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PLC-Based Safety Instrumented System of a Boiler using HAZOP

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Abstract: HAZOP Analysis is used to determine great deviations which will affect the operational safety of a boiler of an existing petrochemical plant that may affect on persons, material and the environment. PLC is proposed to provide the safety function to fit into the overall machine control system as a safety-related part. It reads from the temperature, pressure sensors via its input interface modules and outputs commands in the case of critical deviation via the output module to the final control elements such as actuators allowing an improvement in the safety of the overall boiler system.

Keywords: Safety instrumented system, HAZOP, PLC.

1. INTRODUCTION

Past events and experience has shown that a great number of the boiler accidents has occurred in the industry. This was generally due to improper operation, control and maintenance, aging and deterioration of safety devices leading to potential hazards [1-3]. Because of variety and intensive uses of boiler and hence their high frequency hazards, a design of efficient safety system becomes a necessity to prevent human beings lives, environment, and utilities damages, Hazop Analysis, which is a flexible and structured method, can be applied to this thermo-hydraulic industrial processes [4]. The analysis deals with hazard evaluation of the strategic sub-system such as boiler in which the physical parameters deviations are measured and quantified using instrumentation and PLC; the physical parameters deviations are measured using adequate instrumentation which may act to keep the process into a safe state and guard against hazardous situations.

The safety of a plant is therefore dependent on the integrity of its instrumentation to reliably detect the inception of a hazardous condition ensuring adequate process protection. This is being backed up by a preventive of methodology can be maintenance on the process and an improved reliability of the safety instrumentation system.

2. BOILER SYSTEM

The boiler system consists mainly of the following parts: burner, vessel, Programmable logic controller (PLC), control panel with warning indicator and alarms Sensor transmitter – receiver as shown in Fig.1.
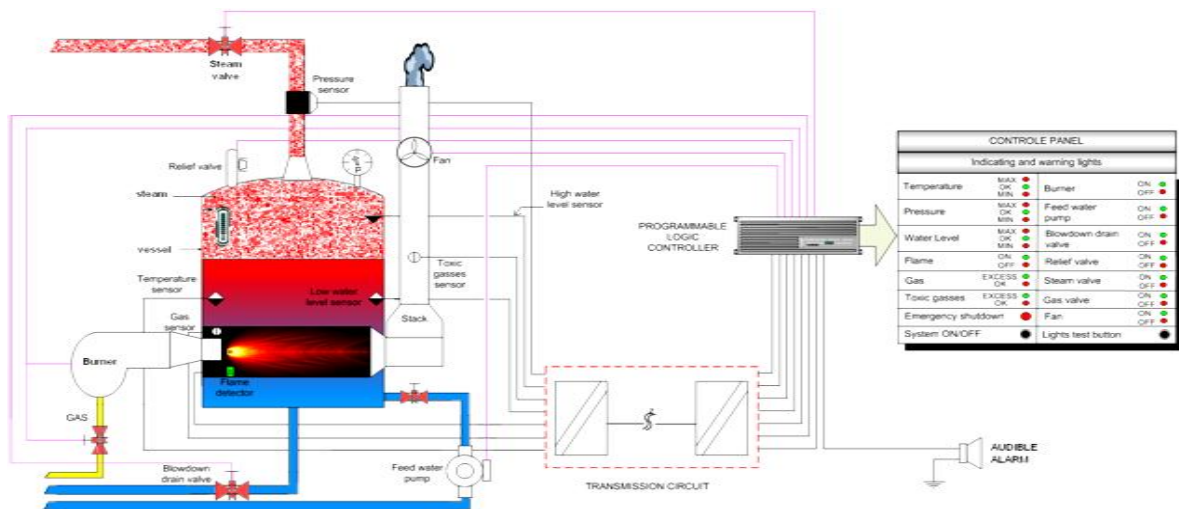

Fig.1 Boiler system

The boiler is essentially a closed vessel in which water is stored. Fuel or gas is burnt in a furnace and hot gasses are produced. These hot gasses come in contact with water vessel where the heat of these hot gases transfer to the water and consequently steam is produced in the boiler. Then this steam is piped to the turbine of thermal power plant.

