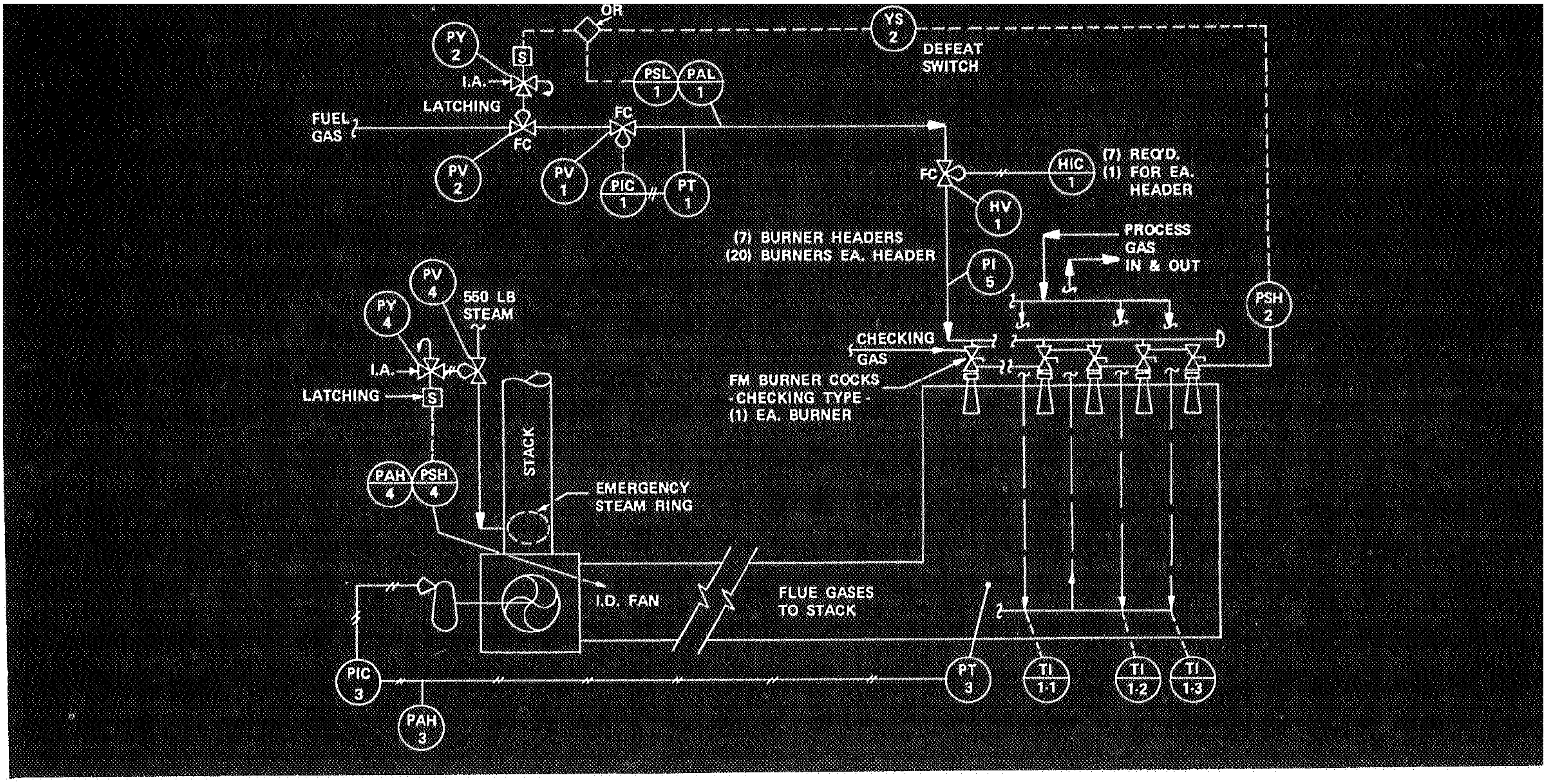

Figure 1. Primary reformer firing controls.

AMMONIA PLANT OPERATIONS:

Safety Instrumentation for Ammo

Here is a detailed review of the controls needed to protect personnel, equipment, and overall operations in synthetic ammonia manufacturing.

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Ammonia production utilizing the direct synthesis of nitrogen and hydrogen has over the past generation become the major source of ammonia required in the production of chemical fertilizers. The modern single-train ammonia plant requires a coordinated approach to safety instrumentation due to 1) greatly increased throughput, 2) the utilization of centrifugal compressors, 3) a highly integrated heat exchange system, and 4) the high-pressure reforming reactor and low-pressure synthesis concept.

A large plant of recent design offers lower initial investment and reduced operating expense per ton of production. In exchange for these benefits, the designer and operator must provide greater control instrumentation reliability to minimize down-time and maintain a high onstream factor. Due to the single-train concept in design, even a brief plant outage can be serious in terms of lost production.

Three centrifugal compressors are basic to all high-capacity single-train ammonia units. They are the process air compressor, the synthesis gas compressor, and the ammonia refrigeration compressor. Each has its own characteristic antisurge, speed control, and safety requirements.

Effective recovery of all available heat is essential to low-cost large-scale ammonia production. An integrated heat exchange system effectively recovers waste heat, utilizing process gas, process air, boiler feed-water preheat, and steam superheat coils within the primary reformer.

A large quantity of steam is required as a process reactant and to power the numerous pump and compressor steam turbines. Therefore, 1,500 lb./sq. in. gauge steam is generated by heat exchange between boiler feed-water and hot process gases at various points in the process. In addition, many boiler feed-water pre-heat exchangers are provided throughout the process.

The objective of ammonia plant safety instrumentation is protection of personnel, mechanical equipment, and catalyst inventory. Activation of plant shutdown systems for any other reason is unnecessary.

