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TECHNIQUES FOR THE REMOTE MONITORING OF HYPERGOLIC PROPELLANT LEAKS

by

Peter M. Ricca, PhD

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ABSTRACT

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In this report are reviews of techniques for detecting and verifying malfunctions in vehicle ground support equipment. Optimization of detection, verification, display, decision, and reaction are presented from a systems standpoint; and sensor systems which may be operable over a wide range of gas concentrations are discussed.

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SECTION I
INTRODUCTION

A. TYPES OF HAZARDS

Launching a liquid propelled rocket is hazardous because of the copious quantities of propellants it carries. Propellant hazards can be classified into two main categories: (1) those affecting personnel (2) those affecting hardware. Hazards affecting personnel may be classed as those of toxicity, suffocation, and fire and explosion.

B. TOXIC GASES AND SUFFOCANTS

Toxic propellants of specific interest to NASA are nitrogen tetroxide, elemental fluorine, and the hydrazines; such as, hydrazine, monomenthylhydrazine, and unsymmetrical dimethylhydrazine. Of these, only hydrazine base propellants present fire and blast hazards, while all of them present dermal and respiratory hazards. In enclosed, inhabited spaces, there exists the possibility of anoxia from dilution of atmospheric oxygen by leakage of high pressure helium and nitrogen.

Each hazard requires a different detection subsystem, since it is impossible for a single detector to operate satisfactorily in many different atmospheres.

C. MALFUNCTION CHARACTERISTICS

Many failure modes are possible at a launch or test facility. Except for uncontrollable abort, all failure modes are qualitatively, if not quantitatively, similar. Typical propellant malfunction characteristics of rocket ground support equipment (GSE) are listed following:

1. Location - point external sources
2. Location - single point failure
3. Gas concentrations - wide range
4. Gas concentrations - rapid fluctuations
5. Time release pattern - discontinuous or sporadic
6. Phases - gas or liquid, present simultaneously
7. Temperatures - wide range of release

Experience with both ballistic weapons and manned space vehicles has shown that the majority of accidental releases of toxic liquids and gases occurs during active propellant transfer and flow operations. The probability of propellant release following its transfer is quite low until the vehicle tanks are pressurized prior to flight. The majority of recorded flight-weight hardware malfunctions are single point failures such as fitting, point, and seal leaks. The leak or spill probability from a passive ground storage vessel, even under pressure, is almost negligible.

SECTION II
PHILOSOPHY OF INSTRUMENTATION

Concepts for monitoring toxicants cannot be detached from overall system requirements and constraints. The chronology of system development using state-of-the-art techniques includes: (1) hazard recognition, (2) identification of system requirements, (3) preliminary hardware testing and evaluation, (4) specifications and hardware procurement, and (5) hardware improvement and/or modification.

Hazards must be recognized at the appropriate management organizational level to critically evaluate and justify action. Not only is high level management approval necessary to justify the high cost of toxic monitoring and control systems, but considerable engineering effort is also required, early in the program, to determine technical feasibility.

Two important decisions must be made during the requirements identification period: (1) Should area or point detection be used? (2) Should displays be local or remote?

The safety policy at the John F. Kennedy Space Center is that area detection be used in the blockhouse air-conditioning systems, unpressurized control buildings, test cells, and spacecraft white rooms; and that point detection be used when considerable personnel activity will take place around highly pressurized or fragile equipment. In such instances, sensors should be mounted directly on pipes or valves.

It is recommended that data be transmitted and visually displayed at a central control point such as the control room or blockhouse, with a direct communication link to an audible warning system. This philosophy is consistent with the concept of removing personnel from possible hazards. For passive GSE at a support facility, a duplicate display, slaved to the unit at the primary control point, may be located in the secondary facility control center.

SECTION III
TOXIC GAS MONITORING SYSTEM REQUIREMENTS

A. GENERAL

A monitoring system collects information on the cause and effects of a spill or leak but does not control the resulting hazards. Point detectors measure the causes; area detectors determine effects, such as gas concentration. When a Red condition is detected, the decision to ignore the malfunction (if noncritical), evacuate the site, or initiate countermeasures must be made. Countermeasures can be: inerting purges, switching to alternate systems, offloading propellants, depressurizing, activating suppression systems, etc. It is important to note that the decision to override or countermeasure the malfunction rests jointly with the chief test conductor and the pad safety supervisor, not with the hazard monitoring system operators. The cause-effect-decision-control relationships are shown in Figure 1. For Apollo/Saturn V, an active monitoring system is required from T-180 hours to T+24 hours to support the prelaunch countdown and deservicing in the event of a mission scrub. Hazardous conditions are not uniformly severe during this 204-hour period. The variable criticality of operations for a nominal Apollo mission is shown in Figure 2.

The installation and checkout time required for activation is also a variable item. Communication and display installation may precede launch by several months, while sensors and transducers are installed and system calibration is conducted about 1 week before activation.

B. SYSTEM COMPONENTS

To meet automated launch system requirements, a toxic gas monitoring system will consist essentially of three basic subsystems as shown following and in Figure 3. These subsystems are explained in detail in succeeding sections.

1. Data Collection Subsystems

   Sensors and Transducers
   Amplifiers and Contact Meters or Switches
   Alarm Relays and Circuits

2. Data Transmission Subsystem

   Oscillators and Coders (Frequency Shift Keying)
   Transmission Hardlines
   Decoders

