normal operating conditions to identify hazard and operability issues. Causes, consequences, safeguards and any actions/recommendations were identified and recorded for each deviation.

The deviations used for the nodes are listed in Table 3.1. The nodes are summarised in Attachment 1.

Figure 3.1 Hazop Technique

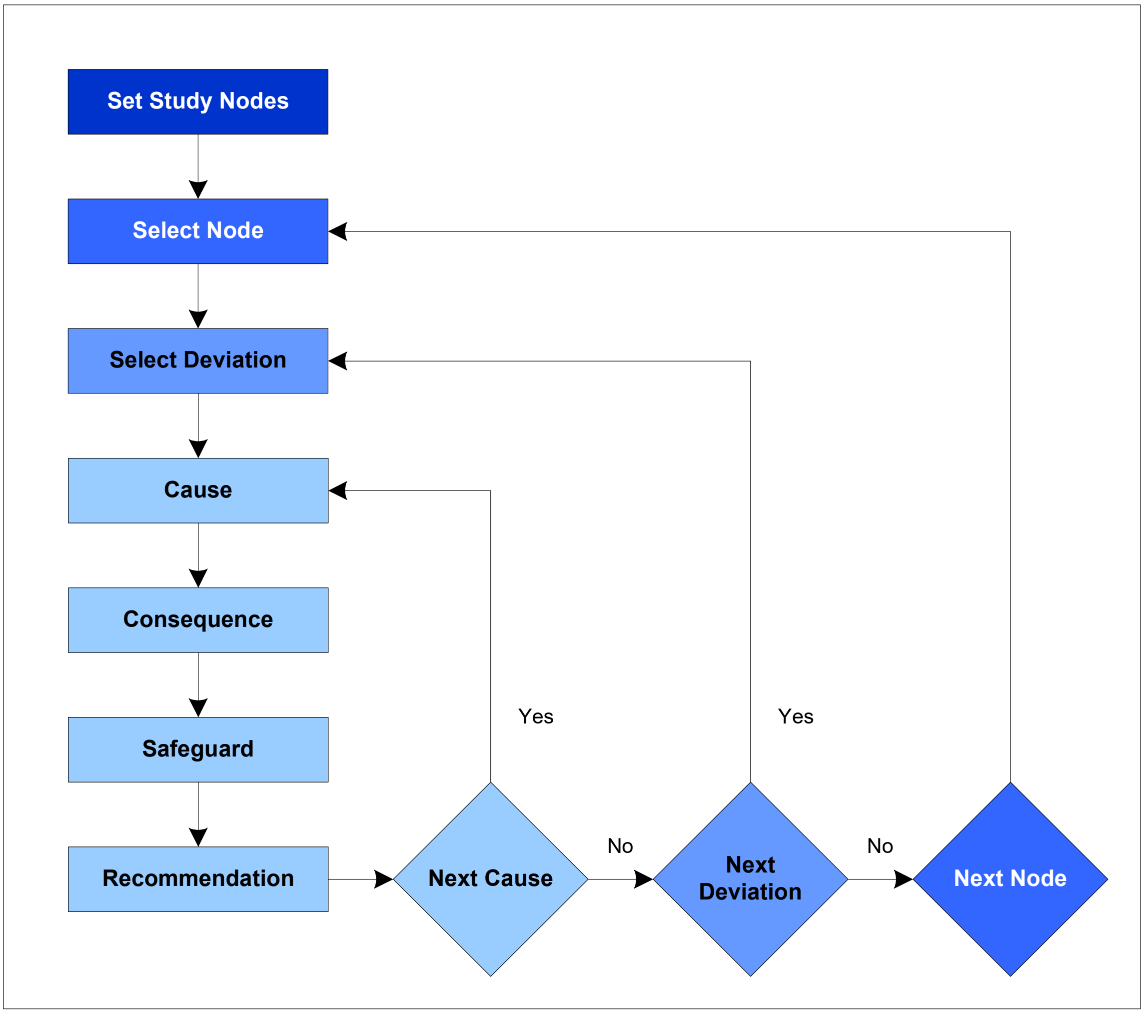


Table 3.1 Hazop Node Deviations Used in the Workshop

Deviation	Guideword	Parameter
Low / No Flow	Low	Flow
High Flow	High	Flow
Reverse Flow	Reverse	Flow
"As well as" Flow	Additional	Flow
Too Early / Too Late	Early	Timing
High Level	High	Level
Low Level	Low	Level
High Pressure	High	Pressure
Low Pressure	Low	Pressure
High Temperature	High	Temperature
Low Temperature	Low	Temperature
Impurities / Composition (concentration)	Other than	Composition
Instrumentation / Control	Suitability	Control
Plant Items	Operability	Operability / Maintainability

4 FINDINGS AND RECOMMENDATIONS

The Hazop proceedings were documented using the process hazards analysis (PHA) software PHA Pro [2] and the Hazop worksheets were projected onto a screen for the workshop team to view and agree. A complete record of the HAZOP minutes is included in Attachment 3.

There were 67 recommendations developed and agreed during the Hazop Study. A detailed listing of the Hazop recommendations (including Hazop minute references) is included in Attachment 4. Key items identified included:

- Opportunities to reduce the likelihood of the occurrence of geopolymerisation in the feed bin (Attachment 4, recommendations 3-8);
- The potential for an emergency shutdown situation that requires provision of a high level switch in the reactor feed chute (recommendation 29);
- Safety-in-design sufficiently addresses the loss of reactor water scenario (recommendation 36);
- Assess requirement and location for a pressure transmitter in reactor exhaust line to the kiln for the purpose of controlling static pressure in the kiln (recommendation 41); and
- Verification that the reactor "Always open flammable gas vent" is sized sufficiently to achieve required suction pressures (recommendation 60).

Responsibility for actioning of recommendations is to be assigned and confirmation of action close-out will be managed by the relevant Regain Project Manager.

