Fermi National Accelerator Laboratory

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# A Solenoid Shut Off Valve Specification for Flammable Gas Systems

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# 1 Introduction

The use of flammable gas and high voltage in detector systems is common in most experiments at Fermilab. To "mitigate the hazards associated with these systems" Fermilab Engineering Standard SD-45B was adopted. As part of their mission the Research Facilities Department (RFD) and the Site Operations Department (SOD) have assisted the fixed target experiments in satisfying some of the requirements of SD-45B. This note describes the devices that are available to experimenters that will satisfy points 9, 13, 14, and 17 of SD-45B. This note is meant to be used as a guide and not a mandatory standard, each experiment is reviewed for compliance with SD-45B by the flammable gas safety subcommittee.

This note describes a generic system that should fit the majority of class 1, 2 and low pressure class 3 systems (less than 15 psi). There are several "safe" assumptions that can be made;

- There are only two types of flammable gasses in use, ethane and isobutane.

- The highest pressure anywhere in a system will be 550 psi, this is for type 1A cylinders of pure ethane.
- The pressure after the regulator will be 15 psi or less

For the systems where these assumptions do not apply both RFD and SOD will assist the experimenters in design of a shutoff and relief valve system.

## 2 Relief Valves

After the main pressure regulator on the flammable gas supply there will be a pressure relief valve set at 24 psi. (Figure 1) This relief will vent to the outdoors through metal pipe of sufficient diameter to vent 83 cubic feet of gas per minute. (see appendix 1 for the calculation) The vent line will be 1 inch diameter and no longer than 20 feet. For the case of methane gas the relief valve will vent 270 scfm of gas and have a 2 inch diameter vent pipe. The purpose of this relief valve is to protect the shut off valve from catastrophic failure of the main regulator. (A failure of this sort would put 40 psi on the output of the regulator.)

## 3 Solenoid Valves

Each solenoid valve will be a 2-way Normally CLOSED valve. There will be one valve for each flammable gas supply in use. The valve bodies will be stainless steel with Buna-N seals and be specified "clean for oxygen". This is to prevent any contaminant for getting into chamber gas systems. If Buna-N or stainless steel is unacceptable for a particular application the gas safety committee may approve a substitute material. The fittings will all be NPT pipe thread of a size compatible with the lines and flow rates in use. The operating pressure differential will be at least 25 psi. A straight forward calculation shows that for a 1/4 inch NPT valve with a 1/8 inch orifice and a 50-50 mixture of argon ethane a total flow of 4.6 SCFM is possible. This flow rate should be sufficient for any system in use. These valves are to be installed in the gas shed immediately after the main pressure reducing regulator for the flammable gas. For systems where mixing is done this system will not interrupt the flow of non-flammable gas. The solenoid themselves will operate on 12 VDC but need not be explosion proof. All electrical connections and pipe runs in the gas shed will conform to explosion proof standards for Class 1 Division 2 locations. (See the National Electrical Code section 500-5 (b) for the definition)

# 4 Solenoid Relay Box

Between the General Monitors DC-110 and the solenoid valves there will be a solenoid relay box (SRB). The SRB will be rack mountable, contain four (4) 12 VDC relays, and a power supply to drive the relays. (Figure 2) Each relay will have three (3) double pole double throw contacts. One of the normally closed contacts will open causing all the solenoid valves to shut. A second set of contacts will ored together to power two LEDs on the front panel of the SRB and by the entrance to the gas shed. These LEDs will indication green for any flammable gas flowing or red for no flow. The remaining set(s) of contacts will be terminated on the back of the of the box for future use. In addition there will be an LED to indicate DC-110 permit and another to indicate crash button permit.

Either a high level alarm from the DC-110 or any one of the crash button opening up will case the SRB to shut off power to the solenoid valves. To restart the flow of gas a manual reset at the SRB must be given. There will be a key operated bypass switch for the DC-110 input to the SRB. This bypass will allow for leak checking of the detectors and testing of the DC-110 module with out interruption of the gas flow to the chambers. There will be crash buttons located as needed The number and location of the crash buttons will be approved by the gas safety committee. There will be a crash button on the front panel of the DC-110.

The SRB will report to FIRUS. If the DC-110 goes into alarm or any crash button is pushed a high level alarm will be sent to FIRUS and summand the fire department. If the key bypass switch is used a maintenance or trouble alarm will go to FIRUS.

The SRB will have a battery backup that will keep the valves open and gas flowing for a minimum of two (2) hours. This assumes that the DC-110 has a separate battery backup or the manual bypass is used.

# 5 Flow Lights

As required by SD-45B visual indication of gas flow will be provided through the SRB. One of the four contacts on each relay will "ored" together so that if any one solenoid valve is open a warning light on the SRB and on the gas shed will indicate gas flow. In addition there will be light boxes that indicate gas flow at the major entrances to the experimental halls.

