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ABSTRACT.

The JET Facilities Active Gas Handling System (AGHS) comprises ten interconnected processing sub-systems that supply, process and recover tritium from gases used in the JET Machine. Operations require a diverse range of process instrumentation to carry out a multiplicity of monitoring and control tasks and approximately 500 process variables are measured. The different types and application of process instruments are presented with specially adapted or custom-built versions highlighted.

Forming part of the Safety Case for tritium operations, a dedicated hardwired interlock and alarm system provides an essential safety function. In the event of failure modes, each hardwired interlock will back-up software interlocks and shutdown areas of plant to a failsafe condition. Design of the interlock and alarm system is outlined and general methodology described.

Practical experience gained during plant operations is summarised and the methods employed for routine functional testing of essential instrument systems explained.

1. INTRODUCTION

The AGHS began commissioning in 1991 and has successfully supported JET machine operations, including experimental tritium campaign, to date [1, 2]. During this period, process instrumentation and safety interlocks have contributed to the safe and reliable operation of the AGHS. With careful selection of equipment, routine functional testing of safety critical instrumentation systems and evolution of operational and maintenance procedures, a minimum number of process interruptions resulting from instrumentation and interlock system failure has occurred.

This paper provides a brief overview of the types of instrumentation and safety protection system in use and remarks on the practical experience gained with relevance to future instrumented systems.

2. PROCESS INSTRUMENTATION

2.1 GENERAL

The main AGHS control features a Distributed Control System [3]; in addition two plant subsystems are operated by Programmable Logic Controllers. All process instrumentation, which is not safety related, interfaces directly with the control systems. For the purpose of functionality and standardisation, the majority of analogue signals are conditioned to a 4 to 20mA process variable signal and converted to plant wide process units, typically mbar or Kelvin.

It is a JET Quality Assurance requirement that all-primary process instrumentation and connecting pipework must comply with national standards and has undergone extensive inspection and testing. This includes the certification of materials for construction and testing for pressure and vacuum leak tightness [1].

Instrumentation installed within the AGHS demonstrates several unique safety features. The majority of instruments are placed in secondary containments and some of those are subject to elevated temperatures up to 473K. Within purged containments, the environment is also subject to pressure changes. Hermetically sealed ultra high vacuum electrical feedthroughs provide connection to external equipment and all

manufacturers standard cables have been adapted or changed. To comply with JET standards, all installed cables are manufactured from Low Smoke Zero Halogen insulation material.

An overview of general process instrumentation showing the process parameters and measurement methods employed throughout the plant including typical applications is given in Table I.

Examples of general instrumentation systems specific to AGHS requirements are:

- A critical humidity measurement on the outlet of the EDS alerts operators to molecular sieve dryer changes required [4]. Four identical aluminium oxide sensors mounted in a common copper manifold block provide a ‘two out of four’ high humidity alarm at greater than -60°C Dew Point. The arrangement is designed to avoid false alarms generated by sensor faults.

Table I: Overview of AGHS General Process Instrumentation

<i>Process parameter</i>	<i>Method of measurement</i>	<i>Safety functions</i>	<i>Sequence function</i>	<i>Typical task</i>
Pressure	Strain Gauge Sensor	Yes	Yes	–Uranium Bed Controls –Primary Process Pressure
	Mechanical Pressure Switch	Yes	Yes	–Transfer Line Overpressure –Pump Protection
	Capacitance Manometers	Yes	Yes	–Gas Inventory Control
	Mechanical Gauge	No	Yes	–Secondary Containment Controls
Vacuum	Pirani Gauge	No	Yes	–Secondary Containment Vacuum Controls
	Penning Gauge	No	Yes	–Secondary Containment Vacuum Controls
	Capacitance Manometers	Yes	Yes	–Ultra High Vacuum Pumping Operations
	Mechanical Gauge	No	No	–Secondary Containment Vacuum Controls
Temperature	Thermocouple	Yes	Yes	–Uranium Bed Controls –Heater Controls
	Resistance (RTD)	Yes	Yes	–Pressure Volume Temperature Calculations
	Vapour Pressure	No	No	–Cryogenic Module Operations
	Strain Gauge	No	Yes	–Liquid Nitrogen Supply
	Silicon Diode	No	Yes	–Cryogenic Module Operations
Humidity	Aluminium Oxide	Yes	No	–Molecular Sieve Performance
Flow	Thermal Mass	No	Yes	–Primary Process Flow –Detritiation Operations –Distillation Mass Balance Controls
	Differential Pressure	Yes	No	–Detritiation Operations
Level	PT100 Temperature	No	Yes	–Liquid Nitrogen Supply
	Resistance	No	Yes	–Liquid Helium Supply
	Capacitance	No	Yes	–Water Drain Tank