All of the recommendations will be implemented. The program for implementation of the recommendations is included in Attachment 4 and it shows:

- 26 recommendations implemented prior to completion on design scheduled at end February, 2020;
- 23 recommendations implemented in the plant control system scheduled for completion during March, 2020;
- 12 recommendations implemented during construction scheduled for completion in April, 2020;
- Three recommendations implemented during commissioning which is scheduled for completion by end May, 2020; and
- Three recommendations implemented within three months of completion of commissioning.

5 REFERENCES

[1] 'Tomago Aluminium – SPL Processing Facility – Thermal Treatment Plant No. 2 P&ID', Regain Services Pty Ltd, 246TD002, Revision H, 26 November 2019

[2] 'PHA Pro Software', Dyadem, Version 8.

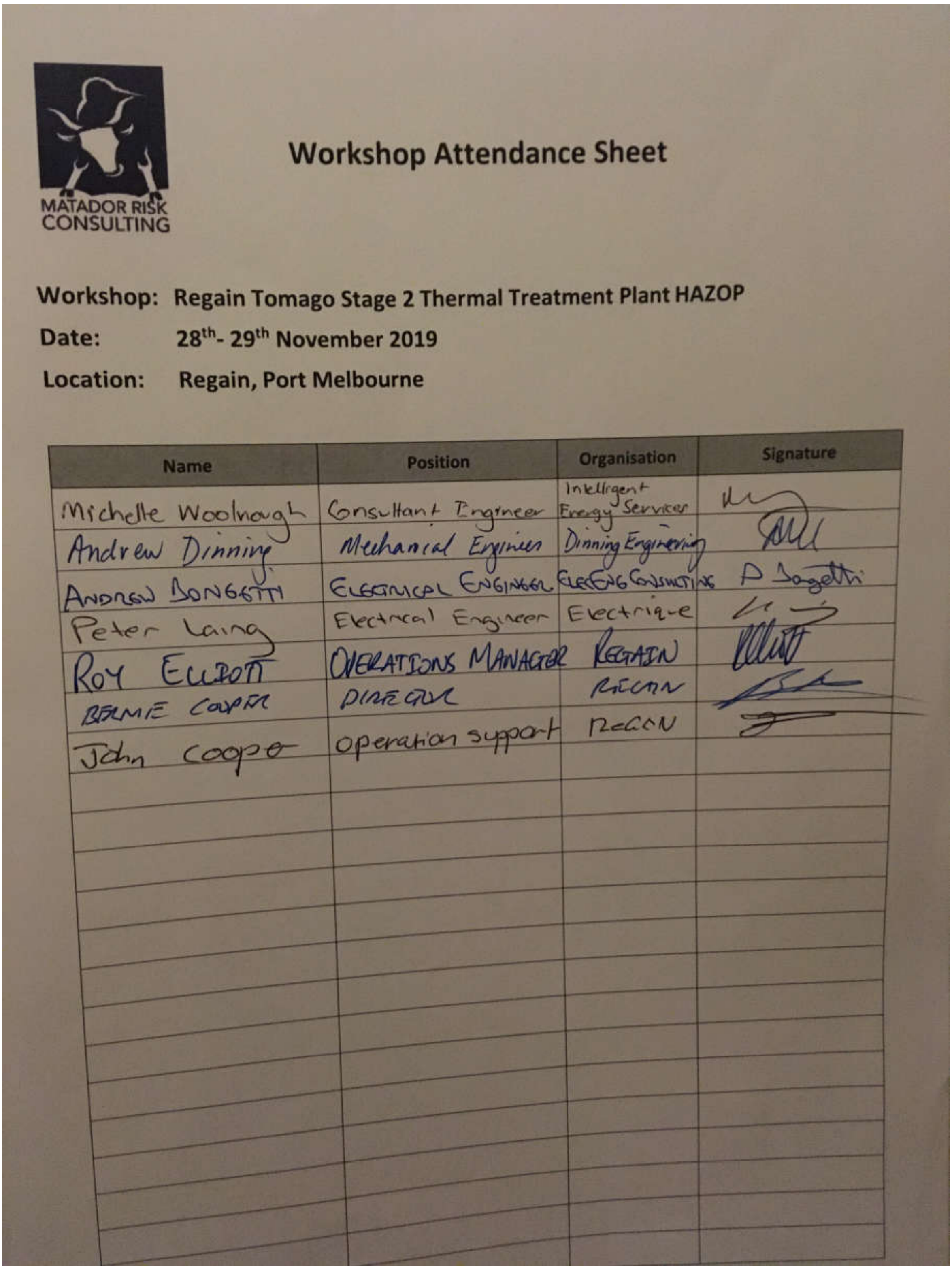
[3] *NSW Government Department of Planning, Industry and Environment Hazardous Industry Planning Advisory Paper No 8 HAZOP Guidelines*

ATTACHMENTS

Attachment 1
Summary of Nodes

Nodes	Design Conditions/Parameters	Drawing No.
1. TTP2 Feed	Feed via conveyor to TTP2. Design flowrate 4-7 tph ambient conditions Feed size nominal less than 10mm particle size. Feed bin, TTP2 feeder, transfer conveyor, feed elevator	246TD002
2. TTP2 Main Gas and Combustion Air	Natural gas supply and combustion air to TTP2. Natural gas regulated down from 100kPa to 10kPa for feed to burner, modulated through TIC Discharge pressure from combustion air fan, downstream of damper 1.5 kPa Difference between this system and existing Tomago (120 plant) is removal of excess air control valve and modulation of gas via TIC (combustion air flow constant)	246TD002
3. TTP2 Kiln and Reactor including induced draft fan	TTP2 Kiln and Reactor. Crushed product enters kiln via kiln feed chute from the feed elevator. Kiln operates at 600 degC which removes cyanide, transferred to reactor via kiln discharge chute. Kiln residence time of 20 minutes. Reactor operating conditions - flowrate of 4-7 tph. Addition of water, mixing via agitator - produces steam, hydrogen and methane which is extracted by the reactor exhaust fan and passed back through the kiln. Operates under a slight negative pressure via reactor exhaust fan. Induced draft fan collects exhaust gases and dust. Incorporates dust collector baghouse and cooling air inlet damper.	246TD002
4. TTP2 treated material to stockpile	Thermally treated material to stockpile Three chain conveyors in series. The second conveyor is where the 120 and 246 systems come together. Downstream combined capacity is 10 tph.	246TD002