3. BOILER ACCIDENTS, VIOLATIONS AND CAUSE

Boiler accidents can occur when the boiler is allowed to operate without enough water in the boiler. Boiler damage can run from severe buckling and deforming of the boiler to complete meltdown or potential boiler explosions. Another type of boiler accident and the most lethal is an excessive pressure. These accidents occur when the boiler can no longer contain the excessive pressure allowed to build in the boiler. Excessive pressure accidents, even in small boilers, have been known to completely destroy a building.

Fuel related accidents usually occur when there is a failure to purge combustible gases from the boiler before ignition is attempted. Leaking fuel valves can also be the cause of these accidents.

Some of the areas where attention is needed are:
- Leaking safety relief valves,
- Feed water to boiler (low level water),
- Steam leaks (steam systems),
- High temperatures/high pressures,
- Constantly resetting of safety devices.

Figure 2 shows the statistics of boiler accidents and their different causes recorded by North Carolina boiler safety bureau in 2005/2006 annual report [5].

The four high frequency causes are: pressure vessels, boiler control, boiler pressure reliving devices and boiler components. Together they present 89% of boiler hazards. In this report, it can be concluded that the most hazardous causes is overpressure. Any designed boiler safety system must take into consideration these critical elements.
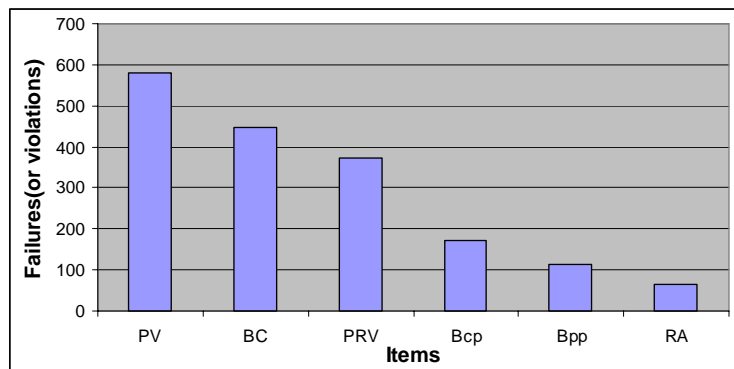

Fig.2 Frequency and categories of boiler's violations (PV:pressure vessels, BC:boiler control, BRV: boiler pressure reliving devices and Bcp: boiler components).

4. HAZOP ANALYSIS APPLIED TO BOILER

HAZOP is an inductive technique that can help identify potential failures by listing for each element under consideration in the boiler system, its deviation, its possible causes and effects on the system together with suggestions for required action [2]. The effort has required the technical competence of a multidisciplinary team with sufficient practical knowledge on process, operating procedures, instrumentation and structural disciplines of the plant under study. In table A1 of appendix, the results obtained by the extended HAZOP analysis are shown.

5. CRITICALITY ANALYSIS

The purpose of the criticality analysis is to rank each event or sequence as identified in the HAZOP analysis according to each failure mode severity S, and its probability of occurrence P.

5.1 Severity

This important criterion is defined as a function of the effect of failures on the retained function or mission of the system such as the safety. Attention is turned especially to the deviation that may create a hazard or a danger for the users, material damage and environment pollution. In this vein, safety parameter S is classified according to STD1629 whose excerpts is given in table A.2 of appendix classifying the consequences of major industrial accidents and environment impacts consideration.

5.2 Failure probability

The constant failure rate pertains to reliability model of electrical systems while the linearly increasing failure rate (with shape parameter $\beta > 1$) is typical of mechanical component subject to wear, corrosion and aging processes. In this case, we assume that the considered mechanical systems have constant failure rates for short–time interval of operation t, so that the probability of occurrence is given as follows:

$$P = 1 - R(t) = 1 - \exp(-\lambda.t) \tag{1}$$

Where R(t) is the reliability and λ is the failure rate .
The Probability P is ranked according to the table A3 of appendix.

5.3 Criticality matrix:

The critical event is developed from the severity of its failure effect S, the probability of the failure mode occurrence P. The total criticality effects is obtained from the following matrix cross product:

$$C = Se.X.P \tag{2}$$

The ranking of the overall criticality is obtained from the matrix given in table A4 of Appendix. The events are assumed to be more critical are therefore given a higher priority than those having a lower criticality C as shown in table I.