- The JET Machine is protected from overpressure by a ‘two out of three’ pressure switch interlock alarm. Upon overpressure condition, the transfer line will automatically vent to EDS, preventing the machine from reaching atmospheric pressure.
- Operation of the JET Machine is conditional upon operation of EDS as key safety related equipment. EDS availability is monitored using recombiner low temperature and low ventilation flow alarm signals to provide a pulse inhibit request to the JET Central Interlock and Safety System.
- Within the product storage, gas introduction and gas distribution subsystems, calibrated volumes combined with measurements from precision capacitance manometer and resistance thermometer allow the calculation of Pressure, Volume and Temperature gas inventory measurements [5].

The control system, process instrumentation and radiological protection instrumentation are operated from an Uninterruptable Power Supply with a minimum autonomy period of 30 minutes, sufficient to monitor and shutdown the plant safely in the event of total site power failure.

2.2 IONISATION CHAMBERS

Ionisation chambers (ICs) play an important role in AGHS control and protection. The two main types of JET’s purpose built flange mounted IC are small 15cm³ chamber, used to monitor tritium activity in primary process containment for control purposes and large 570cm³ (Figure 1), used to monitor tritium activity in secondary purged containment for evidence of process leakage. In addition commercial ionisation chamber instrumentation is installed on process subsystems including monitoring inlet and outlet of the Exhaust Detritiation System (EDS) using 10000cm³ chambers.

2.3 ON-LINE ANALYTICAL MEASUREMENTS

The main applications of on-line analytical measurements are:

- JET designed hydrogen-oxygen recombination sensors installed on the transfer lines between AGHS and the JET Machine are capable of detecting oxygen on-line at low pressures to warn of process leaks [6].
- On the inlet of the EDS, a commercial grade, non-depleting electrochemical oxygen sensor is interlocked to provide air inlet upon low oxygen level for the purpose of maintaining recombiner efficiency.
- The process gas chromatography subsystem column diagnostics are equipped with Katharometers for control of product valve switching.

3. HARDWIRED INTERLOCK AND ALARM SYSTEM

An independent, non-programmable, hardwired safety interlock and alarm system shuts down equipment to a failsafe condition. Software interlock trips and alarms alert operators in advance of abnormal process conditions before the final hardwired safety circuits are activated. The plant fail

safe condition ensures that the plant remains in a safe state following removal of all electrical power and instrument air to equipment including pumps, valve actuators and heaters etc.

3.1 INTERLOCK CIRCUITS

JET design interlock circuits are relay based in modular form, dedicated to the relevant plant subsystem processes. Relays are energised from a 24VDC supply and fail safe on loss of power. The block diagram in Figure 2 shows the AGHS Hardwired Interlock Modules interfacing with alarm systems, control systems and plant equipment.

3.2 ALARM SYSTEM

The hardwired alarm annunciation panel located in the AGHS control room provides 159 individual alarms to alert the operator that hardwired interlocks have tripped. The alarm panel comprises three categories of alarms with different levels of severity characterised by three different colours demanding appropriate operator response.

A number of critical alarm windows are duplicated on the JET Control Room Incident Desk alarm panel and alert operators during periods of unattended AGHS operation.

3.3 TESTING

Routine 6 monthly functional testing of safety related hardwired interlocks and alarms is an essential feature of the operating safety case. The normal testing method is to raise the process parameter such as pressure or temperature to the trip level in order to demonstrate fault sequence. Where it is impractical to do so, then the trip point of the instrument is adjusted to activate. A control system test program is loaded, per sub-system basis, as part of the test procedure to inhibit software interlocks used to trip equipment in advance of hardwired trips.