Attachment 2
Study Team Attendance Sheet



MATADOR RISK CONSULTING

Workshop Attendance Sheet

Workshop: Regain Tomago Stage 2 Thermal Treatment Plant HAZOP

Date: 28th- 29th November 2019

Location: Regain, Port Melbourne

Name	Position	Organisation	Signature
Michelle Woolnough	Consultant Engineer	Intelligent Energy Services	
Andrew Dinning	Mechanical Engineer	Dinning Engineering	
ANDREW BONGETTI	ELECTRICAL ENGINEER	ELECENG CONSULTING	A Bongetti
Peter Laing	Electrical Engineer	Electrique	
ROY ELLIOTT	OPERATIONS MANAGER	REGAIN	
BERNIE COOPER	DIRECTOR	REGAIN	
John Cooper	operation support	REGAIN	

Attachment 3
Hazop Worksheets

Node: 1. TTP2 Feed

Deviation	Causes	Consequences	Safeguards	Recommendations	General Comments
1. Low / No Flow	1. Empty bin	1. Conveyors run empty, waste gas and water overflow from reactor	1. Feed bin LT	1. Configure a low level alarm off the feed bin LT	
			2. Feed bin LSL	2. Configure feed bin LSL to interlock with downstream plant to allow time for transfer and processing of material in train	
	2. Blockage (bridging in bin; solidification)	1. Conveyors run empty, waste gas and water overflow from reactor	1. Feed bin LT	3. Configure a high level alarm off the feed bin LT	Solidification of material occurs due to geopolymerisation in the feed bin
		2. Potential to overfill the feed bin leading to jamming of crushed product transfer conveyor	2. Upstream LSH (mounted on feed bin but part of upstream system)	4. Configure feed bin LSH to interlock with the upstream plant (sequence stop and run-out)	
		3. Safety impact to operators required to clear the blockage (involves cutting the bin, use of a jack-hammer, exposure to stored energy / engulfment risk, toxic dust exposure)	3. First and second cut pre-blend	5. Further investigate options to reduce the likelihood of geopolymerisation in the feed bin (e.g. forward/reverse feeder)	
			4. Feed bin vibration	6. Develop process sequencing to purge feed bin	
				7. Install temperature monitoring in the feed bin to detect geopolymerisation.	
				8. Provide a low flow switch on TTP2 feeder.	
	3. Conveyor breakdown	1. Conveyors run empty, waste gas and water overflow from reactor	1. Conveyor underspeed switch		
		2. Potential to overfill the feed bin leading to jamming of crushed product transfer conveyor	2. Drive fault alarms		
		3. Safety impact to operators required to clear the blockage (involves cutting the bin, use of a jack-hammer, exposure to stored energy / engulfment risk, toxic dust exposure)			
	4. Bucket elevator breakdown	1. Build-up of material at boot leading to overload of the elevator	1. Elevator underspeed switch	9. Ensure that the underspeed software performs self-check on start-up or stop	
			2. Elevator Boot LSH	10. Develop a PM for all level switches	
2. High Flow	1. Belt overspeed	1. Downstream conveyor or bucket elevator blockage	1. Belt speed set-point limiting		
		2. Failure to destroy cyanide requiring reprocessing	2. Batch testing of cyanide levels		
			3. Conveyor overload protection (shear pin for VSD; circuit breaker for DOL)		

Node: 1. TTP2 Feed

Deviation	Causes	Consequences	Safeguards	Recommendations	General Comments
			4. Elevator Boot LSH		
3. Reverse Flow	1. Manual intervention on VSD only	1. Feeder in reverse resulting in emptying feed bin on to floor, loss of production	1. Unable to run in reverse in auto-mode 2. Conveyor overload protection (shear pin for VSD; circuit breaker for DOL)	8. Provide a low flow switch on TTP2 feeder.	
4. “As well as” Flow	1. Sodium ring in kiln	1. Additional material in bucket elevator leading to overload	1. Conveyor overload protection (circuit breaker for DOL)	11. Update P&ID 246TD002 to correctly indicate the destination of the drop-out chute from the kiln to the TTP2 feed transfer conveyor and label accordingly	
		2. Potential to melt the bucket elevator belt	2. Elevator Boot LSH	12. Provide a thermocouple at the feed end of the kiln and alarm on high temperature	
			3. Direct drop-out chute to upstream point (allow sufficient cooling)	13. Ensure DOL circuit breakers are provided with remote reset capability	
			4. Kiln scraper		
5. Too Early / Too Late	1. Feed to kiln before kiln has reached temperature	1. Out of spec product	1. Process sequence control 2. Batch testing of product 3. Dilution of batches		
6. High Level	1. Kiln feed chute blockage	1. Build-up of material in kiln feed chute leading to elevator overload	1. Feed chute LSH 2. Conveyor overload protection (circuit breaker for DOL) 3. Elevator Boot LSH		
7. Low Level	1. No new issues				
8. High Pressure	1. No issues				
9. Low Pressure	1. No issues				
10. High Temperature	1. Drop-out chute return to transfer conveyor	1. Potential operator exposure to hot material and surfaces		14. Provide two high level switches in the kiln drop-out chute to detect blockages (one below and one at top)	
11. Low Temperature	1. No issues				
12. Impurities / Composition (concentration)	1. Oversize material	1. Leads to operability issues with kiln and material handling and out of spec product	1. Upstream screening 2. Batch testing of product	15. Review technology for upstream screening of material	
	2. Entrained metal / other debris	1. Leads to operability issues with kiln and material handling and out of	1. Upstream screening 2. Batch testing of product		