With fired furnaces, boilers, high-pressure high-

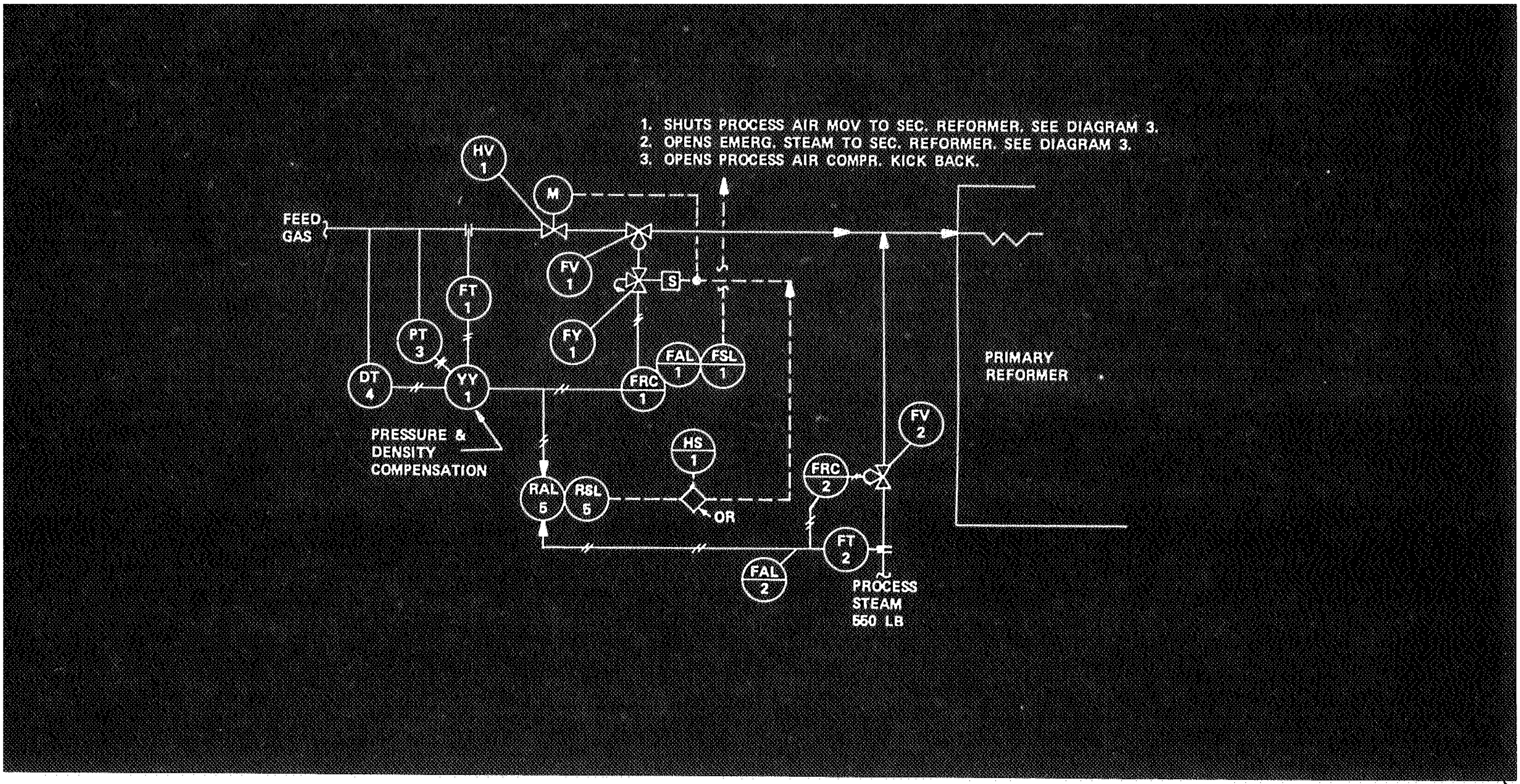

Figure 2. Steam/feed gas ratio control system.

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temperature reactors, and a complex high-pressure steam system, potential safety hazards exist which must be adequately instrumented to assure personnel protection. Modern control philosophy provides continuous, or alarm, monitoring of all significant variables for operations and automatic actuation of shutdown, isolation and relieving devices for all critical variables.

The high-capacity equipment utilized in single-train ammonia plants is expensive to replace and may require a lengthy shutdown and significant lost production during replacement.

Included as part of the critical equipment in a modern ammonia plant are the three centrifugal compressors, boiler feedwater pumps, cooling water pumps and the reformer induced-draft fan. Adequate instrumentation is imperative to protect these critical items. Sensors are provided to alert operators of abnormal conditions on these items. If the condition cannot be cleared, the subsystem is placed in a bypass or recirculating mode. Normally, difficulties are of short duration and may be cleared while in the "by-pass" mode. Production is then resumed with minimum upset and without shutting down any plant subsystem.

Only as a last resort should a plant or subsystem be shut down. It has been documented by plant experience that more equipment problems occur during shutdown and start-up phases than during normal operation.

Of the several catalysts in the plant reactors, the primary reformer catalyst is the most sensitive to damage. An interruption of reforming steam for very short periods while feed gas is flowing can coke up the entire inventory. The cost of the replacement can be in the order of $50,000 for new catalyst and at least a week of downtime for unloading and reloading. Another critical catalyst is in the methanator, where a short breakthrough of carbon oxides, due to failure of the CO_2 absorber system, can result in a temperature run-away with damage to catalyst and possibly the reactor. The low-temperature shift converter is also subject to possible catalyst damage.

In all these cases, the instrumentation is such as to block-in the reactor and maintain the remaining plant subsystem in operation if possible.

Variations in instrumentation

The instrumentation philosophy described here is M. W. Kellogg standard unit instrumentation. Numerous variations have been utilized at the client's option.

The Primary Reformer

The Kellogg reformer is a fired furnace containing catalyst-filled tubes through which feed gas and steam pass during reaction. As mentioned previously, the catalyst is quite expensive and is very sensitive to coking if steam is interrupted while feed gas continues to flow. The furnace is a long, large cabin-type box with as many as 150 burners evenly spaced at the top of the box firing vertically downward. A slight negative pressure is held in