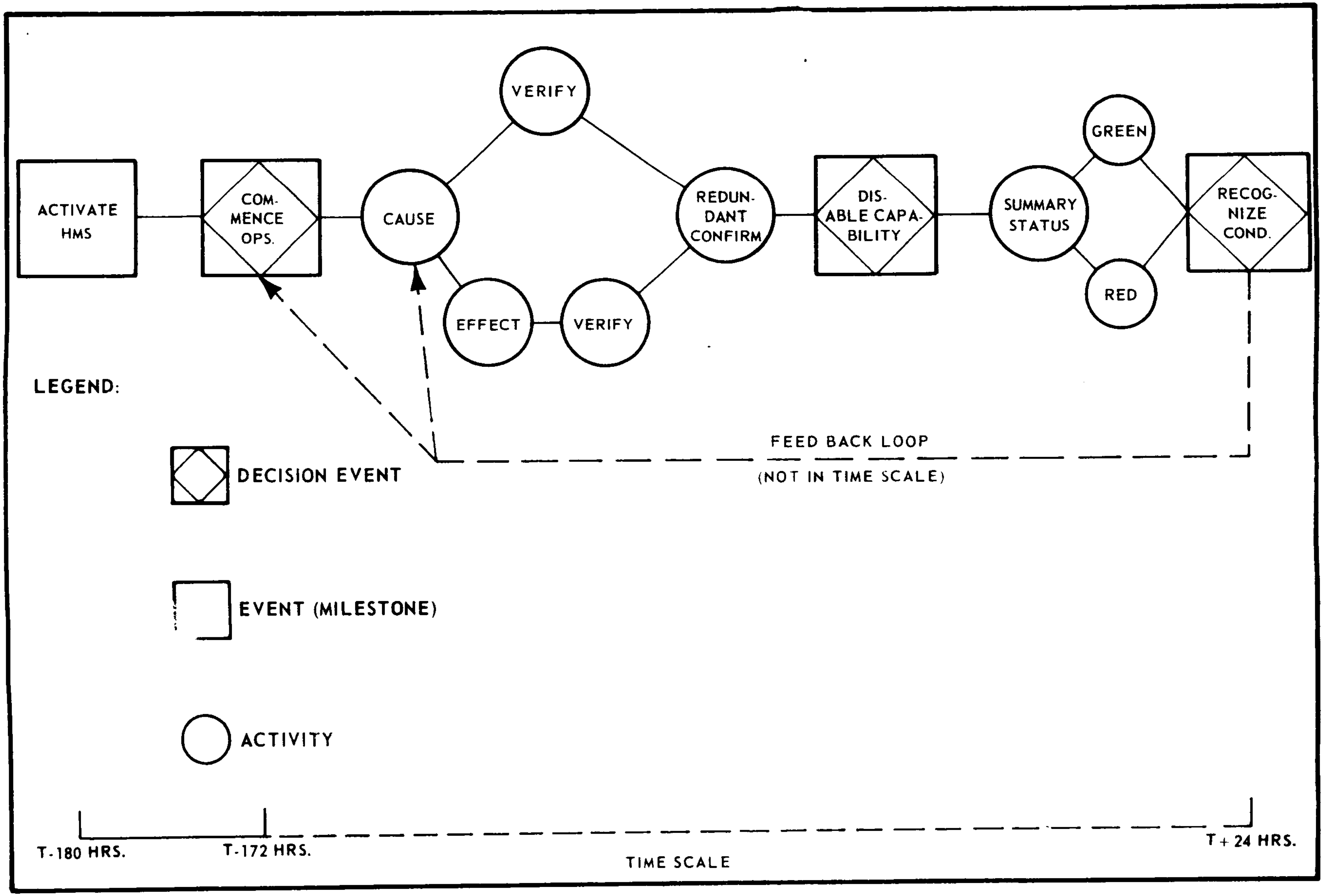

FIGURE 1. DECISION LOGIC OF MONITORING SYSTEM

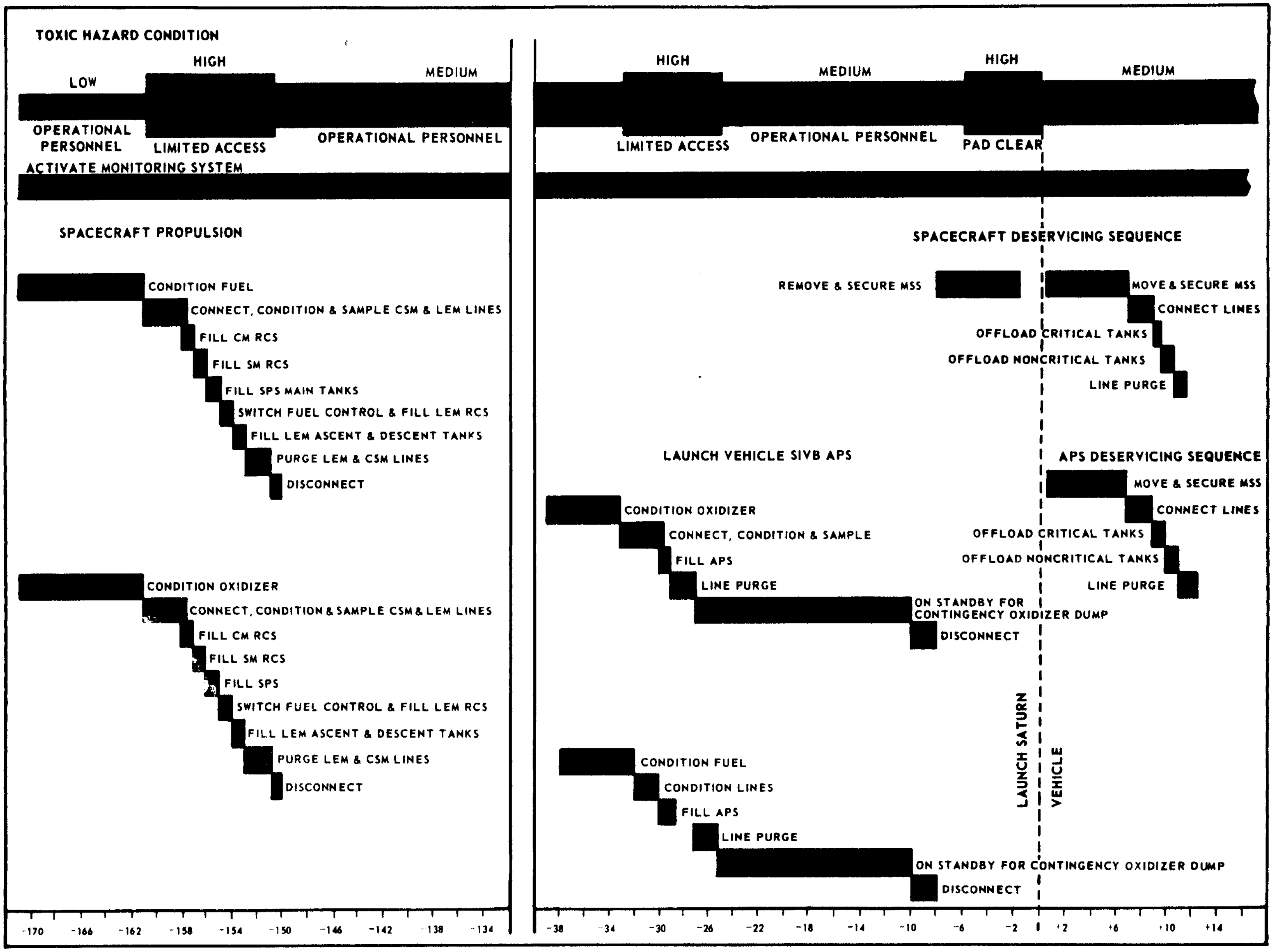

FIGURE 2. NOMINAL PRELAUNCH SEQUENCE, APOLLO/SATURN V, LAUNCH COMPLEX 39

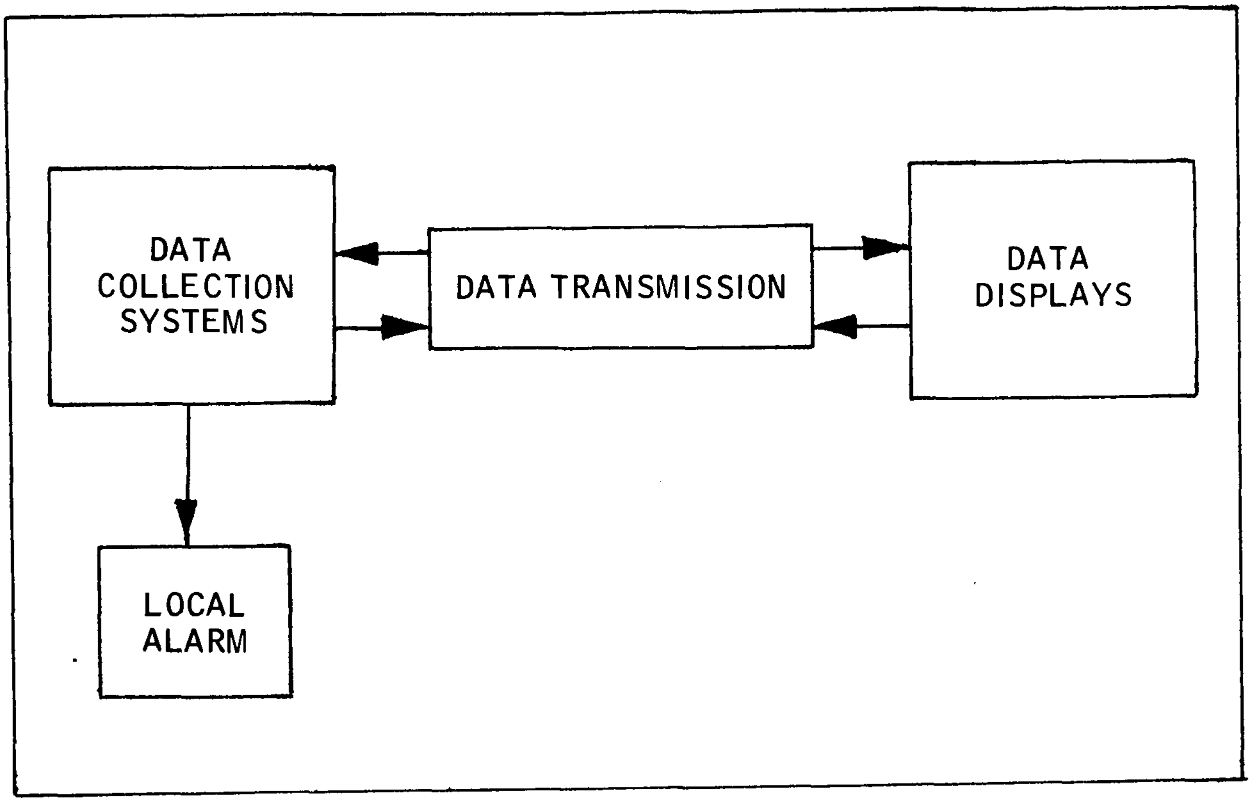

FIGURE 3. MONITORING SUBSYSTEM LOGIC

3. Data Display Consoles

   Subsidiary Operations Display
   Operations Safety Display

C. THE SYSTEM LIFE CYCLE

The life cycle of a monitoring system extends from activation of equipment through test, operation, termination, deactivation, maintenance, and refurbishment. Reliability is paramount during activation and testing, and durability is important during maintenance and refurbishment.

SECTION IV
DATA COLLECTION SUBSYSTEMS

A. GENERAL

Sensors or transducers produce electrical pulses in the presence of toxic vapors. These pulses are usually in the millivolt or microvolt range and generally require amplification at the transducer. This will magnify and/or condition the signal for transmission. Transducers based on physical/chemical principles are most often used as point detectors. In some instances, however, area or scanning devices such as ultrasonic microphones and long path infrared techniques have been used. Ideally, gas sensors should meet the specifications shown in Table 1.

TABLE I

SENSOR SPECIFICATIONS

Primary Consideration	Specification
Configuration	Small, simple, and rugged
Operating Environment	Capable of withstanding noise, vibration, humidity, and thermal stresses 120 to 160 db at 20 cps 40 to 100 percent relative humidity -40 to 140°F
Range of Sensitivity	Response between 1X to 100X TLV* low range 100X to 1000X TLV high range
Response Time to 90 Percent Full Scale	Approximately 60 seconds
Recovery Time to 10 Percent of Peak	Approximately 70 seconds
Zero Drift	Less than ± 0.5X TLV over 9-day period in the absence of shock or vibration

*Threshold Limit Value

TABLE I (Continued)

SENSOR SPECIFICATIONS

Primary Consideration	Specification
Fail-Safe Features	Local and remote circuit check capability Local and remote alarm capability

Secondary Consideration	Specification
Operation Principle	Physical or chemical
Lower Sensitivity	0.5X TLV
Specificity of Fuel Detectors	50:1 versus other fuels and solvents
Specificity of Oxidizer Detectors	50:1 versus other oxidizers
Orientation	Independent of position
Electrical Output	Analog dc/convertible to digital dc
Electrical Input	None or 110v ac
Accuracy	± 25 percent at full scale