Node: 1. TTP2 Feed

Deviation	Causes	Consequences	Safeguards	Recommendations	General Comments
		spec product			
13. Instrumentation / Control	1. No new issues				
14. Plant Items	1. Plant sirens	1. Potential for confusion / inability to identify specific plant area		16. Provide a siren for TTP2	
				17. Review sirens in use and identify means to differentiate between plant and equipment	

Node: 2. TTP2 Main Gas and Combustion Air

Deviation	Causes	Consequences	Safeguards	Recommendations	General Comments
1. Low / No Flow	1. Main gas line blockage	1. Loss of flame or insufficient heat input to kiln or loss of efficiency	1. Batch testing	18. Review the functionality of the low temperature alarm off the kiln temperature transmitter	
			2. BMS (loss of flame trip)	19. Review the improvement reports over the last five years to identify pertinent requirements for the new TTP2	
			3. Main gas PSL	20. Review TTP1 sequencing logic to identify improvements to sequencing functionality of TTP2	
			4. Kiln TT	24. Ensure BMS reset is accessible outside the panel	
	2. Blocked main gas filter	1. Loss of flame or insufficient heat input to kiln or loss of efficiency	1. Batch testing		
			2. BMS (loss of flame trip)		
			3. Main gas PSL		
			4. Kiln TT		
			5. Filter Maintenance Regime		
	3. Main gas regulator failure	1. Loss of flame or insufficient heat input to kiln or loss of efficiency	1. Batch testing		
			2. BMS (loss of flame trip)		
			3. Main gas PSL		
			4. Kiln TT		
	4. Gas control valve failure	1. Loss of flame or insufficient heat input to kiln or loss of efficiency	1. Batch testing		
			2. BMS (loss of flame trip)		
	5. OPSO trip	1. Loss of flame or insufficient heat input to kiln or loss of efficiency	1. BMS (loss of flame trip)		
			2. Batch testing		
			3. Main gas PSL		

Node: 2. TTP2 Main Gas and Combustion Air

Deviation	Causes	Consequences	Safeguards	Recommendations	General Comments
	6. Loss of supply	1. Loss of flame or insufficient heat input to kiln or loss of efficiency	1. Main gas PSL 2. Batch testing 3. BMS (loss of flame trip)		
	7. Failure of pilot regulator	1. Loss of pilot gas, inability to start or relight	1. BMS (loss of flame trip)	21. Improve fault finding mechanism for pressure measurement points	
	8. Failure of main gas SOVs	1. Loss of flame or insufficient heat input to kiln or loss of efficiency	1. Batch testing 2. BMS (loss of flame trip and tightness testor)		
	9. Failure of pilot gas SOVs	1. Inability to light burner	1. BMS (failure to ignite pilot)		
	10. Main gas isolation valve closed	1. Loss of flame or insufficient heat input to kiln or loss of efficiency	1. BMS (loss of flame trip and tightness tester) 2. BMS (failure to ignite pilot) 3. Batch testing		
	11. Pilot gas isolation valve closed	1. Inability to light burner	1. BMS (failure to ignite pilot)		
	12. Combustion air fan failure	1. Loss of flame or insufficient heat input to kiln or loss of efficiency 2. Potential for excessive CO	1. Combustion air PSL 2. BMS (loss of flame trip and tightness tester) 3. Dust collector fan (maintains negative pressure)		
	13. Blocked combustion air filter	1. Low combustion air flow leading to poor combustion and excessive CO	1. Combustion air filter PSH 2. Combustion air PSL 3. Dust collector fan (maintains negative pressure)		
	14. Combustion air damper failure	1. Loss of flame or insufficient heat input to kiln or loss of efficiency 2. Potential for excessive CO	1. BMS (loss of flame trip and tightness tester) 2. Damper Position Switch 3. Dust collector fan (maintains negative pressure)	22. Confirm dilution air flow requirements for the burner 23. Confirm that the combustion air damper position is exercised via the position switches during the purge sequence	
2. High Flow	1. Main gas regulator failure	1. Low air/fuel ratio - inefficiency of burner 2. High CO - explosive risk	1. OPSO 2. Dust collector fan (maintains		

Node: 2. TTP2 Main Gas and Combustion Air

Deviation	Causes	Consequences	Safeguards	Recommendations	General Comments
			negative pressure)		
		3. Flame failure	3. BMS (loss of flame trip)		
		4. Overtemperature - regulatory reporting requirement if above 800 degC	4. Overtemperature protection (kiln)		
		5. Dust collector filter bag damage	5. Overtemperature protection (dust collector)		
		6. Downstream equipment exposed to high pressure	6. Cold air inlet damper		
	2. Gas control valve stuck open	1. Overtemperature - regulatory reporting requirement if above 800 degC	1. Overtemperature protection (kiln)		
		2. Dust collector filter bag damage	2. Overtemperature protection (dust collector)		
			3. Dust collector fan (maintains negative pressure)		
			4. Cold air inlet damper		
	3. Pilot regulator failure	1. Pilot will not light due to excessive gas	1. BMS (fail to ignite)		
			2. BMS purge		
	4. Combustion air damper stuck open (during ignition)	1. Failure to ignite pilot	1. BMS (fail to ignite)		
			2. BMS purge		
3. Reverse Flow	1. No issues				
4. "As well as" Flow	1. No issues				
5. Too Early / Too Late	1. Industrial fuel hazards	1. Kiln explosion	1. Designed and certified to AS1375 and AS3814 (Industrial fuel fired appliance standards)		AS1375 AS3814
6. High Level	1. N/A				
7. Low Level	1. N/A				
8. High Pressure	1. No new issues				
9. Low Pressure	1. No new issues				
10. High Temperature	1. High ambient conditions	1. High temperature combustion air	1. Air conditioning on MCCs		