According to this classification, the first priority is given to the events F1, F2, F3 concerning combustion regulating system if under bad control can lead to multiples hazard consequences such as explosion and fire as well CO and CH4 temperature radiation may lead to an explosion .The same level of priority is given to this system that can pollution. The second is given to the gas release whose confinement and high generate gas pollution in the plant as well as in the environment.

CRITICALITY RANKING

Subsystem	Events	Criticality
Combustion system	F1	4B
	F2	3B
	F3	3C
Vessel	V1	2B
	V2	2C

6. CORRECTIVE ACTIONS

A drastic reduction in the potential impacts can be achieved in one hand through preventive maintenance on identified critical elements of the process and on sensing safety device proper; in the other hand in improvement of their reliability.

6.1 Preventive Maintenance of the Process

There are basically two types of preventive maintenance: a systematic one and a condition based one [6].

a) Systematic Preventive maintenance

For a complex system such as boiler system, an increased safety and reduced environment pollution can be achieved through a preventive maintenance program as suggested in the last column of table A1.This is obtained by conducting regular inspections, dust cleaning, calibrations and component replacement in priority on the combustion system, precipitator and pre-heater. In this approach, for each identified critical component, appropriate specific tasks and periods are to be taken as indicated on the following table with the intention of increasing the reliability and hence decreasing the failure probability P.

SYSTEMATIC PREVENTIVE MAINTENANCE

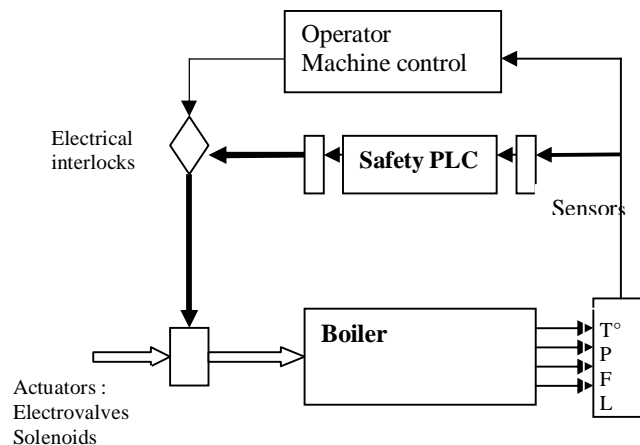| SPM		PM action								Pnew
		Inspectio	Replace	Dust	Lubricat	Testing	Calibrati	6	1y 2y	
Event										Pnew
F	F1	*		*		*		*		B➜C
	F2	*		*				*		B➜C
	F3	*	*	*		*		*		C➜D
E	E1	*	*	*		*		*		B➜C
	E2	*	*	*		*		*		C➜D

Fig.3 PLC as safety-related part

b) *Condition based maintenance (CBM)*

This Condition Based maintenance is based on the detection of parameters deviation; in view of limiting stresses to prevent hazard or breakdown [6] primarily on combustion systems. Shutting down the boiler system is last resort action. In fact, it is desired to provide a monitoring which can be achieved by keeping parameters such as the pressure , temperature, combustion gases and so on, within specified limits to minimize their effects on the reliability of the critical element burning zone systems [7].This results in an increase in detection factors and hence a decrease in the severity.

By applying this technique on the identified critical components, new values on criticality C are obtained as shown in table A4.