# 6 Appendix 1: Relief Valve Size

To specify the size of the relief valve need for the "standard" installation I will assume the flammable gas is pure ethane. This has the highest bottle pressure of any flammable gas in use. I will follow the method used in CDF note no. 652 "Flow Limiting Orifice for the CDF Argon/Ethane Gas system" by Harry Carter. In that note the flow of gas through an orifice is given by the equation:

$$q = YCA\sqrt{\frac{2g(144)\Delta P}{\rho}}$$

Where;

- q is the flow rate in $ft^3$ per second
- Y is the net expansion factor
- C is the discharge coefficient
- $\Delta$ P is the pressure drop across the orifice in psi
- g is the acceleration due to gravity 32.2 $ft/sec^2$
- $\rho$ is the inlet density of ethane gas 3.0 $lbs/ft^3$
- A is the orifice area in $ft^2$

This equation comes from Crane Technical Paper 410, Equation 2-15 page 2-14. I will further assume the regulator is a Victor Model VTS-700MD two stage regulator with a nozzle diameter of 0.090 inches. This gives the following values;

- Nozzle Diameter $d_o$ = 0.090 in (0.0075 ft.)
- Nozzle area = 4.42 x $10^{-5}$ $ft^2$
- Inlet Pipe diameter $d_1$ = 1.097 in
- $d_o$ / $d_1$ = 0.082

From Crane A-19 then C = 0.986

- The inlet pressure is 550 psi, 564.7 psia
- The outlet pressure is 15 psi. 29.7 psia
- The pressure drop $\Delta$ P is 535 psi
- $\Delta P / P_1 = \frac{535}{550} = 0.907$

The constant k is the ratio specific heat at constant pressure to the specific heat at constant volume. For ethane this is

$$k = \frac{12.750 \frac{cal}{mol-^oC}}{10.700 \frac{cal}{mol-^oC}}$$

Using k = 1.2, $\Delta P/P$ = 0.907 and the ratio of the orifice size as 0.8, the nomograph A-20 gives the expansion factor Y to be 0.64. Putting this into the equation give;

$$q = 0.036 \ ft^3 /sec$$

or at standard temperature and pressure

$$q = 0.036 \ ft^3 /sec \times 564.7 / 14.7 = 1.4 \ ft^3 /sec$$

The maximum flow rate for the relief valve is then 83 SCFM of ethane. For isobutane the bottle pressure is 34 psi, a similar calculation gives a valve for q of 3.6 SCFM.

NOV 6, 1989

# SAFETY RELIEF VALVE SIZING FOR FLAMMABLE GAS SYSTEMS

PROPOSED BY: JT VOLK
CALCULATIONS BY: H ROSTAMIAN

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This proposal considers the following (4) Gas flow systems.

| | | |
|---|---|---|
| CASE 1, | Methane At | 2300 Psi |
| 2, | Ethane At | 550 Psi |
| 3, | 50/50 Argon/Ethane At | 300 Psi |
| 4, | Isobuthane At | 34 Psi |

In all cases the regulated orifice dia is assumed to be 0.09 inches, and the valves include a 20 ft venting pipe.

The calculated Flow & Valve capacities are summarized on page 4, and they are based on the following assumptions.

1) Sonic flow through regulator orifice.
2) Sonic flow through relief valve.
3) Ideal gas, compressibility factor = 1.0
4) Vent pipe length is inceased by 50% to account the effect of exit loses and elbows.
5) Small pressure drop, 1.0 psi, on inlet to relief valve.
6) Flow coefficient on regulator orifice K=1.0 is highest possible value.

(7) Formula REF./Attached.

# RELIEF VALVE SIZING CALCULATIONS

## PART I. FLOW CAPACITIES, W(lbs/hr)

### CASE 1 Methane At 2300 Psi:

DATA: $A$ = Orifice Area = $0.09^2 \times \pi/4 = 0.00636\ in^2$
$M$ = Molecular Wt = 16, $T = (60°F + 460) = 520°R$
$Z$ = Compressibility $\simeq 1.0$, $K \simeq 1.0$
$P_1 = 2300 + 14.7 = 2314.7$ psia, $C = 346$

$$W = ACKP_1\sqrt{M}/\sqrt{TZ}$$

$$= \left(\frac{0.00636 \times 1.0}{\sqrt{520 \times 1.0}} = 0.0002789\right) \times \left(346 \times 2314.7 \times \sqrt{16}\right) = 894\ lbs/hr$$