Node: 2. TTP2 Main Gas and Combustion Air

Deviation	Causes	Consequences	Safeguards	Recommendations	General Comments
		impact on density - not expected to cause any issues given method for air fuel ratio control planned for this kiln			
		2. Shortening of life-span of electrical/electronic equipment	2. Selection of field equipment with high ambient temperature ratings		
11. Low Temperature	1. No issues				
12. Impurities / Composition (concentration)	1. Rainwater and airborne dust	1. Conductive impurities causing failure of instrumentation on the BMS	1. Location of instruments in MCC	25. Provide signage to warn against use of water hoses in vicinity of TTP2	
			2. Selection of field equipment with high IP ratings	26. Review requirements and means for protection of TTP2 gas train from rain	
			3. Fused terminals on field wiring		
	2. Rainwater entrained in combustion air	1. Low combustion air flow		26. Review requirements and means for protection of TTP2 gas train from rain	
		2. Internal corrosion			
13. Instrumentation / Control	1. 240V AC field instruments, solenoids and actuators	1. Electrocution of maintenance personnel	1. Electrical schematics		
	2. HV on ignition circuits	1. Electrocution of maintenance personnel	1. Electrical schematics	27. Determine HV and 240 VAC signage requirements	
	3. Main gas flow meter	1. Local indication		28. Ensure flow meter on main gas line is an FIT	
14. Plant Items	1. No new issues				

Node: 3. TTP2 Kiln and Reactor including induced draft fan

Deviation	Causes	Consequences	Safeguards	Recommendations	General Comments
1. Low / No Flow	1. Failure of material delivery system	1. Generation of slurry in the reactor leading spill of material in to bunded area	1. Upstream material handling interlocks with reactor water supply		
	2. Blockage in reactor feed chute	1. Generation of slurry in the reactor leading spill of material in to bunded area		29. Provide high level switch in the reactor feed chute (Note: this is potentially an emergency shutdown situation)	
		2. Overfill kiln and spill of material outside system - exposure of personnel to hot material, dusty,			

Node: 3. TTP2 Kiln and Reactor including induced draft fan

Deviation	Causes	Consequences	Safeguards	Recommendations	General Comments
		chemically reactive			
	3. Blockage in reactor discharge chute	1. Overfill reactor leading to back-up of material in the reactor feed chute and potential kiln overfill and spill of material outside system - exposure of personnel to hot material, dusty, chemically reactive	1. Vibrating motor	30. Provide high level switch in reactor discharge chute (Note: this is potentially an emergency shutdown situation)	
			2. Reactor LT	31. Configure process shutdown on high level in reactor (LT P246J150) (Note: this is potentially an emergency shutdown situation)	
				32. Immediately stop the Burner on detection of a blockage in the reactor discharge chute	
	4. Water control valve failure (closed)	1. Reactor overheats leading to very hot material and very hot material handling equipment (to stockpile) - personnel safety risk, plant damage, process failure	1. Water FT	33. Show reactor water control valve on the P&ID	
		2. Unable to flash off volatile gases or degas, non degassed material sent to stockpile	2. Reactor TT	34. Configure process shutdown on high reactor temperature off reactor TT	
				35. Configure process shutdown on low reactor water flow off reactor water FT	
				36. Conduct dedicated risk assessment on the loss of reactor water scenario to ensure sufficient safety in design	
	5. Water SV closed	1. Reactor overheats leading to very hot material and very hot material handling equipment (to stockpile) - personnel safety risk, plant damage, process failure	1. Reactor TT	33. Show reactor water control valve on the P&ID	
		2. Unable to flash off volatile gases or degas, non degassed material sent to stockpile	2. Water FT	34. Configure process shutdown on high reactor temperature off reactor TT	
				35. Configure process shutdown on low reactor water flow off reactor water FT	
				36. Conduct dedicated risk assessment on the loss of reactor water scenario to ensure sufficient safety in design	
	6. Blocked reactor water nozzle	1. Unable to flash off volatile gases or degas, non degassed material sent to stockpile	1. Water FT	33. Show reactor water control valve on the P&ID	

Node: 3. TTP2 Kiln and Reactor including induced draft fan

Deviation	Causes	Consequences	Safeguards	Recommendations	General Comments
		2. Reactor overheats leading to very hot material and very hot material handling equipment (to stockpile) - personnel safety risk, plant damage, process failure	2. Reactor TT	34. Configure process shutdown on high reactor temperature off reactor TT	
				35. Configure process shutdown on low reactor water flow off reactor water FT	
				36. Conduct dedicated risk assessment on the loss of reactor water scenario to ensure sufficient safety in design	
	7. Loss of water supply (pressure pump failure)	1. Unable to flash off volatile gases or degas, non degassed material sent to stockpile	1. Water FT	33. Show reactor water control valve on the P&ID	
		2. Reactor overheats leading to very hot material and very hot material handling equipment (to stockpile) - personnel safety risk, plant damage, process failure	2. Reactor TT	34. Configure process shutdown on high reactor temperature off reactor TT	
			3. Revert to mains supply on pressure pump failure	35. Configure process shutdown on low reactor water flow off reactor water FT	
				36. Conduct dedicated risk assessment on the loss of reactor water scenario to ensure sufficient safety in design	
	8. Reactor exhaust fan failure	1. Reactor gas and steam aspirates from the reactor vent, personnel safety risk	1. Exhaust fan VSD power monitoring for low power	37. Interlock reactor exhaust fan run/fault status with process shutdown	
				38. Conduct hazardous area classification of reactor and associated systems e.g. vent	
				39. Review reactor vent discharge location with respect to personnel access points around and above the reactor	
	9. Reactor exhaust pipe blockage	1. Reactor gas and steam aspirates from the reactor vent, personnel safety risk	1. Exhaust fan VSD power monitoring for low power	40. Monitor reactor exhaust fan flow via exhaust fan power monitoring and implement alarm on low fan power	
	10. Blocked filter bags	1. Low flow through kiln leading to pressurisation of the kiln and dust and products of combustion leaking from kiln	1. Baghouse pulsing with compressed air	42. Configure high alarm off baghouse differential pressure monitoring.	
		2. Dust flow from baghouse to reactor inhibited	2. Differential pressure monitoring across bags (dPT P246H150)	43. Configure high alarm off kiln exhaust pressure monitoring.	
			3. Kiln exhaust pressure monitoring (PIT P246G130)		