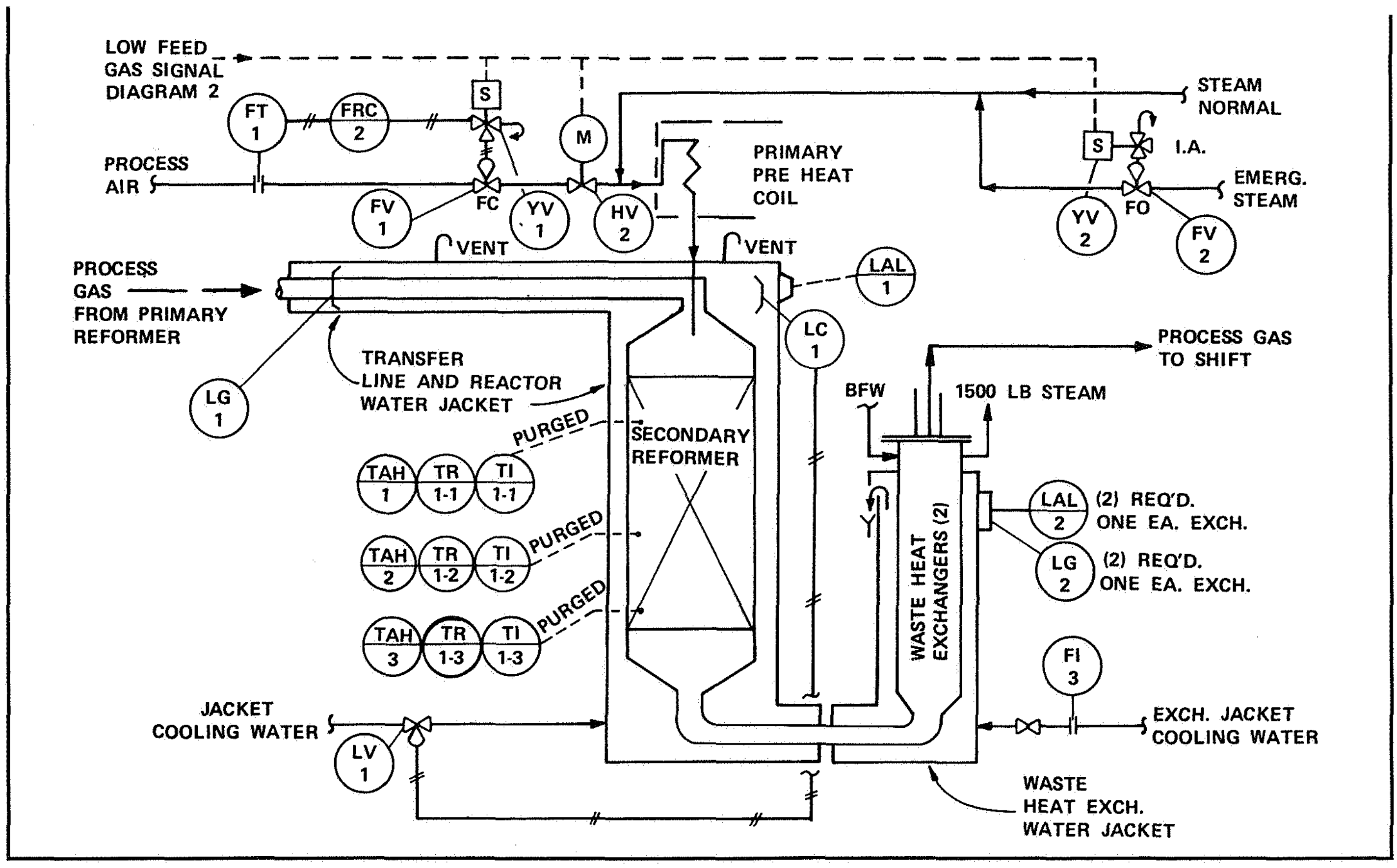

Figure 3. Secondary reformer controls.

the box by means of an induced draft fan at the stack end of the furnace.

Reformer firing. These controls can be broken into those for start-up and combustion safety. (See Figure 1.)

Start-up Controls. To ensure a safe light-off of the reformer, a means is provided to verify that all burner cocks are initially closed prior to introduction of fuel gas. This ensures that no fuel can flow into the furnace before light-off, thus preventing a possible explosive mixture from developing. The checking system as shown in the diagram in Figure 1 involves the use of Factory Mutual plug-type cocks on every burner feed. These cocks have plugs which are drilled and then series-connected with small-diameter tubing. When all cocks are in the closed position, the inter-connecting tubing forms a continuous path so that when pressurized at one end, it actuates a pressure switch at the other end. Prior to light-off, the inter-connecting tubing is pressurized, usually with natural gas and with the cocks all in the closed position. The pressure switch (PSH-2) is tripped which actuates the fuel shut-off solenoid valve (PY-2). Latching this valve open pressurizes the header. The header pressure switch (PAL-1) will hold the solenoid valve (PY-2) open as long as sufficient pressure is available for firing. The operator then disengages the Factory Mutual system utilizing YS-2, opens the individual burner cocks, and lights the system.

Too many burners for flame detectors to be used

Burner flame detectors are not utilized due to the large number of burners involved. The high density of burners and large heat capacity insures self-piloting or reignition of any isolated burner. Utilization of flame detectors would present problems in sighting of detectors in the high-density furnace and cause false shutdown due to equipment failure with so many burner detectors involved.

Combustion Safety Controls. Due to the physical size of the reformer and large heat capacity, automatic safety controls on the many process tubes are not required. Nor are they feasible. The operator monitors individual tube effluent temperatures. From a remote point, he manually fires and balances the various rows of burners with the manual loading stations (HIC-1), to optimize effluent gas composition via analytical monitors. Temperature alarms may be provided to annunciate any burner imbalance.

Combustion draft is maintained by a pressure controller (PIC-3), which actuates the induced-draft fan governor. If the draft pressure increases above the minimum required, a pressure alarm (PAH-3) alerts the operator. Failure of the induced-draft fan is detected by a pressure switch (PSH-4) in the fan suction.

This is a severe emergency, requiring shutdown of the reformer; however, it must occur in a logical sequence. An emergency steam ring is provided in the primary reformer stack for this purpose. This, when "tripped open," allows a relatively large quantity of steam to flow into the stack producing a "mild" draft keeping the fire box slightly negative until all burners are turned down.

Reformer Steam/Feed Gas Ratio Controls. Steam to the reformer must be supplied in excess of the quantity required for reaction, to minimize coking of the reforming catalyst. To accomplish this, a ratio monitoring system is employed as shown in Figure 2.