Functional testing of installed safety related ICs is carried out using a 3GBq Caesium-137 source contained within a lead-shielded pot positioned near to the chamber for exposure to ionising radiation. The source is capable of triggering the interlock circuits in the majority of applications. A 115GBq Iridium-192 source, capable of promoting sufficient ionisation current for testing chambers under vacuum conditions and those exhibiting memory effect is also used. The Iridium source is supplied and handled by an external radiographer.

4. OPERATION AND MAINTENANCE

In most cases preventative maintenance of instrumentation is generally not possible without interruption of processing unit. Maintenance of instrumentation is carried out on a replacement basis only when faults occur or during planned processing unit interventions so as to keep disruptions to operations at a minimum.

Once instruments have been exposed to tritium, off-site repair or re-calibration at the manufacturer premises is not practicable. Calibration status of general instrumentation can be verified in practice

either: a) against other installed precision instruments, b) against recently replaced standard sensors with valid calibration data.

Ionisation chambers, which are exposed to tritium, experience contamination of inner surfaces leading to reduction in low range sensitivity. Attempts to purge and bake the instrument in situ led to limited success on reduction of tritium retention and range reduction.

Other forms of instrumentation likewise exposed to tritium during operations have demonstrated no detectable changes in performance.

5. ENHANCEMENTS AND FURTHER DEVELOPMENT

Ongoing activities to provide continuous improvements to instrumented systems include the development of on-line tritium monitor for waste water transfer, installation of precision thermal mass flowmeters to EDS ventilation system and replacement of obsolete instruments no longer supported by the manufacturer subject to review. It is found that non-programmable instruments used in hardwired safety interlocks circuits are becoming increasingly difficult to source due to market adoption of programmable devices.

6. SUMMARY

- High integrity equipment is used and faulty instruments are repaired on a replacement basis only to minimise process downtime.
- Ionisation chambers exhibit degradation of performance through exposure to tritium, however these effects on other instrumentation have not been noted.
- Ongoing continuous improvement for instrumentation and protection systems, through operational experience, will aid the continued safety and efficiency of AGHS operations.
- The approaches taken so far have been effective in providing many years of safe and reliable operation.
- Future plant subsystems will be integrated into the AGHS using the same proven control and safety interlock methodology in compliance with current safety standards.