6.2 Safety Instrumentation System Enhancement

For process industry system, a hazard is the result of a misbehaving process. The safety instrumented function must act to bring the process to a safe state. A false trigger can lead to a costly shutdown loss of production, whereas a failure to trigger can possibly have more far-reaching consequences. The reliability and safety of a plant is therefore dependent on the integrity of its sensor-transmitter to detect this hazardous condition to ensure that the process is adequately protected according to the IEC 61511 standard [4]. This can be obtained using preventive maintenance as well as redundancy which offer sizable savings for safety systems in the process industry.
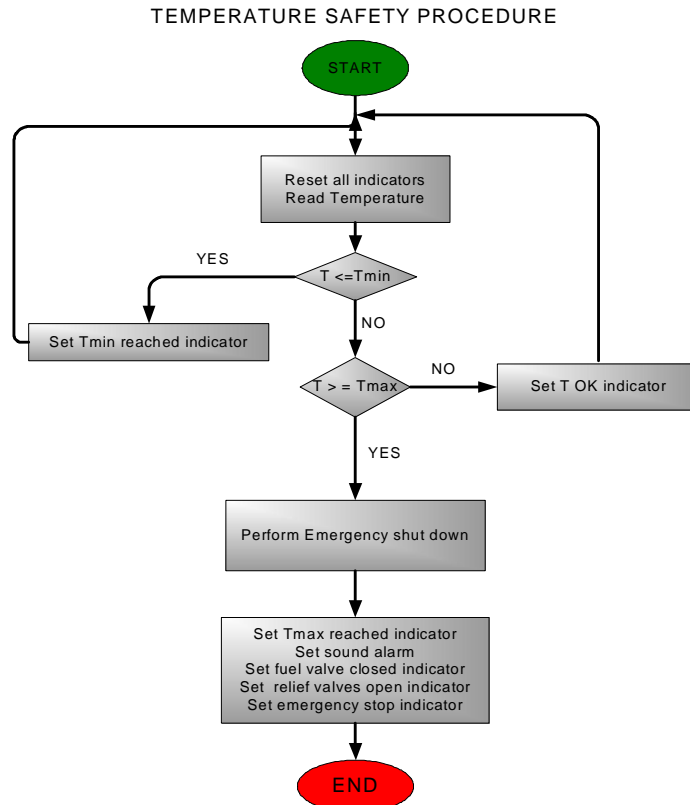
TEMPERATURE SAFETY PROCEDURE

Fig.4 Temperature safety algorithm flowchart

a) PLC as safety-related part

Figure 3 uses a PLC for the logic solver element of the safety function and provides the input and output interface through its input and output subsystems. The PLC that performs the safety function fits into the overall machine control system as a safety-related part. It reads in the safety sensors via its interface modules and outputs commands via the interface to the final control elements (which remain hard-wired and electromechanical) [8].

In Figure 2, the PLC provides the logic solver subsystem for several safety functions. It follows that the PLC must then be engineered to meet the highest safety integrity level required for the functions.
- Safety procedures:
-Temperature and Pressure:

The PLC keeps temperature and pressure in the maintained ranges by comparing between the user's set values (max and min) and boiler's actual values. When real value reaches one of the limits, the PLC trigger Emergency Shut Down procedure to avoid hazards, and at the same time it sets alarm indicators. Otherwise OK indicator is displayed as shown in Fig.4 and 5. This information is updated every scan cycle [9 10].
- Water level: Whenever Water level is exceeding the user's fixed range the PLC force the system to an emergency shutdown (see Fig.6).

-Flame watch: The Flame is extinguished while fuel valves are opened so the PLC will deny this state by performing emergency shutdown (see Fig.7).

-Gas detection: Gas should not exceed low quantities in the combustion air, but whenever it does, the PLC interferes to perform an emergency shutdown.

b) Preventive maintenance on safety instrumentation

To ensure a reliable and successful function of the instrumentation safety system a periodic preventive maintenance of its constitutive devices and their connection is required. Different preventive actions are taken in the light of HAZOP recommendations as shown in table A1 of Appendix to prevent from any failure or degradation of these protective devices and hence any unacceptable consequences. Physical parameters deviation can be confused with error in deviation due to sensor degradation and drift.
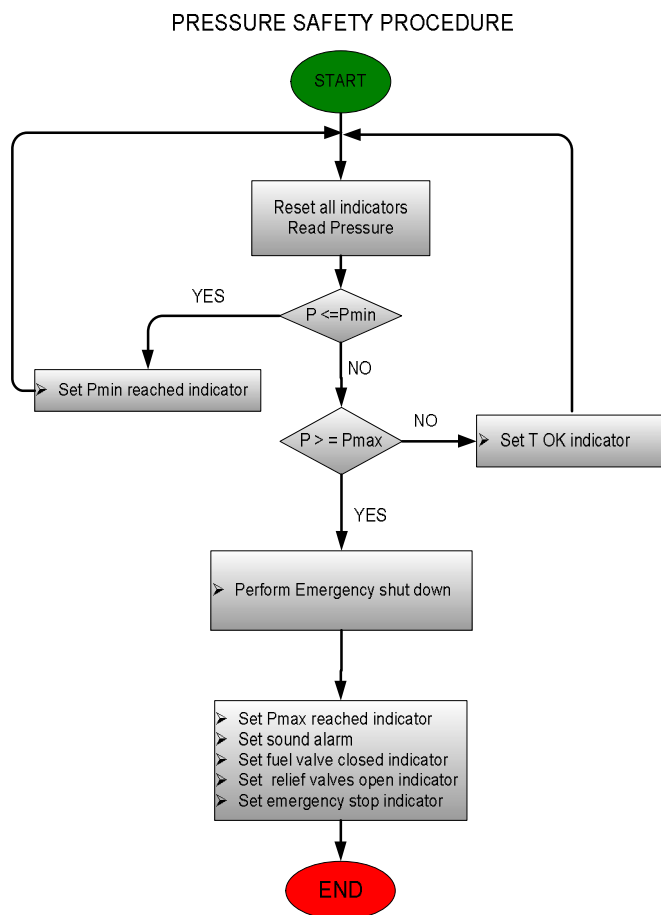
PRESSURE SAFETY PROCEDURE