The feed gas and the steam flow are held constant by individual flow controllers (FRC-1 and FRC-2). Depending on the variation in composition and pressure of the feed gas, it may be necessary to compensate for pressure and density variations, as shown in Figure 2, to achieve an accurate flow measurement. The feed gas flow is then ratioed to the steam flow in a ratio comparison relay,

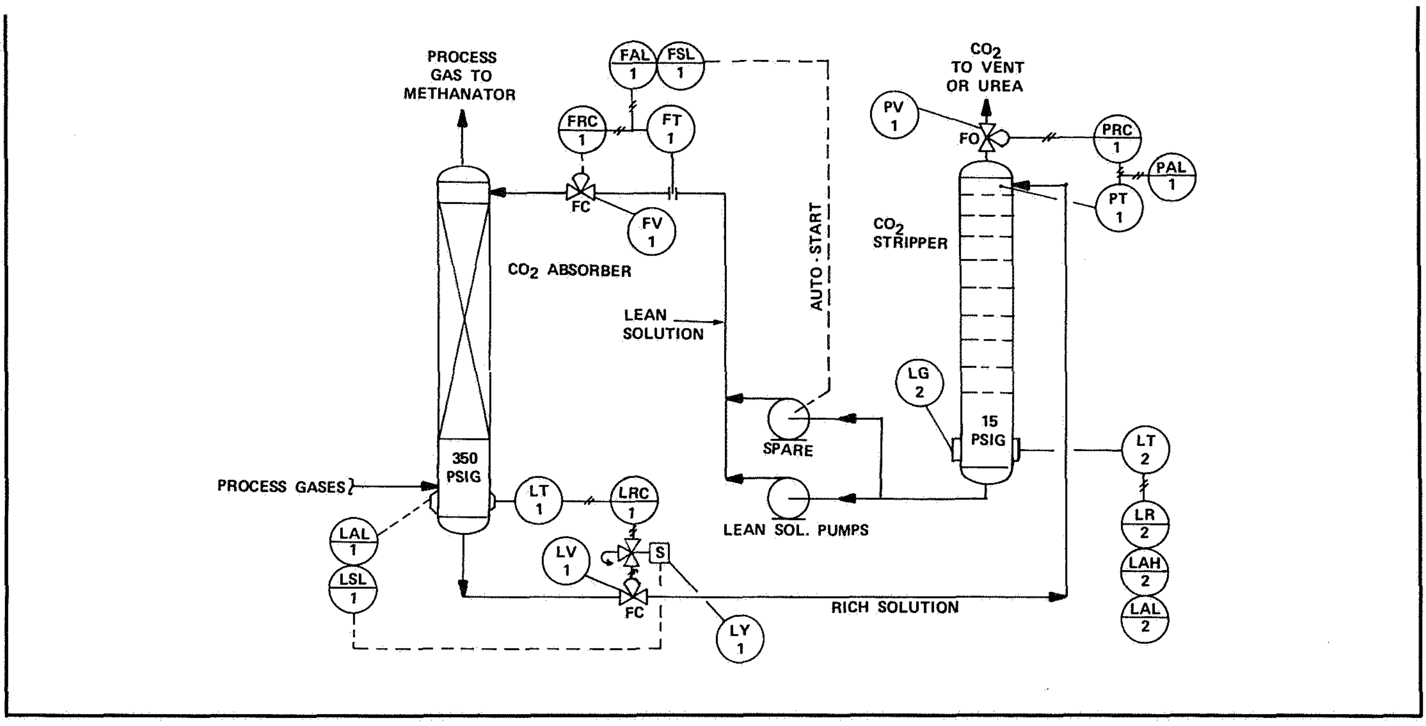

Figure 4. Carbon dioxide absorber controls.

(RAL-5), which calculates the flowing ratio and compares it to a pre-set limit. If the ratio of steam flow to gas flow falls below the ratio setting, an alarm is sounded to warn the operator of an impending emergency. If the ratio continues to fall, the low ratio switch (RSL-5) actuates the feed gas shutdown system. This is accomplished by the closure of the solenoid valve (FY-1) and the motorized gate valve (HV-1). The solenoid valve operates the fast-closing control valve (FV-1) while the slower motor-operated valve is required to insure absolute shutoff of the gas flow. The steam valve (FV-2) remains on automatic flow control to maintain near normal reformer tube temperature.

The Secondary Reformer

This is a large catalyst-filled pressure reactor in which a partial combustion reaction occurs between the effluent gases from the primary reformer and combustion air from the process air compressor. This reaction provides the proper ratio of nitrogen for the synthesis reaction downstream and raises the gas temperature to 1,800°F. to supply heat for the reaction occurring in the catalyst beds below. Because of the high temperature involved, the reactor shell is protected by an internal refractory lining and an external water jacket. It is imperative that 1) the internal reactor bed temperatures are not allowed to become excessive, and 2) sufficient jacket water level is maintained for cooling.

The secondary reformer bed temperature measurement is a difficult application. In addition to the high temperatures, the high content of hydrogen penetrates the thermocouple wells and reduces the life and reliability of the thermocouples. Specially purged and sheathed couples have been developed to provide a "reasonable" life in hydrogen service.

A number of bed temperature points are recorded to constantly track the reformer temperature profile. (See Figure 3.) High temperature alarms (TAH-1, 2, & 3) are provided to warn the operator of excessive bed temperatures. No automatic corrective action is taken.

Secondary Water Jacket Controls. A common water jacket cools the reformer and associated transfer line by vaporizing the jacket water to atmosphere. This vaporization requires constant make-up water, which is provided by the level controller (LC-1). A level alarm (LAL-1) is provided to warn the operator of falling water level. The waste-heat exchanger water jackets are also provided with a low level alarm (LAL-2). No automatic corrective action has been designed into these systems.

Combustion Air Control. Combustion air to the secondary reformer is controlled by a flow controller (FRC-2). In the event of feed gas failure, combustion air flow must be interrupted to prevent damage to the catalyst and downstream equipment. Activation of the feed gas flow switch (FAL-1 in Figure 2) closes solenoid valve (YV-1), which in turn closes the control valve (FV-1) and activates the motorized gate valve (HV-2), insuring both fast and tight shutoff. The feed gas flow switch (FAL-1) also actuates the solenoid valve (YV-2) opening the emergency steam valve (FV-2). This provides sufficient steam to keep the primary preheat coil below its design temperature during the shutdown operation.

The CO_2 removal system.

Prior to entering the synthesis loop, the gas must be free of carbon oxides. The CO_2 absorber system removes all but a fractional percent of the carbon oxides, using MEA absorption. All remaining oxides are removed by the methanator. The CO_2 system shown in Figure 4 has two essential safety systems.

Lean Solution Failure. The low flow alarm (FAL-1) will warn the plant operator that a dangerously low solution flow rate has occurred. (FSL-1) will start the spare pump if the flow continues to drop beyond the level required to insure carbon oxide removal.