Node: 3. TTP2 Kiln and Reactor including induced draft fan

Deviation	Causes	Consequences	Safeguards	Recommendations	General Comments
			4. Dust collector temperature monitoring		
	11. ID fan failure including vee-belt slippage or failure	1. Low flow through kiln leading to pressurisation of the kiln and dust and products of combustion leaking from kiln	1. ID fan motor interlock with BMS and process plant		
		2. Dust flow from baghouse to reactor inhibited			
	12. ID fan incorrect speed	1. Low flow through kiln leading to pressurisation of the kiln and dust and products of combustion leaking from kiln	1. ID fan range limit (PLC code)		
			2. Long fan acceleration and deceleration time on fan motor VSD because of effect of VSD current on current sensing relay		
	13. Ducting leak	1. Low flow through kiln leading to pressurisation of the kiln and dust and products of combustion leaking from kiln	1. Kiln exhaust pressure monitoring (PIT P246G130)		
		2. Fugitive emissions from ducting	2. Ducting PM		
	14. Cooling air damper fully open	1. Low flow through kiln leading to pressurisation of the kiln and dust and products of combustion leaking from kiln	1. Cooling Air Damper position transmitter	44. Implement damper proving check for the TTP2 cooling air damper during pre-start.	
			2. Kiln exhaust pressure monitoring (PIT P246G130)		
	15. Cooling air damper fully closed	1. Low flow of cooling air leading to high dust collector temperature leading to bag damage and shutdown	1. Cooling Air Damper position transmitter	44. Implement damper proving check for the TTP2 cooling air damper during pre-start.	
		2. Low kiln temperature resulting in maximum burner flame (High flow through kiln)	2. Dust collector temperature monitoring	45. Implement deviation alarm between control signal to cooling air damper and feedback from position transmitter.	
		3. After shutdown, flammable gases are unable to ventilate through high point	3. Kiln exhaust pressure monitoring (PIT P246G130)	46. Provide mechanical stop to prevent cooling air damper fully closing	
				47. Configure high alarm off dust collector temperature transmitter	
				48. Configure low alarm off kiln exhaust pressure monitoring	
	16. Compressed air to baghouse SOV	1. Blocked dust bags	1. Compressed air supply PSL (plant	49. Show compressed air to baghouse, cooling air	

Node: 3. TTP2 Kiln and Reactor including induced draft fan

Deviation	Causes	Consequences	Safeguards	Recommendations	General Comments
	failure	2. Cooling air damper won't operate	services P&ID)	damper and opacity meter on P&ID	
	17. Dust material handling equipment failure	1. Build-up of material in baghouse hopper (leading to blockage in baghouse)	1. Baghouse hopper LSH 2. Equipment SSLs (Underspeed alarms)	50. Ensure baghouse hopper LSH places kiln in idle-mode	
2. High Flow	1. Material hang-up	1. On shutdown, rapid dumping of material hang-up leads to overloading transfer conveyor	1. Dust rotary valve	51. Confirm reactor capacity is sized to receive full contents of kiln and full baghouse contents in shutdown event. 52. Limit the minimum speed of the transfer conveyor VSD in automatic operation.	
	2. ID fan running too fast	1. Increased product through dust collector leading to overloading dust transfer equipment	1. ID fan range limit (PLC code) 2. Kiln exhaust pressure monitoring (PIT P246G130)	53. Confirm capacity of existing dust material handling equipment	
	3. Reactor water CV fully open	1. Creation of slurry inside reactor and continual overflow through outlet 2. Discharge transfer conveyor unable to handle slurry	1. Reactor water FT	54. Configure deviation alarm to detect high flow of reactor water (via FT)	
3. Reverse Flow	1. Steam ingress to dust transfer line	1. Creates sticky product leading to blockages	1. Reactor design - location of dust transfer inlet	55. Consider rotary valve between reactor and dust transfer conveyor	
4. “As well as” Flow	1. Burner flame out	1. Reactor exhaust feed to kiln during flame out leading to uncombusted gases aspirating through kiln exhaust line	1. Process design - reactor exhaust diluted to a level such that the hazardous area is of negligible extent (IEC60079)	58. Verify reactor exhaust gases dilution target achieves a hazardous area of negligible extent	
			2. Reactor "Always Open Flammable Gas Vent"	59. Implement an interlock between the BMS run signal and the reactor exhaust fan motor. If BMS indicates burner not running, then reactor exhaust fan must not run. 60. Verify reactor "Always open flammable gas vent" is sized sufficiently to achieve required suction	
5. Too Early / Too Late	1. Reactor water starting too early during sequence start	1. Loss of water out of reactor (too early)	1. Reactor temperature transmitter	56. Configure process interlock to open reactor water CV on reaching reactor temperature set-point (to indicate product in reactor).	
	2. Reactor water starting too late during sequence start	1. Reactor too hot and impact on degassing (too late)	1. Reactor temperature transmitter	57. Install reactor feed chute TT and investigate using the reactor feed chute TT to control water start and stop.	

Node: 3. TTP2 Kiln and Reactor including induced draft fan

Deviation	Causes	Consequences	Safeguards	Recommendations	General Comments
6. High Level	1. No new issues				
7. Low Level	1. No new issues				
8. High Pressure	1. High pressure from reactor exhaust fan	1. Positive pressure in kiln leading to flammable gas and dust leakage from kiln seals		41. Assess requirement and location for a pressure transmitter in reactor exhaust line to kiln for purpose of controlling static pressure in the kiln	
		2. Potential impact on combustion			
	3. Deflagration event in the reactor	1. Reactor overpressure leading to catastrophic failure / damage of the reactor	1. Deflagration vents on reactor exhaust vent		
	4. Ignited gas release from reactor	1. Flash fire event leading to possible injuries to operators / personnel in the vicinity	1. Hazardous Area Classifcation IEC60079		
			2. Adhoc gas testing		
9. Low Pressure	1. Low pressure compressed air supply	1. Unable to clean bags leading to blockages	1. Compressed air supply PSL (plant services P&ID)		
10. High Temperature	1. Production of steam in reactor	1. Personnel exposure to very hot surfaces	1. Reactor is fully guarded	61. Consider an additional barrier around the top and sides of the reactor	
11. Low Temperature	1. No new issues				
12. Impurities / Composition (concentration)	1. Stack emissions	1. Breaching EPA conditions	1. Opacity meter		
			2. Dust collection baghouse		
			3. Stack emissions testing program		
	2. Spills to bunded area	1. Contaminated run-off water	1. Stormwater containment system		
	3. Water ingress to compressed air lines	1. Damage to equipment and poor operation of pneumatics		62. Add an air receiver and automatic drain in compressed air system	
13. Instrumentation / Control	1. No new issues				
14. Plant Items	1. No new issues				