### CASE 2 Ethane @ 550 Psi

DATA: Same Except: $M = 30$, $C = 339$
$P = 550 + 14.7 = 564.7$

$$W = 0.0002789 \times 339 \times 564.7 \times \sqrt{30} = 293\ lbs/hr$$

### CASE 3 50/50 Argon/Ethane @ 300 Psi

DATA: Same Except: $M = (40+30)/2 = 35$
$C = (377+324)/2 = 350$
$P = 314.7$

$$W = 0.0002789 \times 350 \times 314.7\sqrt{35} = 182\ lbs/hr$$

### CASE 4 Isobuthane @ 34 Psi

DATA: Same Except: $M = 58$, $C = 328$, $P = 48.7$ Psi

$$W = 0.0002789 \times 328 \times 48.7 \times \sqrt{58} = 34\ lbs/hr$$

## PART II. REQUIRED STAMPED (ASME) RELIEF VALVE CAPACITY (SCFM AIR)

$W = CKAP\sqrt{\frac{M}{T}}$ Solve for KA, where

$KA = \frac{W}{CP}\sqrt{\frac{T}{M}}$

W = Flow (lbs/hr)

P = (24 Psi + 10%) + 14.7 = 41.1 Psia

**CASE 1** Methane 2300 psi

$$KA = \frac{894}{346 \times 41.1}\sqrt{\frac{520}{16}} = 0.3584 \text{ in}^2$$

Solving For Volumetric flow, V(SCFM) for AIR

$V = 6.32\,CKAP_1 / \sqrt{MTZ}$ where:

Z≈1, M = 28.97 Air

C = 356

$$\frac{6.32 \times 356(0.3584)(41.1)}{\sqrt{28.97 \times 520 \times 1.0} = 122.7371} = 270 \text{ SCFM Air}$$

**CASE 2** Ethane 550 psi

$$KA = \frac{293}{339 \times 41.1}\sqrt{\frac{520}{30}} = 0.0876 \text{ in}^2$$

$$V = 6.32 \times 356(0.0876)(41.1)/122.7371 = 66 \text{ SCFM Air}$$

**CASE 3**

$$KA = \frac{182}{350 \times 41.1}\sqrt{\frac{520}{35}} = 0.0488 \text{ in}^2$$

$$V = 6.32 \times 356(0.0488)(41.1)/122.7371 = 37 \text{ SCFM Air}$$

**CASE 4**

$$KA = \frac{34}{328 \times 41.1}\sqrt{\frac{520}{58}} = 0.0076 \text{ in}^2$$

$$V = 6.32 \times 356(0.0076)(41.1)/122.7371 = 6 \text{ SCFM Air}$$

# PART III. VENT PIPE SIZING

REF: Crane Paper #410
Equation 3-5

$\Delta P = 3.36 \times 10^{-6} f L W^2 \bar{V} / d^5$ where $\bar{V} = \frac{1}{\rho}$

f = Friction factor for fully developed flow
(Values from Crane A-25

## CASE 1 Methane: $\rho = 0.041702$ #/ft³

For Pipe Size Try 2" DIA SCH 40, ID = 2.067"
∴ f = 0.019 from A-25

$\Delta P = 3.36 \times 10^{-6} \times 0.019 \times 30' \times 894^2 / (0.041702 \times 2.067^5)$
= 1.0 Psi

Try 1½" DIA SCH 40, ID = 1.61"
∴ f = 0.02
= 3.6 Psi Too high ∴ USE 2" DIA. SCH 40

## CASE 2 Ethane: $\rho = 0.078659$ #/ft³

Try 1" DIA SCH 40 ID = 1.05"
∴ f = 0.0228

$\Delta P = 3.36 \times 10^{-6} \times 0.0228 \times 30' \times 293^2 / (0.078659 \times 1.05^5)$
= 2 Psi

Try 1½" DIA, ID = 1.61"
∴ f = 0.02
= 0.2 Psi

USE 1" DIA. SCH. 40

For 1¼" DIA, ID = 1.38
& f = 0.0224
= 0.5 Psi

# RELIEF VALVE DATA SUMMARY

| CASE | FLOW CAPACITY (lbs/hr) | VALVE CAPACITY (SCFM) AIR | KA | *K | A ($IN^2$) |
|---|---|---|---|---|---|
| 1 | 894 | 270 | 0.3584 | 0.816 | 0.440 |
| 2 | 293 | 66 | 0.0876 | ↓ | 0.107 |
| 3 | 182 | 37 | 0.0488 | ↓ | 0.060 |
| 4 | 34 | 6 | 0.0076 | ↓ | 0.010 |

* K = Valve Coeff of Discharge = 0.816

VALVE MANUF. ANDERSON GREENWOOD CO.