Loss of Absorber Level. Loss of level in the high pressure (390 lb./sq. in. gauge) absorber could allow a gas pulse "blowing by" to the atmospheric stripper, causing possible serious damage to the internals (i.e., trays). To prevent this carry-over, low level switches (LAL-1 and LSL-1) are provided in the absorber to warn the operator of impending danger and to close the tight shutoff valve (LV-1) in case of level failure. (LSL-1) will trip the latching solenoid valve (LY-1), venting the control valve (LV-1) to isolate the absorber from the stripper. The latching solenoid valve must be reset manually by the operator after he has cleared the malfunction.

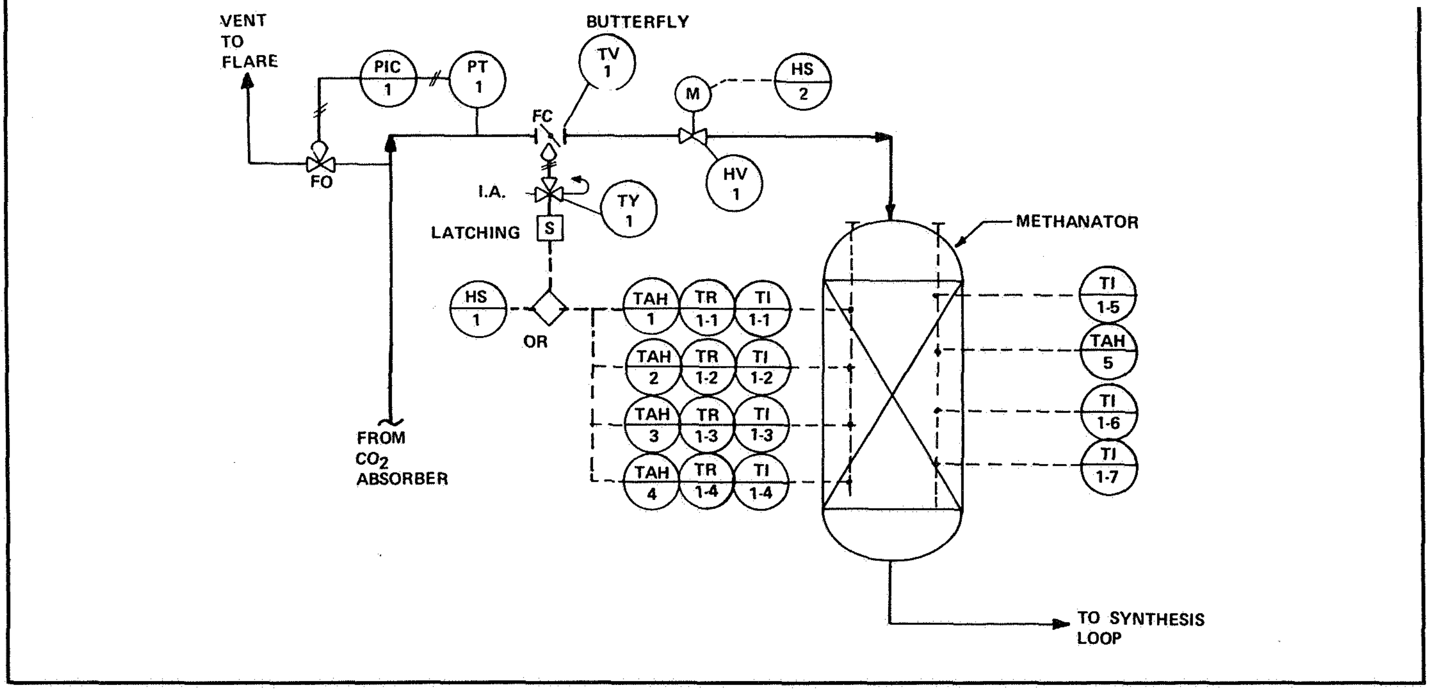

Figure 5. Methanator controls.

Methanator Temperature Failure. The methanator utilizes a highly exothermic reaction to convert the remaining trace carbon oxides into methane. A large breakthrough of carbon oxides from the absorber can cause a very rapid and dangerous temperature rise. (See Figure 5.) A multipoint recorder (TR-1) continually monitors the reactor temperature profile. An independent alarm (TAH-5) warns the operator of abnormally high temperature operation. A critically high temperature will trip the redundant recorder temperature alarms (TAH-1 through 4), actuating the solenoid valve (TY-1) and closing the quick-closing butterfly valve (TV-1). A pushbutton (HS-1) allows the operator to close (TV-1) if he notes impending danger in the system. A tight shutoff, motor operated valve (HV-1) is provided to insure bubble tight shutoff. A pressure controller (PIC-1) is included to prevent over-pressuring the upstream system during methanator shutdown and to allow operation of the CO_2 absorber during malfunction isolation of the methanator.

Three levels of steam pressure

There are three levels of steam pressures in the modern ammonia plant, 1,500, 550, and 50 lb./sq. in. gauge. The high-pressure steam is generated by means of process gas waste heat exchangers at the secondary reformer and shift converters, and also by the auxiliary boiler. These steam generators feed from a common elevated steam drum. Feedwater flows from the steam drum to all the generators by free convection. Feed water make-up is pumped through a preheat coil in the primary reformer furnace and several other process boiler feed-water exchangers in parallel and then to the steam drum.

All the 550 lb./sq. in. gauge steam is generated by the extraction steam from the synthesis gas compressor steam turbine driver which uses all the 1,500 lb./sq. in. gauge steam generated.

Steam Drum Controls. The steam drum is elevated approximately 100 ft. above grade to provide free feedwater flow to the steam generators. Due to its location, care must be taken to provide necessary monitoring instruments at grade level. (See Figure 6.)

To keep close surveillance on drum level, two independent transmitters (LT-1 and LT-2) are provided which transmit to the main control board. One of them (LT-2) sends a signal to a field level indicator located near both the boiler feedwater pumps and valve. It can be used as a guide for manual operation of the equipment in the event of instrument failure.

Independent drum high- and low-levels alarms (LAH-3 and LAL-4) are provided to warn an operator of an emergency situation. In many cases, local codes or insurance requirements call for shutdown of boiler firing in the event of low boiler drum level.

Boiler Feedwater Controls. (See Figure 7.) The steam drum retention time is relatively short. Any interruption of water flow to the drum must be corrected quickly. The most likely cause of boiler feed-water failure is a malfunction of the boiler feed-water pump. A low flow alarm (FAL-1) is provided to automatically start a spare boiler feed-water pump. If the flow of water is not resumed, the low level switch (LSL-4) on the steam drum will initiate manual or automatic reduction of the auxiliary boiler and primary reformer firing. Upon loss of drum level, the plant shutdown procedure should be initiated by the plant operating personnel.