Fig.5 Pressure safety algorithm flowchart

- Environment protection

In this power plant, sensors are generally exposed to external harsh and stressing environment such as dust, heat radiation, and vibrations and therefore the environment factor π_E is relatively of high value [11] and hence resulting in higher failure rate and confirmed in the survey with a proportion of 45 % of the overall failures. Dust or dirt may deposit and cause bad sensing, short period inspection and cleaning are required. Also it is desirable to use an enclosed conditioned system not only against dust but also against acoustic vibration, choc and heat radiation to reduce the π_E factor and hence the new failure rate is decreased according to

$$\lambda_p = \lambda_b . \pi_Q . \pi_E \qquad (3)$$

- Calibration

The calibration is an adjustment operation to compensate for amplitude change due to instrument drift to preserve the accuracy. It will normally be repeated at regular intervals, their spacing being determined by the rate at which the performance drifts and the maximum permissible system error. In such harsh environment, the drift is so fast that a calibration as well as regulation is required for short period in the considered process.

- Redundancy

In this case, reliability can be increased by applying an active redundancy at the safety sensors-transmitter circuit. A similar circuit is added in parallel so that one can fail without causing system failure [8] of the protection in the case of combustion gas detection under pressure and dust evacuation. The new increased reliability of the circuit is expressed as:

$$R=2R–R2 \qquad (4)$$
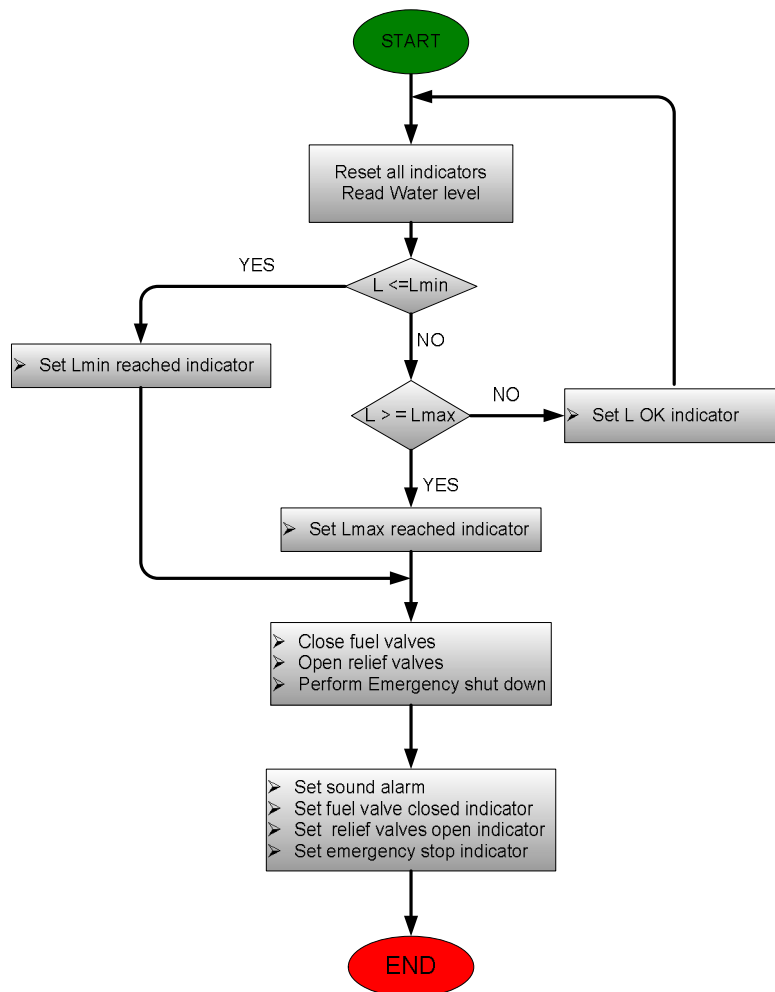
WATER LEVEL SAFETY PROCEDURE