B. SENSORS AND DETECTORS

Table 2 shows a partial list of sensors and detectors that can be packaged to meet NASA specifications. It is desirable that the transducer perform when overloaded without automatically cutting off or switching, and that the output signal remain at maximum when swamped. Transducers may be packaged with or without integral prime movers. KSC policy dictates that air pumps be eliminated where possible. When sensors are required in air-conditioning ducts or closed spaces, natural diffusion will carry gases to the sensors, thereby eliminating air pumps. However, in applications subject to wind gusts, accurate air or gas samples cannot be obtained without an air pump.

TABLE 2. SENSORS AND DETECTORS

DETECTOR NO.	TYPE	OPERATION PRINCIPLE	RANGE	RESPONSE TIME FOR 90% AND RETURN TO 10%	SPECIFICITY	ELECTRICAL OUTPUT TO METER CIRCUIT
A	N_2O_4/Hydrazines FLOX Mixtures	Microfuel Cell	0-100 ppm	10 sec/20 sec	Excellent	100 ma dc
B	N_2O_4/Hydrazines FLOX Mixtures	Thin-Film Chemical Thermistor	0-100 ppm	Unknown	Unknown	Unknown
C	N_2O_4/Hydrazines FLOX Mixtures	Aerosol-ion Chamber	0-100 ppm	5-10 sec/30 sec	Good	10 or 50 mv dc Full Scale
D	N_2O_4/Hydrazines FLOX Mixtures	Electrical Conductivity	0-100 ppm or greater	20 sec/Unknown	Average	Unknown
E and F	N_2O_4/Hydrazines FLOX Mixtures	Coulombmetry	0-200 ppm & 0-250 ppm	Approx. 60 sec	Excellent	Approx. 100 ma dc Full Scale
G and H	FLOX Mixtures	Clathrate/Kryptonate Kr^{85} Tracer Release	0-250 ppm	Approx. 4 min/NA	Average to Poor	100 ma and/or 100 mv dc Full Scale
I and J	Suffocants Indirect (oxygen depletion)	Thermomagnetic	0-25% O_2	75 sec total	Good to Excellent	5 mv at 100-1200 ohms
K and L	Suffocants Indirect (oxygen depletion)	Polarography	0-25% O_2	30 sec/NA	Good	250 mv Full Scale

Most transducers produce an analog direct current signal proportional to incident gas concentration. Instrumentation used both locally and remotely, should have appropriate amplification to enable the transducer to drive a contact meter. The meter then provides a local visual analog reading and switching to trigger local internal or remote relays. For instrumentation used remotely, only a variable threshold go/no-go output is required thus eliminating transmission of analog signals over long wires. Such remote detectors actuate alarm relays at the control point and must certify go before unprotected personnel are allowed back into hazardous areas.