This procedure is a prescribed series of manual and semi-automatic actions resulting in a safe and orderly termination of operation.

Another possible source of failure of boiler feed-water is a malfunction in the demineralized water supply. This upset will be detected by a low flow alarm (FAL-5) in the deaerator make-up water line. The deaerator has a retention time of 15- to 30 minutes, which allows considerable time to clear the difficulty. If the fault is not corrected, the deaerator low level alarm (LAL-3) will annunciate, warning the plant operator to initiate plant shutdown procedures. The loss of deaeration steam will result in unacceptable water quality in a short time. This condition is detected by the low pressure alarm (PAL-1). The inventory of the deaerator usually allows ample time to re-establish the steam flow.

Auxilary Boiler Controls. The auxiliary boiler provides 200,000- to 300,000 lb. of 1,500 lb./sq. in. gauge steam during upset conditions. It must be kept in operation up to the last possible moment to assure safe shutdown of the plant. During normal operation, it operates

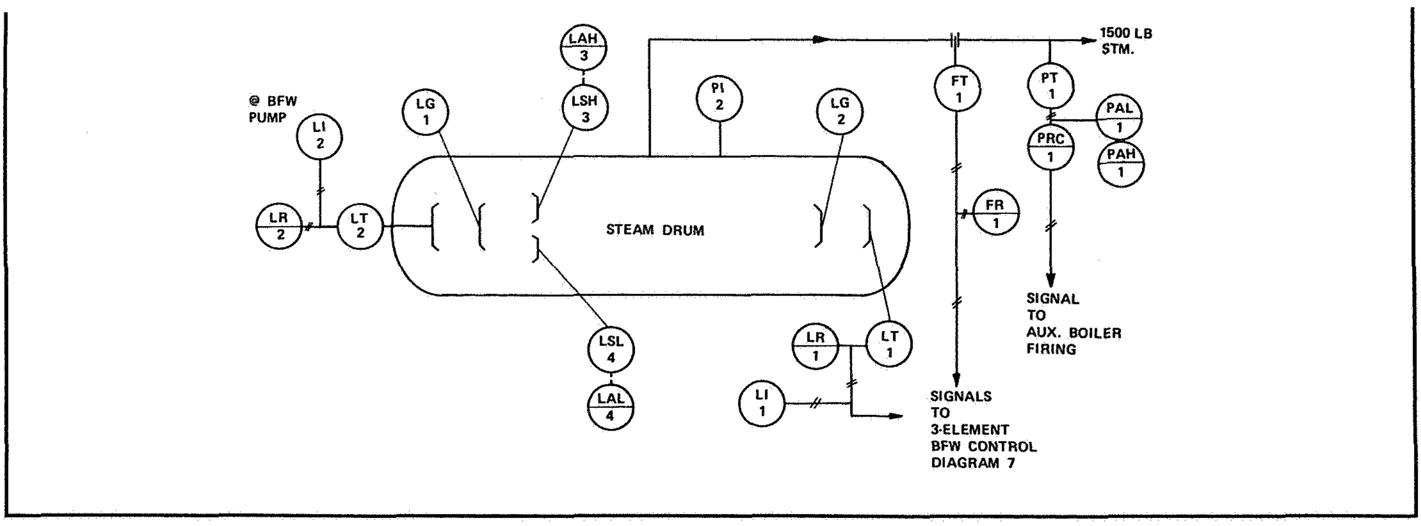

Figure 6. Steam drum controls.

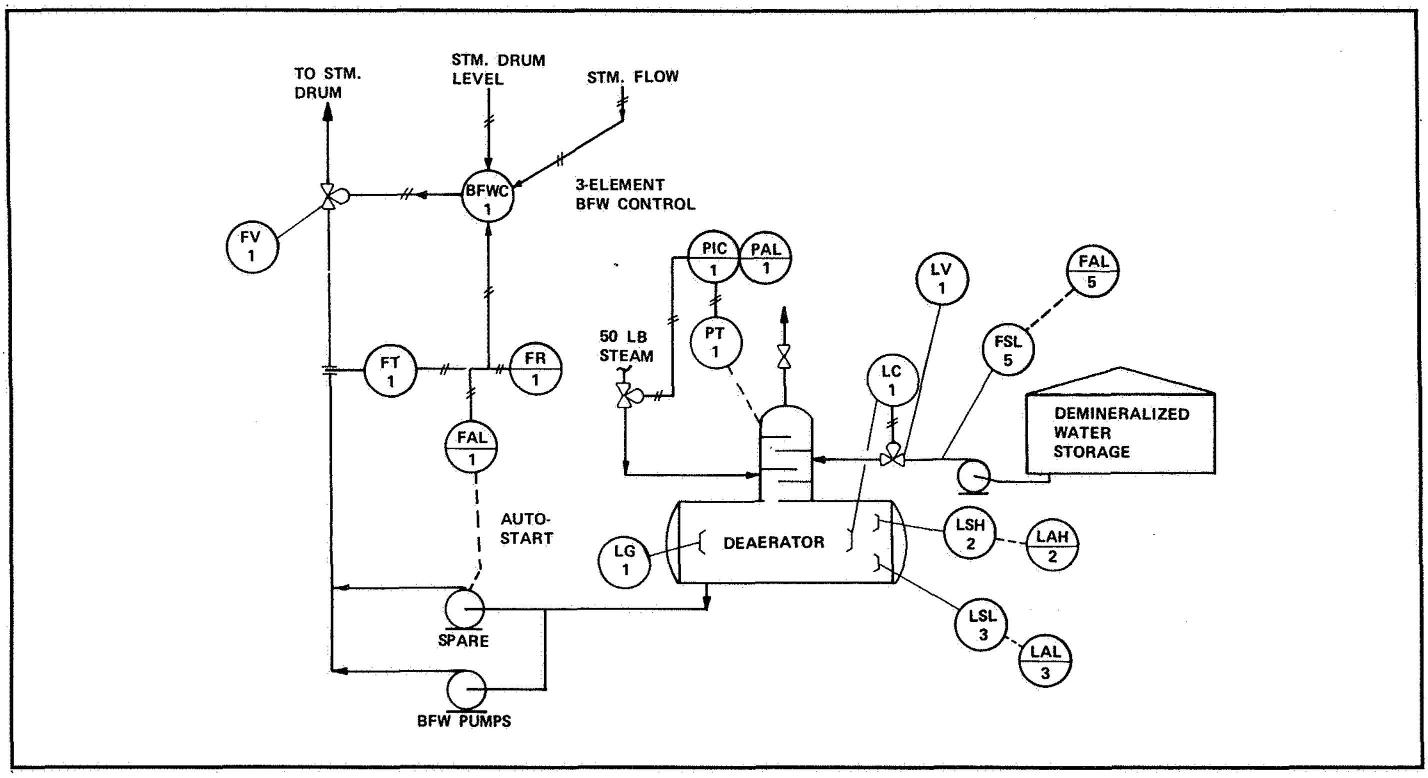

Figure 7. Boiler feed-water controls.

at reduced rates. The minimum but completely adequate controls for the boiler are shown in Figure 8.