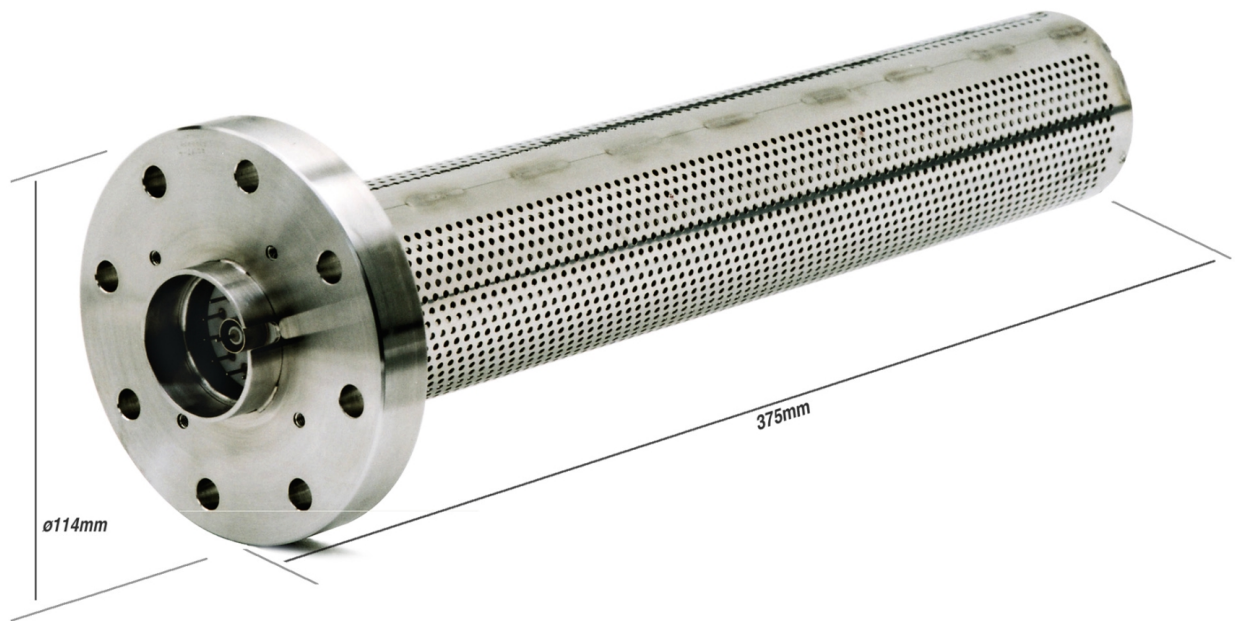
ACKNOWLEDGEMENTS

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Figure 1: Jet Design 570cm³ Ionisation Chamber

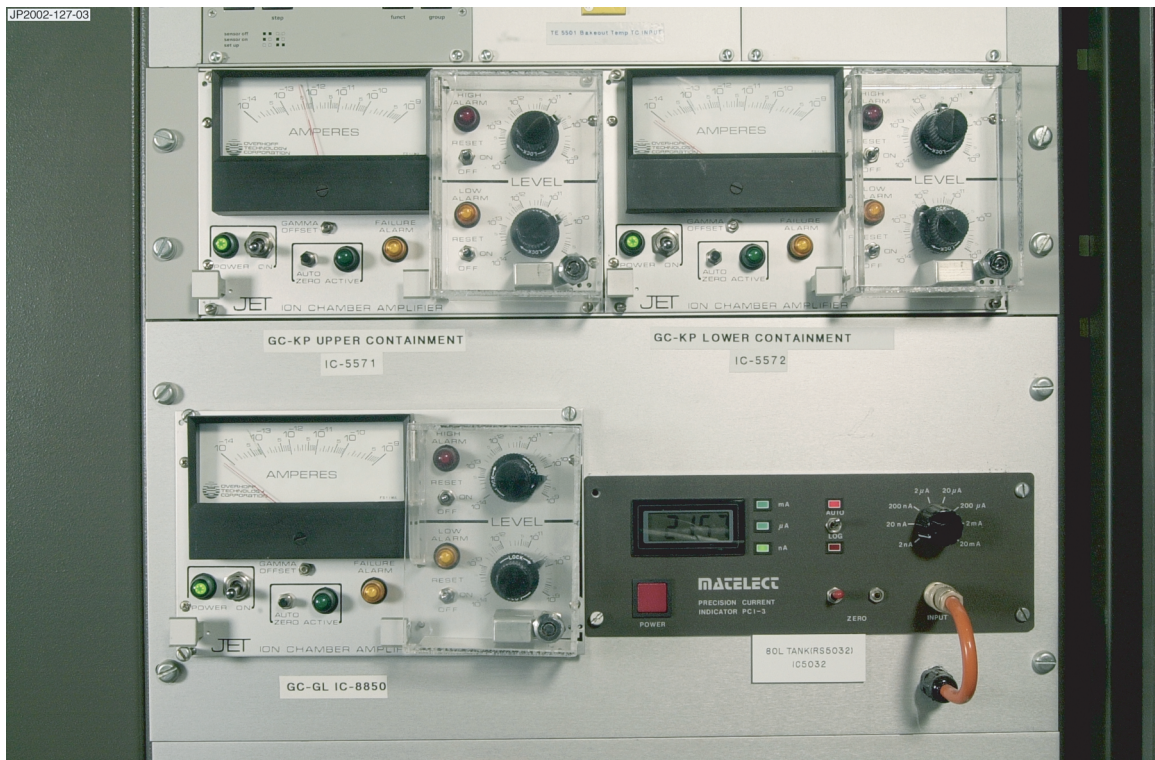


Figure 2: Ionisation Chamber Panel Display



Figure 3: Uranium Storage Beds Hardwired Interlock Modules