SECTION V
THE ACTUAL NETWORK

A. SENSOR LOCATION

The network is best understood by looking at typical sensor subsystems. Figure 4 depicts the toxic leak detection subsystem proposed for the Saturn V mobile service structure (MSS). For semiremote operations from the base of the MSS, data and control signals can be transmitted over hardlines without amplifiers or repeaters external to the sensors. In this case, the control point is only 350 feet from the furthest detector. The oxygen depletion subsystems for the mobile launcher (ML) and the pad terminal connecting rooms (PTCR) are somewhat simpler than the toxic leak detection subsystem (Figure 5) for the MSS. The oxygen detectors are passive and rely on the closed circuit air-conditioning system to move adequate air past the sensors to measure gas concentrations. In these applications, the detectors are located at or in the air return ducts.

B. NUMBER OF SENSORS

The toxic gas detection subsystem will require approximately 15 sensors per launch pad. Five of these sensors will be located at the upper level valve boxes and ten will be located at the conditioning service units. The oxygen depletion subsystems will consist of approximately nine sensors per pad; six in the base of the ML and three in the PTCR.

C. DATA TRANSMISSION

For remote operation, the signals from the detectors at the launch pad must be transmitted 3-1/2 miles to the Launch Control Center (LCC). This digital data relay and test command transmission is accomplished by a technique similar to high speed telegraphy. This technique is called frequency shift keying (FSK). FSK is a digital modulation technique wherein opening or closing a contact causes a discrete frequency shift of a carrier wave between two predetermined values. Each data or command channel is binary coded within a 20-bit segment of the carrier signal. Thus, with a scan rate of 800 bits per second, 40 digital information channels may be transmitted over a single narrow band telephone pair. A diagram of this FSK data transmission system is shown in Figure 6.

D. DATA DISPLAYS

The decoded signals are displayed visually and audibly in the LCC. The transmitted data are displayed on logic panels in appropriate operations consoles located on the second floor of the LCC, (Figure 7). When a leak is indicated by a no-go red light on this