Start-up Controls. A checking system is furnished to make sure that burner and pilot cocks are closed prior to initial light-off of pilots as described in the primary reformer section. The checking gas will actuate a pressure alarm (PAL-5) which is interlocked electrically with the solenoid valve (PY-3), thus allowing it to be latched closed and thereby opening fuel gas shutoff valve (PV-3). The furnace operator may now open the pilot cock and light-off each pilot individually followed by light-off of the main burners. A defeat switch (YS-5) is provided to deactivate the check circuit prior to light-off. This may be done automatically by proper relaying of the interlock circuitry.

Firing Controls. The auxiliary boiler is the swing steam generator in the ammonia unit. Therefore, the 1,500 lb./sq. in. gauge steam pressure controller (PRC-1) sets the firing rate on the auxiliary boiler by actuating fuel gas control valve (PV-1). Because of the quick increase in demand common to this type of boiler, it is necessary to limit the burner pressure from becoming excessive.

A sudden pressure surge in furnace burner pressure can result in unstable and dangerously pulsating burner operation. To prevent this condition, a pressure controller (PC-2) acts upon excessive fuel gas pressure and reduces the fuel pressure to a safe level by partially closing the fuel gas control valve (PV-1) through a selector relay (YY-1).

Combustion air is provided by the burner louvre which operates on the difference between barometric and fire box pressure. Fire box pressure is maintained by means of the pressure controller (PRC-4) which operates the damper (PV-4). A high pressure alarm (PAH-4) warns in the event of draft failure. If this condition persists, boiler firing must be reduced. In the system shown, this must be done manually by the plant operator. However, automatic shutdown of firing is also possible in the event of draft failure. The disadvantage of an automatic shutdown is the high probability of false boiler shutdown and sudden uncontrolled plant shutdowns. Careful manual operation can allow the unit to ride through momentary upsets; and if shutdown is necessary, it may be done in an orderly fashion.

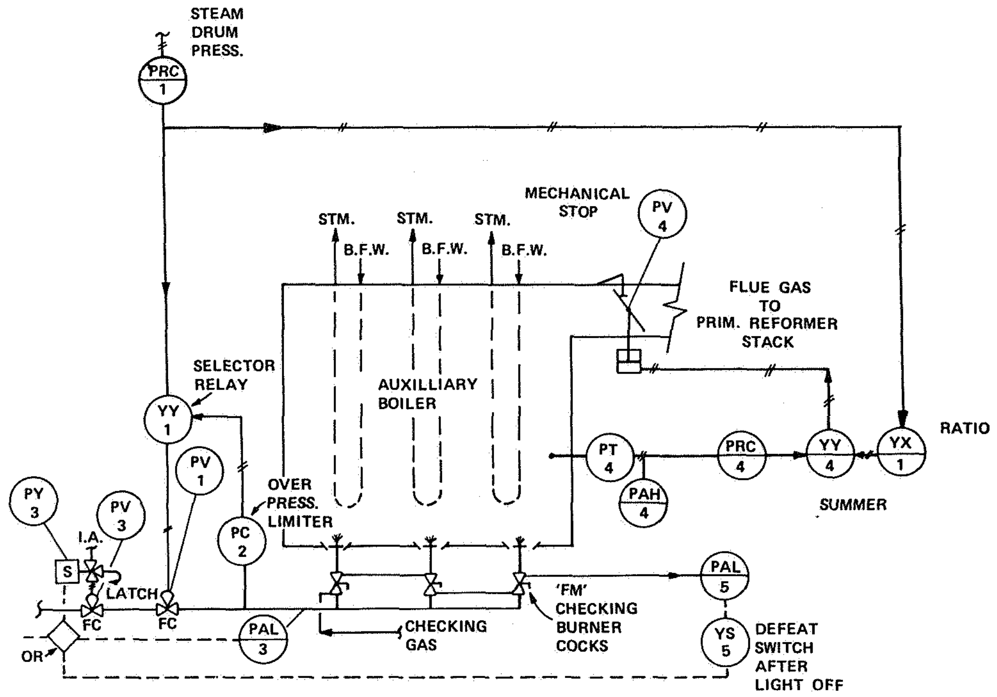

Figure 8. Auxiliary boiler controls.

Insufficient fuel only cause for shutdown

The only operating shutdown is actuated by the low fuel pressure switch (PAL-3). This shutdown switch operates when the fuel pressure drops below a safe operating value. The shutdown signal actuates the solenoid valve (PY-3), which, in turn, vents the diaphragm of the shutoff valve (PV-3). The solenoid valve is of the latching type, which is not reopened until fuel pressure is re-established.

Optional Boiler Instrumentation. Additional instrumentation can be installed on the auxiliary boiler with the intent of providing greater safety. A point of diminishing return in safety is always reached with added instrumentation. Each plant must determine how far it should go in safety controls and still achieve a boiler with an adequate onstream factor.

Steam Letdown Valve Considerations. The emergency letdown valves (PV-2A and PV-2B) and the bypass valve (HV-1), shown in Figure 9, are critical items in the plant from both a personnel and equipment safety standpoint. The operating conditions for these valves are quite severe, and careful consideration must be given to both the design of the valves and the associated piping system.

The valves are heavy-duty, single-seated, straight-through design with oversized piston actuators. In the case of the letdown valves (PV-2A and PV-2B), actuators are air-operated and the air supply to the valve positioner is backed up by local high-pressure air cylinders. In the event of failure of both sources of instrument air, a fail-safe feature on the valve actuator drives the valves to their "safe" position. The actuator for the bypass valve (HV-1) is normally operated by hydraulic oil from the compressor lube oil system. However, it is backed up by an independent hydraulic oil supply set, which automatically takes over in the event of loss of normal oil supply.