Fig.6 Water level safety algorithm flowchart

A substantial improvement is obtained as shown in table III.

The addition of extra circuitry and software enables the device to detect a greater number of dangerous internal failures and alarm the system accordingly. More there are the number of measuring points and add-on instrumentation better will be the monitoring accuracy and the decision making for further safety action.

7. CONCLUSIONS

For a complex system such as boiler system, an increased safety has been achieved using HAZOP method in conjunction with the preventive maintenance on the identified critical elements of the considered process.

This preventive maintenance, that is based on SPM and CBM operations as recommended in the last column of HAZOP table A1 in Appendix, has lead to a decrease in the probability of occurrence (by an improvement in the reliability of the devices) as well as in the severity (by an early detection) of the identified critical physical deviation and hence reducing their criticalities as shown in table IV.
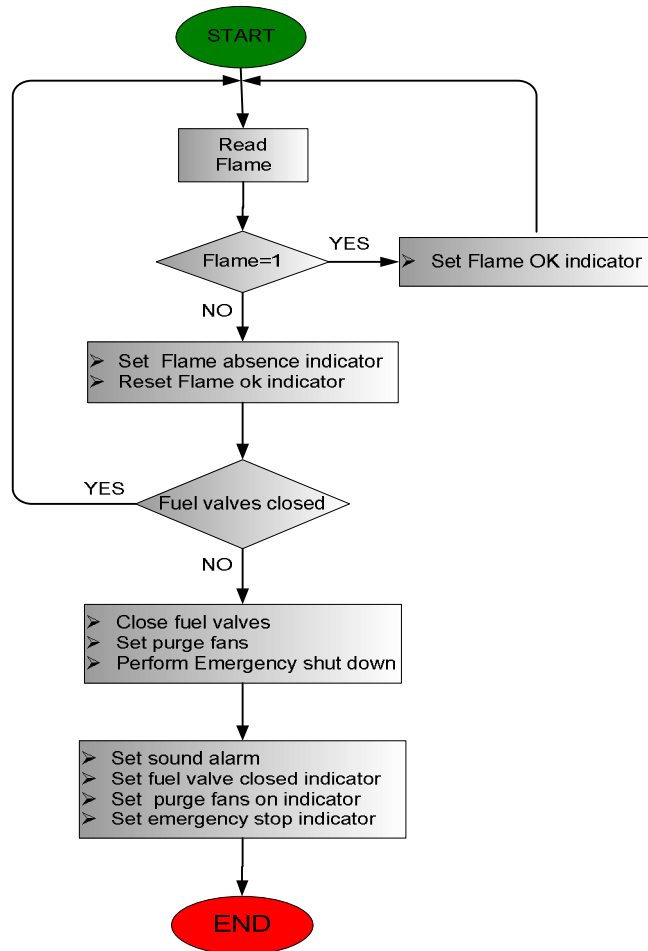
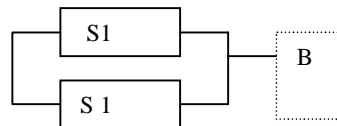FLAME SAFETY PROCEDURE

Fig.7 Flame safety algorithm flowchart

Fig.8 Redundancy in sensor circuit.

Sensor Reliability improvement

Sensor transmitter	R Before	R Improved
CO gas	0.90	0.9900
CH4 gas	0.94	0.9964
thermocouple	0.9802	0.9996
Pressure	0.98	0.9996

New Criticality ranking

Subsystem	Events	New Criticality
Combustion system	F1	3C
	F2	2C
	F3	2D
Vessel	V3	2C
	V1	2C

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