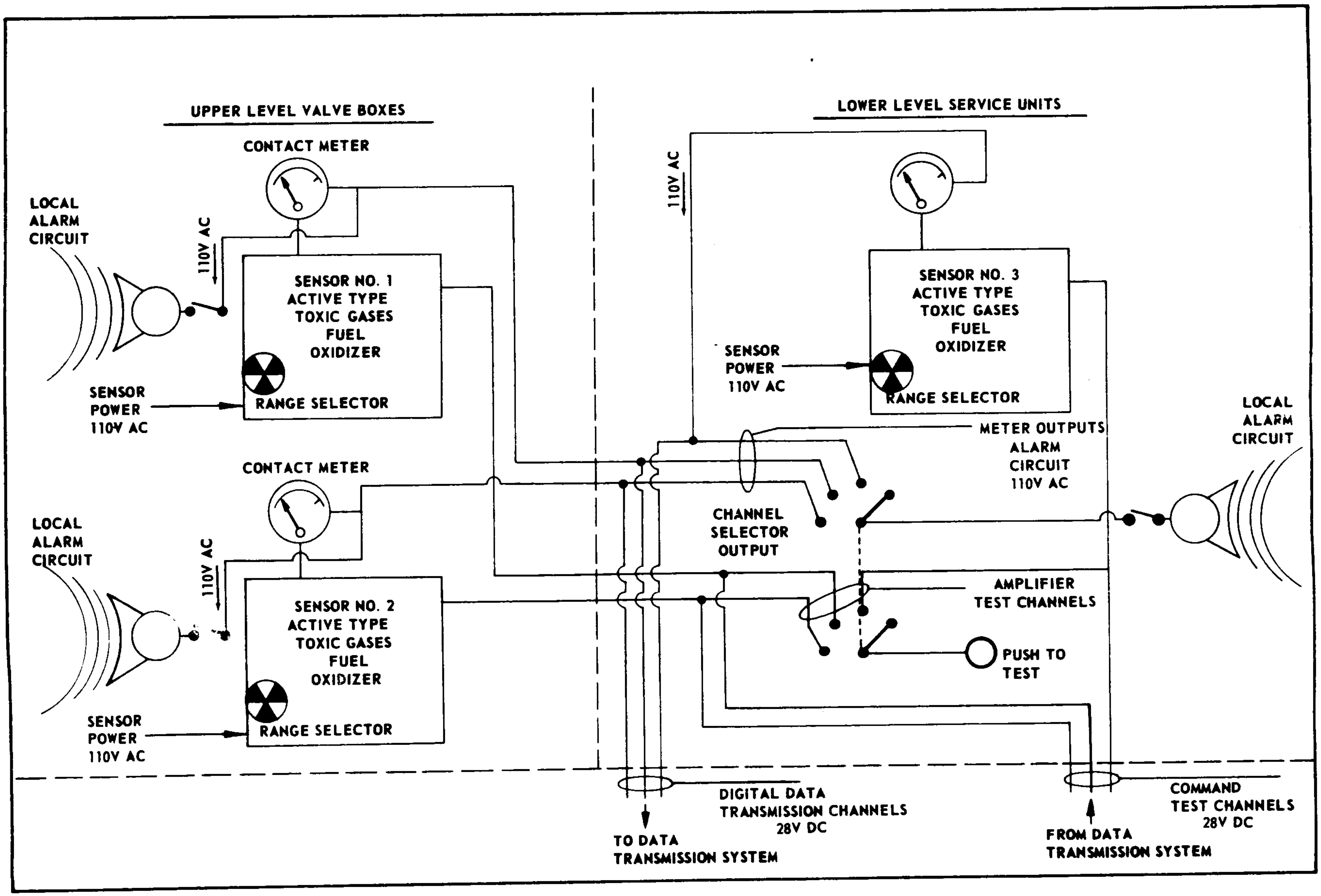

FIGURE 4. PROPOSED TOXIC LEAK DETECTION SUBSYSTEM FOR SATURN V MOBILE SERVICE STRUCTURE

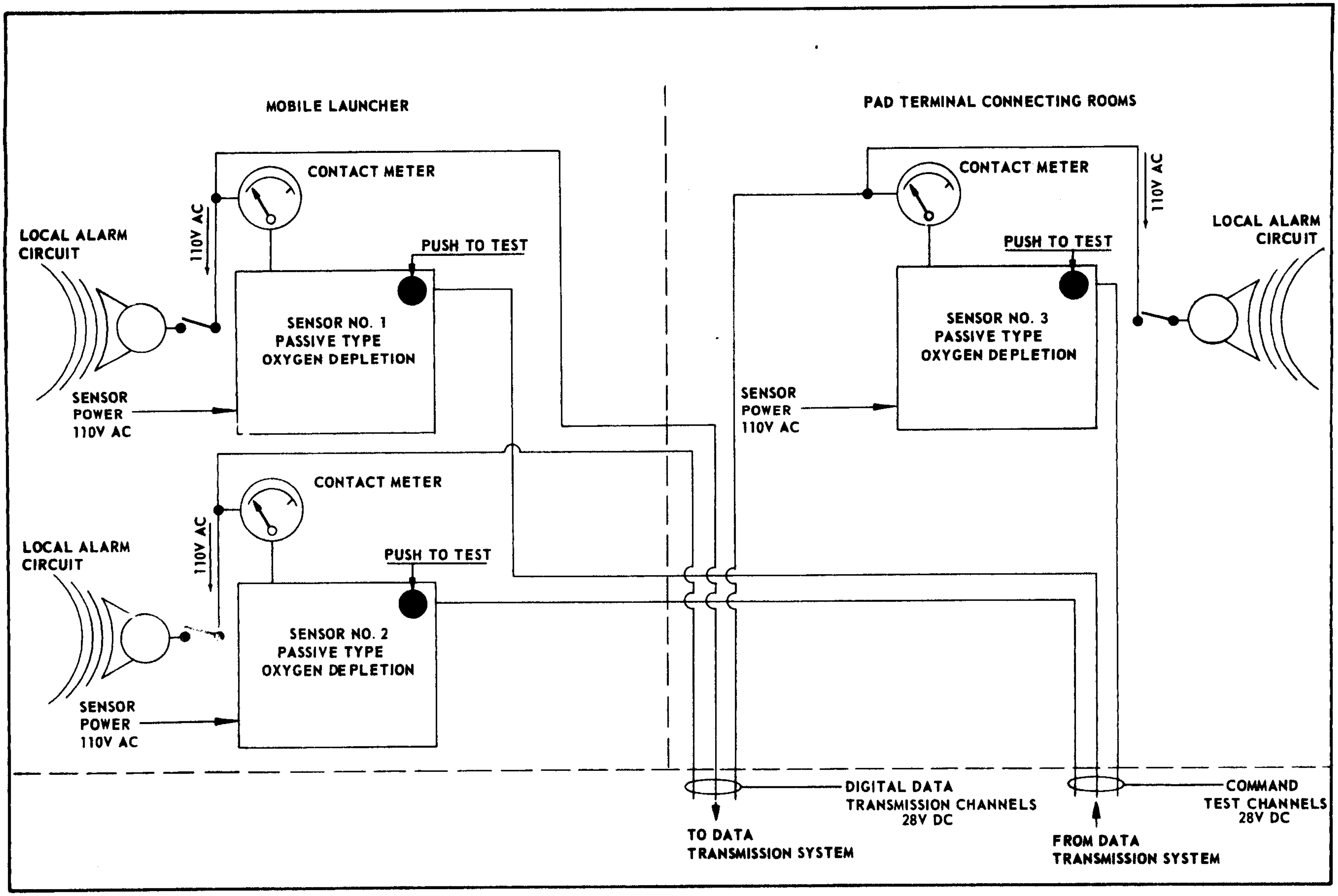

FIGURE 5. PROPOSED OXYGEN DEPLETION SUBSYSTEM FOR SATURN V MOBILE LAUNCHER AND PAD TERMINAL CONNECTING ROOM

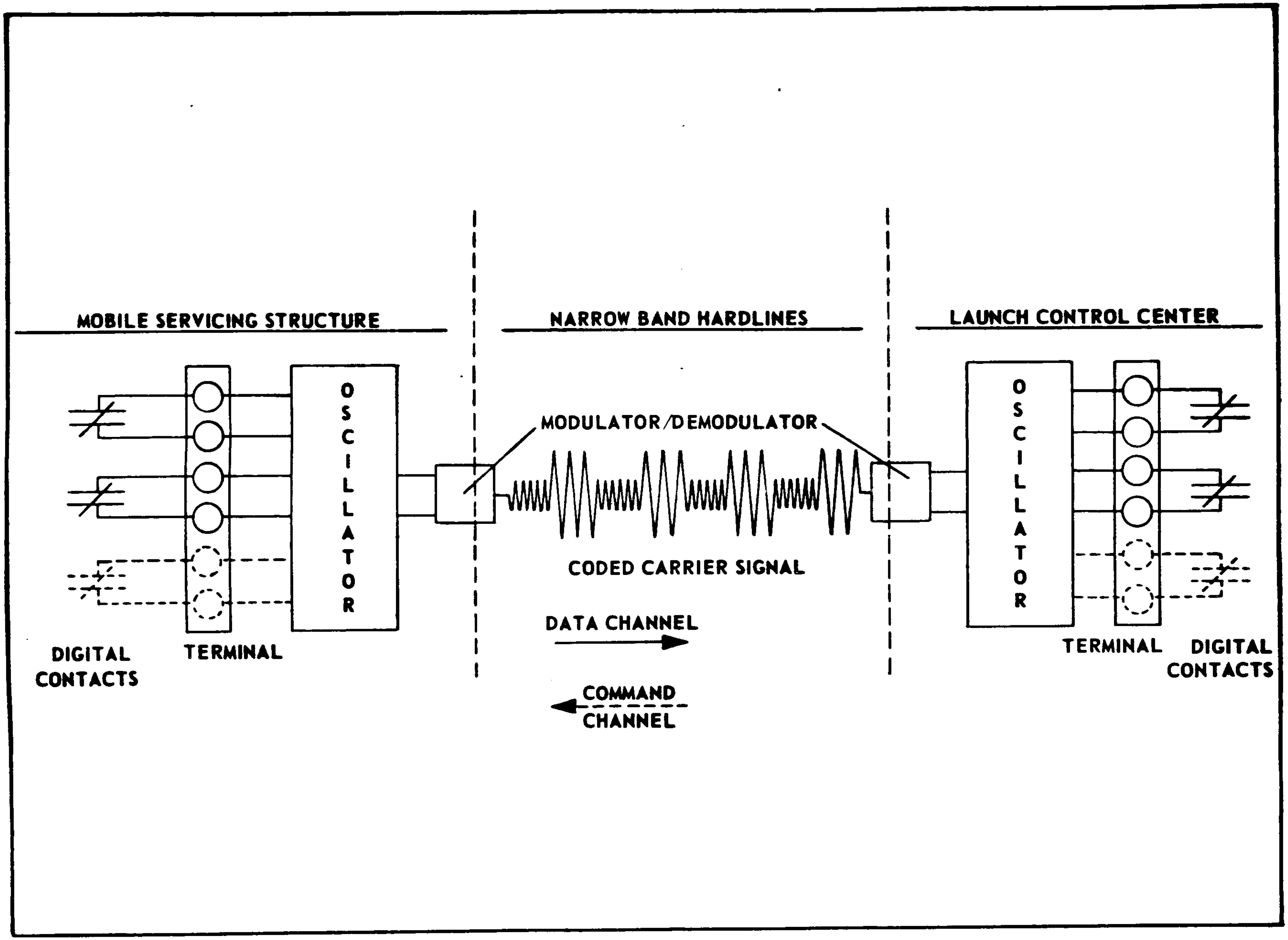

FIGURE 6. FREQUENCY SHIFT KEYING DIGITAL DATA TRANSMISSION SYSTEM

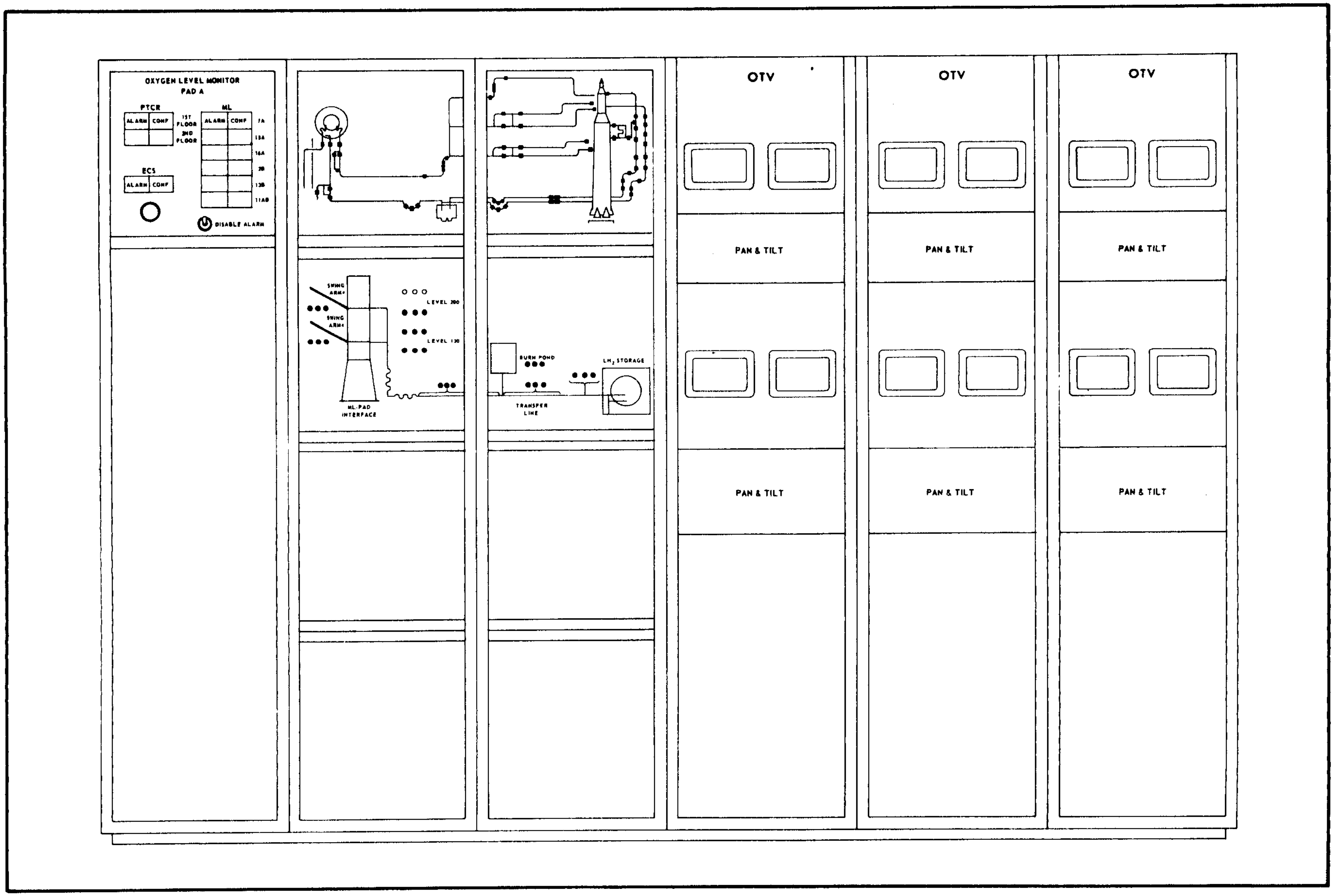

FIGURE 7. APOLLO/SATURN V SUBSIDIARY OPERATIONS CONSOLE, LAUNCH CONTROL CENTER

subsidiary operations console, the operator presses the confirm indicator. This sends a command signal back over the digital transmission system, which initiates an amplifier continuity test at the MSS. If the sensor output amplifier is functioning properly, a second red light will confirm the propellant leak. The operator will then attempt to verify the extent of the malfunction by focusing the operational television system on the indicated trouble spot. Simultaneous with this confirmation and verification, the pad safety supervisor in the vehicle firing room is advised of the suspected malfunction by a signal on his summary display.

Toxic gas and oxygen depletion functions are only two of the many summary functions displayed on this Operations Safety Console (see figure 8). The Operations Safety Console is at all times visible to the test supervisor and advises him of the overall safety status of launch pad personnel.