The letdown of large amounts of steam from 1,500 to 550 lb./sq. in. gauge results in high fluid velocities which can result in excessive noise and dangerous mechanical vibration. In order to minimize these difficulties, the piping system is designed to include suitable noise silencing sections and properly designed piping supports.

Medium Steam System Controls. The medium (550 lb./sq. in gauge) steam system, as previously mentioned, is supplied by the extraction steam from the synthesis compressor steam turbine drive. The 550 lb./sq. in. gauge stream flow must be protected. Since it is the source of process steam to the primary reformer, a short interruption of reformer steam can result in complete coking of the primary reformer catalyst. It also supplies steam to steam turbine drives of major equipment, such as the boiler feed water pumps, cooling water pumps, and the primary reformer induced draft fan.

Pressure of the 550 lb./sq. in. gauge header is held by extracting more or less steam from the synthesis gas turbine by means of the pressure controller (PRC-1) throttling the inlet multi-valves of the turbine. If, for whatever cause, this control cannot satisfy the 550 lb./sq. in. gauge header demand and the pressure falls below safe levels, the under-pressure controller (PRC-2) begins to open the header letdown valves (PV-2A and 2B), which are split range valves. The combined capacity of these valves can more than handle the normal flow through the synthesis gas machine turbine. They have a relatively high speed of operation.

For the overpressure situation, where a sudden reduction in 550 lb./sq. in. gauge steam demand occurs, the overpressure controller (PIC-3) actuates the vent control valve sufficiently to keep the pressure within safe limits. This controller ensures that the system relief valves do not actuate except in extreme emergency. Both high and low pressure alarms (PAH-1 and PAL-1) are provided on the 550 lb./sq. in. gauge header to warn the operator of an impending dangerous situation.

Synthesis Gas Compressor Shutdown. This is a likeli-

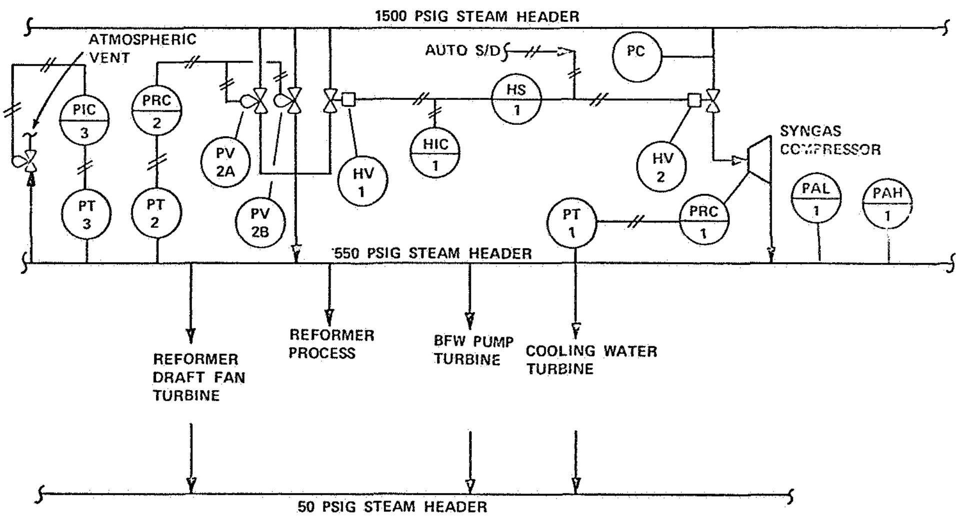

Figure 9. Steam system.

hood during initial plant start-up, and it also may occur during normal plant operation for various possible reasons. The compressor shutdown is effected by automatically or remote manually closing the 1,500 lb./sq. in. gauge steam shutoff valve (HV-2).

This process is quite rapid because the turbine inlet valve is hydraulically operated and set to close in less than one second. This quick closure results in an abrupt stoppage of steam flowing to the 550 lb./sq. in. gauge header through the synthesis gas turbine, which must be replaced immediately through the turbine bypass control station. The hydraulically-operated valve (HV-1) is opened by the same trip system that closes the compressor turbine inlet valve. The bypass valve (HV-1) trips wide open within one second so that only a very small and short duration dip in 550 lb./sq. in. gauge header pressure is experienced. The valve (HV-1) is so sized to pass somewhat less than the normal steam flow through the synthesis gas turbine, resulting in the pressure controller (PRC-2) automatically taking over control of the header pressure and opening control valve (PRC-2A). Normal operating procedure next is to slowly close the synthesis gas bypass valve (HV-1), taking full header control utilizing both split range letdown valves (PRC-2A and 2B).

Conclusions

The safety controls outlined herewith represent a proven, adequate level of safety instrumentation to provide a safe and operable plant during the majority of emergency situations utilizing a minimum number of operating plant personnel.

Considerably more routine instrumentation must be provided for less critical operating difficulties. These generally fall into the "housekeeping" variety of instrumentation, such as compressor lube oil controls and alarms, high level alarms on process vessels, high temperature alarms on reactor walls, etc. Further, much more instrumentation is necessary for the normal process control requirement. No attempt has been made to cover *all* instrumentation requirements.

Great reliance is placed on plant operators to take proper corrective action in response to alarm only devices. This requires well-trained, alert plant personnel who thoroughly understand the plant operation and the characteristics of the plant equipment. There is no substitute for qualified operators, if a plant is to operate safely and have a good "onstream" record.

The alarm devices described can be utilized to take corrective action automatically. The amount of additional instrumentation required to make logical corrective decisions and perform them in proper sequence tends to become excessive. The increased number of components required brings up the question of reduced overall system reliability. It also increases the amount of preventive maintenance necessary and generally the required competence level of maintenance personnel. It is up to plant management to decide, based on knowledge of plant personnel, the point of compromise where additional safety instrumentation will be only marginally beneficial to overall plant safety.

A final point should be made, and this with regard to instrument systems maintenance. It is imperative that a well-planned preventive maintenance program be established at the onset of plant operation and adhered to. Maintenance personnel must be thoroughly familiar with each safety loop from the standpoint of knowing its operating philosophy, the system "circuitry" and the characteristics of its hardware components. Only through the coordination of personnel, major equipment, and safety shutdown systems can one have an effective ammonia plant safety system. #

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