Node: 4. TTP2 treated material to stockpile

Deviation	Causes	Consequences	Safeguards	Recommendations	General Comments
1. Low / No Flow	1. No new issues				

Node: 4. TTP2 treated material to stockpile

Deviation	Causes	Consequences	Safeguards	Recommendations	General Comments
2. High Flow	1. Rapid lifting of discharge gate	1. High flow out of reactor		63. Ensure reactor rotor speed is controlled for discharge	
3. Reverse Flow	1. No issues				
4. "As well as" Flow	1. Feed from 120 system	1. Normal operations - system designed for combined capacity			
5. Too Early / Too Late	1. 120 plant not running	1. Overload discharge conveyor		64. Provide interlock for the 120 system running before starting 246 system	
6. High Level	1. Failure to clear stockpile	1. High stockpile level leading to jammed conveyor 120M	1. High level switch on 120M (sequence stop)		
7. Low Level	1. No new issues				
8. High Pressure	1. No issues				
9. Low Pressure	1. No issues				
10. High Temperature	1. No issues				
11. Low Temperature	1. No issues				
12. Impurities / Composition (concentration)	1. Degassing of product ex-reactor	1. Flammable gas emissions from product on discharge transfer conveyors	1. Hazardous Area Classification (IEC60079) 2. Periodic gas monitoring along conveyors	66. Provide 120K with full-sized always open vent similar to 258S	
	2. Wet material growth on conveyor chain	1. Reduces capacity of conveyor system	1. Periodic conveyor maintenance		
13. Instrumentation / Control	1. No new issues				
14. Plant Items	1. Isolation of 120 or 246 system	1. Inability to run non isolated plant due to shared conveyor		65. Review isolation requirements for the scenario of isolating one kiln whilst continuing to run the other kiln	
	2. Isolation of natural gas to 120 or 246	1. Inability to run non isolated plant due to common natural gas supply		67. Update P&ID 116TD161 to incorporate a bleed lines downstream of the respective isolation valves	

Attachment 4
Recommendations

Recommendations	Responsibility	Place(s) Used	Implementation Program
1. Configure a low level alarm off the feed bin LT	AD	Causes: 1.1.1	See Note A
2. Configure feed bin LSL to interlock with downstream plant to allow time for transfer and processing of material in train.	AD	Causes: 1.1.1	See Note B
3. Configure a high level alarm off the feed bin LT	AD	Causes: 1.1.2	See Note B
4. Configure feed bin LSH to interlock with the upstream plant (sequence stop and run-out)	AD	Causes: 1.1.2	See Note B
5. Further investigate options to reduce the likelihood of geopolymerisation in the feed bin (e.g. forward/reverse feeder)	JC	Causes: 1.1.2	See Note E
6. Develop process sequencing to purge feed bin	AD	Causes: 1.1.2	See Note B
7. Install temperature monitoring in the feed bin to detect geopolymerisation.	AD	Causes: 1.1.2	See Note C
8. Provide a low flow switch on TTP2 feeder.	AD	Causes: 1.1.2, 1.3.1	See Note C
9. Ensure that the underspeed software performs self-check on start-up or stop	AD	Causes: 1.1.4	See Note D
10. Develop a PM for all level switches	RE	Causes: 1.1.4	See Note E
11. Update P&ID 246TD002 to correctly indicate the destination of the drop-out chute from the kiln to the TTP2 feed transfer conveyor and label accordingly	AD	Causes: 1.4.1	See Note A
12. Provide a thermocouple at the feed end of the kiln and alarm on high temperature	AD	Causes: 1.4.1	See Note C
13. Ensure DOL circuit breakers are provided with remote reset capability	PL	Causes: 1.4.1	See Note A
14. Provide two high level switches in the kiln drop-out chute to detect	AD	Causes: 1.10.1	See Note C

Recommendations	Responsibility	Place(s) Used	Implementation Program
blockages (one below and one at top)			
15. Review technology for upstream screening of material	JC	Causes: 1.12.1	See Note E
16. Provide a siren for TTP2	PL	Causes: 1.14.1	See Note C
17. Review sirens in use and identify means to differentiate between plant and equipment	PL	Causes: 1.14.1	See Note A
18. Review the functionality of the low temperature alarm off the kiln temperature transmitter	AD	Causes: 2.1.1	See Note A
19. Review the improvement reports over the last five years to identify pertinent requirements for the new TTP2	AB	Causes: 2.1.1	See Note A
20. Review TTP1 sequencing logic to identify improvements to sequencing functionality of TTP2	AB	Causes: 2.1.1	See Note B
21. Improve fault finding mechanism for pressure measurement points	MW	Causes: 2.1.7	See Note C
22. Confirm dilution air flow requirements for the burner	MW	Causes: 2.1.14	See Note A
23. Confirm that the combustion air damper position is exercised via the position switches during the purge sequence	MW	Causes: 2.1.14	See Note D
24. Ensure BMS reset is accessible outside the panel	PL	Causes: 2.1.1	See Note A
25. Provide signage to warn against use of water hoses in vicinity of TTP2	RE	Causes: 2.12.1	See Note C
26. Review requirements and means for protection of TTP2 gas train from rain	JC	Causes: 2.12.1, 2.12.2	See Note A
27. Determine HV and 240 VAC signage requirements	PL	Causes: 2.13.2	See Note A
28. Ensure flow meter on main gas line is an FIT	AD	Causes: 2.13.3	See Note A
29. Provide high level switch in the reactor feed chute (Note: this is potentially an emergency shutdown situation)	AD	Causes: 3.1.2	See Note C