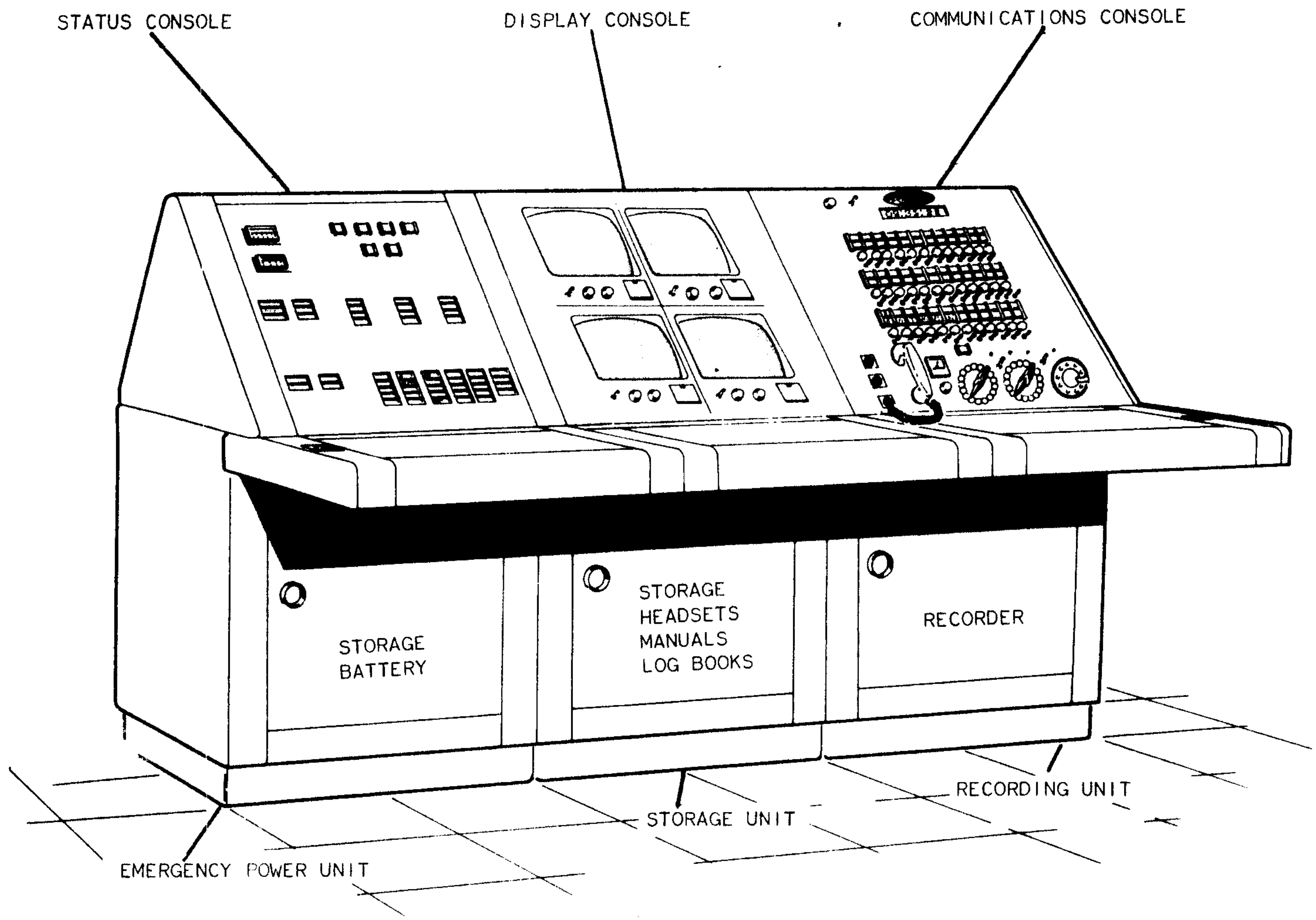

FIGURE 8. OPERATIONS SAFETY CONSOLE

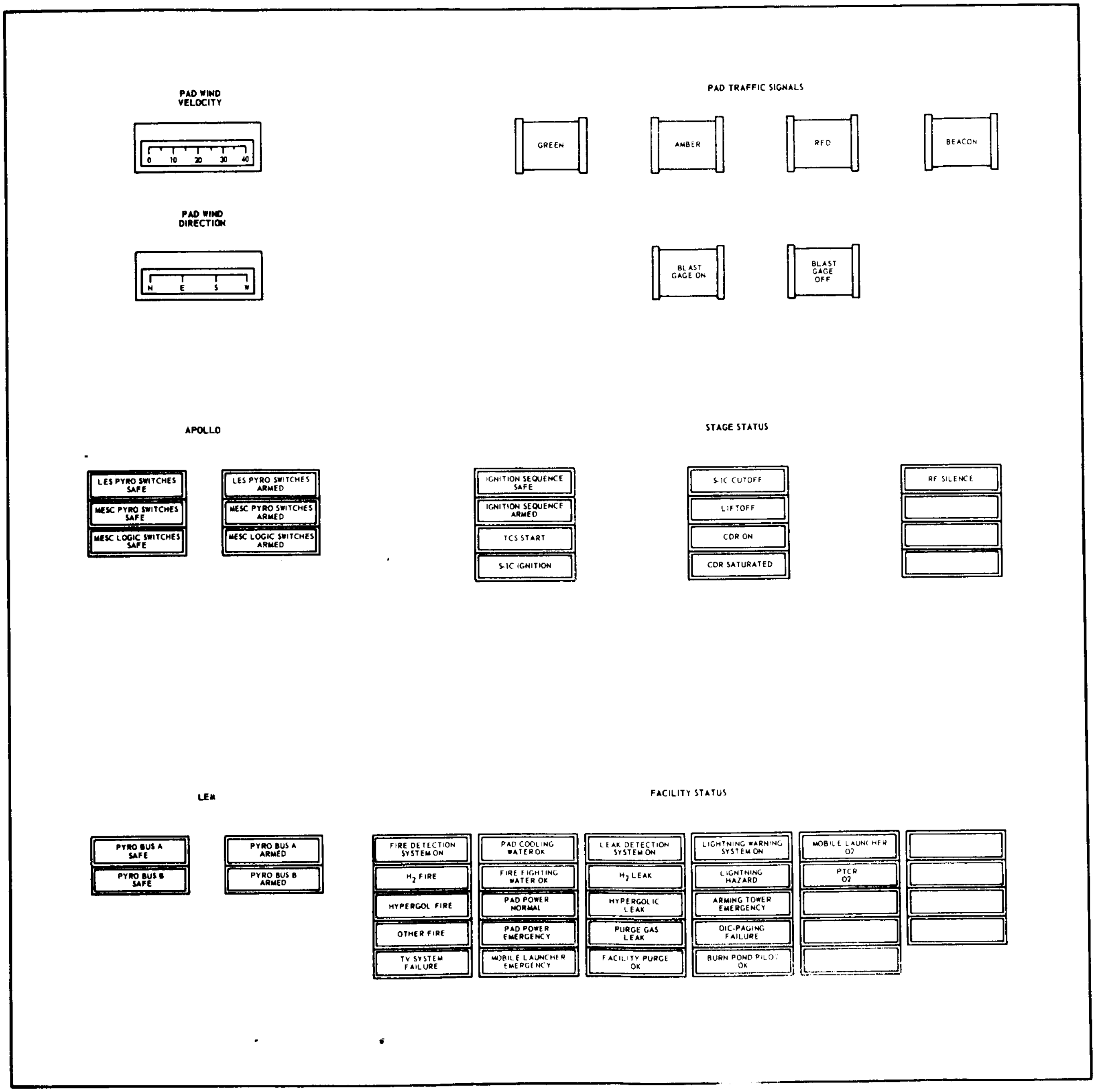

FIGURE 9. OPERATIONS SAFETY STATUS CONSOLE

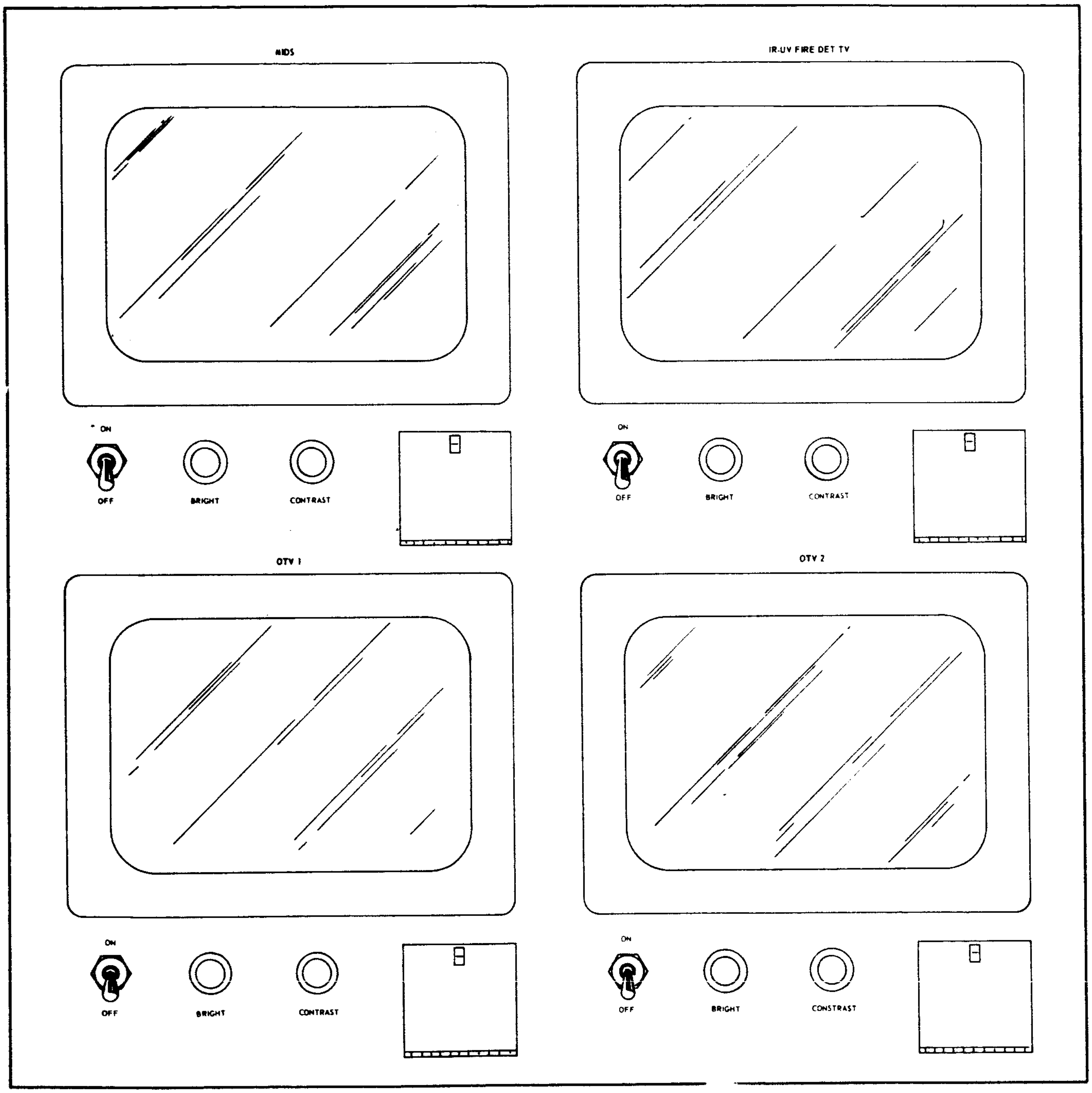

FIGURE 10. OPERATIONS SAFETY DISPLAY CONSOLE

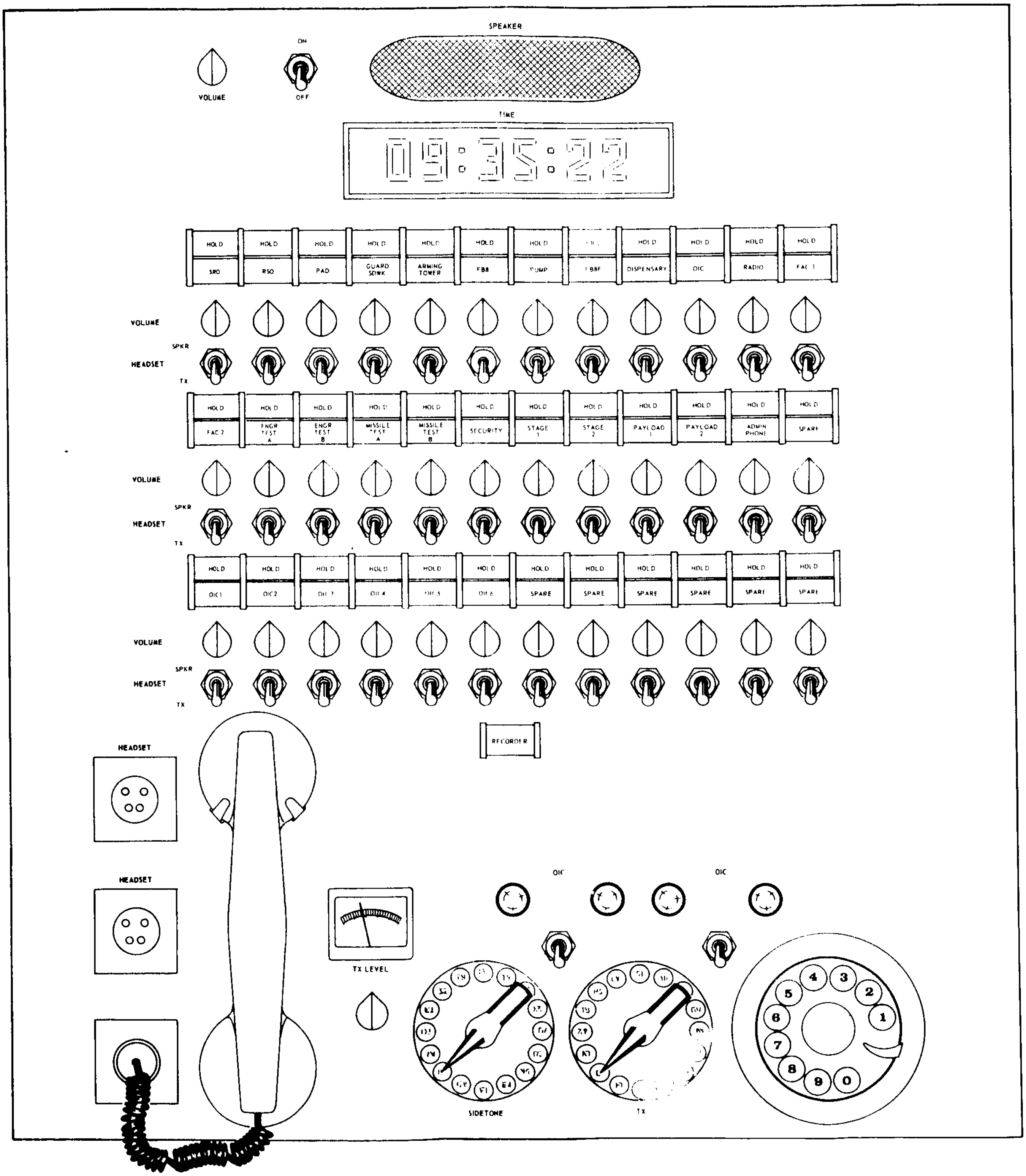

FIGURE 11. OPERATIONS SAFETY COMMUNICATIONS CONSOLE

APPENDIX
ABBREVIATIONS

APS	Auxiliary propulsion system
CM	Command module
CM/SM	Command module/service module
HMS	Hazardous monitoring system
LEM	Lunar excursion module
RCS	Reaction control system
SPS	Space propulsion system

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