Recommendations	Responsibility	Place(s) Used	Implementation Program
30. Provide high level switch in reactor discharge chute (Note: this is potentially an emergency shutdown situation)	AD	Causes: 3.1.3	See Note C
31. Configure process shutdown on high level in reactor (LT P246J150) (Note: this is potentially an emergency shutdown situation)	AD	Causes: 3.1.3	See Note B
32. Immediately stop the Burner on detection of a blockage in the reactor discharge chute.	PL	Causes: 3.1.3	See Note A
33. Show reactor water control valve on the P&ID	AD	Causes: 3.1.4, 3.1.5, 3.1.6, 3.1.7	See Note A
34. Configure process shutdown on high reactor temperature off reactor TT	AD	Causes: 3.1.4, 3.1.5, 3.1.6, 3.1.7	See Note B
35. Configure process shutdown on low reactor water flow off reactor water FT	AD	Causes: 3.1.4, 3.1.5, 3.1.6, 3.1.7	See Note B
36. Conduct dedicated risk assessment on the loss of reactor water scenario to ensure sufficient safety in design	PL	Causes: 3.1.4, 3.1.5, 3.1.6, 3.1.7	See Note A
37. Interlock reactor exhaust fan run/fault status with process shutdown	AD	Causes: 3.1.8	See Note B
38. Conduct hazardous area classification of reactor and associated systems e.g. vent	PL	Causes: 3.1.8	See Note A
39. Review reactor vent discharge location with respect to personnel access points around and above the reactor	BC	Causes: 3.1.8	See Note A
40. Monitor reactor exhaust fan flow via exhaust fan power monitoring and implement alarm on low fan power	AD	Causes: 3.1.9	See Note B
41. Assess requirement and location for a pressure transmitter in reactor exhaust line to kiln for purpose of controlling static pressure in the kiln	AD	Causes: 3.8.1	See Note A
42. Configure high alarm off baghouse differential pressure monitoring.	AD	Causes: 3.1.10	See Note B

Recommendations	Responsibility	Place(s) Used	Implementation Program
43. Configure high alarm off kiln exhaust pressure monitoring.	AD	Causes: 3.1.10	See Note B
44. Implement damper proving check for the TTP2 cooling air damper during pre-start.	AD	Causes: 3.1.14, 3.1.15	See Note B
45. Implement deviation alarm between control signal to cooling air damper and feedback from position transmitter.	AD	Causes: 3.1.15	See Note B
46. Provide mechanical stop to prevent cooling air damper fully closing	AD	Causes: 3.1.15	See Note C
47. Configure high alarm off dust collector temperature transmitter	AD	Causes: 3.1.15	See Note B
48. Configure low alarm off kiln exhaust pressure monitoring	AD	Causes: 3.1.15	See Note B
49. Show compressed air to baghouse, cooling air damper and opacity meter on P&ID	AD	Causes: 3.1.16	See Note A
50. Ensure baghouse hopper LSH places kiln in idle-mode	AD	Causes: 3.1.17	See Note B
51. Confirm reactor capacity is sized to receive full contents of kiln and full baghouse contents in shutdown event.	JC	Causes: 3.2.1	See Note A
52. Limit the minimum speed of the transfer conveyor VSD in automatic operation.	AD	Causes: 3.2.1	See Note B
53. Confirm capacity of existing dust material handling equipment	AD	Causes: 3.2.2	See Note A
54. Configure deviation alarm to detect high flow of reactor water (via FT)	AD	Causes: 3.2.3	See Note B
55. Consider rotary valve between reactor and dust transfer conveyor	JC	Causes: 3.3.1	See Note A
56. Configure process interlock to open reactor water CV on reaching reactor temperature set-point (to indicate product in reactor).	AD	Causes: 3.5.1	See Note B
57. Install reactor feed chute TT and investigate using the reactor feed chute TT to control water start and stop.	AD	Causes: 3.5.2	See Note C
58. Verify reactor exhaust gases dilution target achieves a hazardous area	MW	Causes: 3.4.1	See Note D

Recommendations	Responsibility	Place(s) Used	Implementation Program
of negligible extent			
59. Implement an interlock between the BMS run signal and the reactor exhaust fan motor. If BMS indicates burner not running, then reactor exhaust fan must not run.	AD	Causes: 3.4.1	See Note B
60. Verify reactor "Always open flammable gas vent" is sized sufficiently to achieve required suction	AD	Causes: 3.4.1	See Note A
61. Consider an additional barrier around the top and sides of the reactor	AD	Causes: 3.10.1	See Note A
62. Add an air receiver and automatic drain in compressed air system	AD	Causes: 3.12.3	See Note A
63. Ensure reactor rotor speed is controlled for discharge	AD	Causes: 4.2.1	See Note B
64. Provide interlock for the 120 system running before starting 246 system	AD	Causes: 4.5.1	See Note B
65. Review isolation requirements for the scenario of isolating one kiln whilst continuing to run the other kiln	AB	Causes: 4.14.1	See Note A
66. Provide 120K with full-sized always open vent similar to 258S	JC	Causes: 4.12.1	See Note C
67. Update P&ID 116TD161 to incorporate a bleed lines downstream of the respective isolation valves	AD	Causes: 4.14.2	See Note A

Notes on Implementation Program:

A. Prior to completion of design scheduled at end February, 2020.

B. Incorporate in plant control system scheduled for completion during March, 2020

C. Installed during construction scheduled for completion by during April, 2020

D. Performed during commissioning for completion by end May, 2020

E. Performed within three months of completion of commissioning.