<u>FOR CASE 1</u>

Select "G" ORIFICE $A = 0.503 > 0.44$

FOR CASES 2,3&4

Select #8 ORIFICE $A = 0.196 > 0.107$

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<u>PART IV</u> VALVE CAPACITY (SCFM) of "GAS"

$V = W \times 6.32/M$

<u>Case</u>

1 METHANE : $V = 894 \times 6.32/16 = 533$ SCFM

2 ETHANE : $V = 293 \times 6.32/30 = 62$ "

3 50/50 ARG/ETHANE: $V = 182 \times 6.32/(40+30/2) = 33$ "

4 ISOBUTHANE: $V = 34 \times 6.32/58 = 4$ "

# SIZING ANDERSON, GREENWOOD & CO.

## FORMULAS

All Safety-Relief Valves shown in this catalog are carefully set and tested prior to shipment. The AGCO testing department includes pneumatic facilities for testing valves with set pressures up to 10,000 psig. Valves with set pressures higher than this are set on hydraulic stands. Unless otherwise specified flowdown is factory set at 5-7%. Test reports on each valve are available upon request.

VAPORS OR GASES (capacity in scfm)

$$A = \frac{V\sqrt{MTZ}}{6.32\,CKP_1}$$

VAPOR OR GASES (capacity in #/hr)

$$A = \frac{W\sqrt{TZ}}{CKP_1\sqrt{M}}$$

where:

A = Valve orifice area (in.$^2$)
V = Flow capacity (SCFM)
W = Flow capacity (lbs./hr.)
M = Molecular weight of flowing media
T = Inlet temperature, absolute (°F + 460)
Z = Compressibility factor (Consideration not mandatory by ASME)
C = Gas constant based on ratio of specific heats at std. conditions
K = Valve coefficient of discharge (0.816)
$P_1$ = Pressure at valve inlet during flow, psia (set pressure + overpressure + 14.7).
See note below.

To convert flow capacity from SCFM to lbs./hr. use:

$$W = \frac{MV}{6.32}$$

NOTE: $P_1$ is the pressure at the valve inlet during relief. It may be different than process pressure due to pressure losses in the inlet piping. These losses should be determined for accurate sizing and to ensure proper valve action.

A pressure drop in the inlet piping which exceeds the reseat pressure of the safety valve will cause the valve to rapid cycle. Such cycling can adversely affect the endurance life of the valve.

ASME CODE
SECTION VIII – DIVISION 1

# APPENDIX 11
# CAPACITY CONVERSIONS FOR SAFETY VALVES

## 11-1

The capacity of a safety or relief valve in terms of a gas or vapor other than the medium for which the valve was officially rated shall be determined by application of the following formulas:[1]

For steam:

$$W_s = 51.5KAP$$

For air:

$$W_a = CKAP\sqrt{\frac{M}{T}}$$

$$C = 356$$

$$M = 28.97$$

$$T = 520 \text{ when } W_a \text{ is the rated capacity}$$

For any gas or vapor:

$$W = CKAP\sqrt{\frac{M}{T}}$$

where

$W_s$ = rated capacity, lb/hr of steam

$W_a$ = rated capacity, converted to lb/hr of air at 60°F, inlet temperature

$W$ = flow of any gas or vapor, lb/hr

$C$ = constant for gas or vapor which is function of the ratio of specific heats, $k = c_p/c_v$ (see Fig. 11-1)

$K$ = coefficient of discharge [see UG-131(d) and (e)]

$A$ = actual discharge area of the safety valve, sq in.

$P$ = (set pressure $\times$ 1.10) plus atmospheric pressure, psia

$M$ = molecular weight

$T$ = absolute temperature at inlet (°F + 460)

These formulas may also be used when the required flow of any gas or vapor is known and it is necessary to compute the rated capacity of steam on air.

Molecular weights of some of the common gases and vapors are given in Table 11-1.

For hydrocarbon vapors, where the actual value of $k$ is not known, the conservative value, $k = 1.001$ has been commonly used and the formula becomes,

$$W = 315KAP\sqrt{\frac{M}{T}}$$

When desired, as in the case of light hydrocarbons, the compressibility factor $Z$ may be included in the formulas for gases and vapors as follows:

$$W = CKAP\sqrt{\frac{M}{ZT}}$$

### Example 1

GIVEN: A safety valve bears a certified capacity rating of 3020 lb/hr of stream for a pressure setting of 200 psi.

[1] Knowing the official rating capacity of a safety value which is stamped on the valve, it is possible to determine the overall value of $KA$ in either of the following formulas in cases where the value of these individual terms is not known:

| Official Rating in Steam | Official Rating in Air |
|---|---|
| $KA = \frac{W_s}{51.5P}$ | $KA = \frac{W_a}{CP}\sqrt{\frac{T}{M}}$ |

This value for $KA$ is then substituted in the above formulas to determine the capacity of the safety valve in terms of the new gas or vapor.

Figure 1

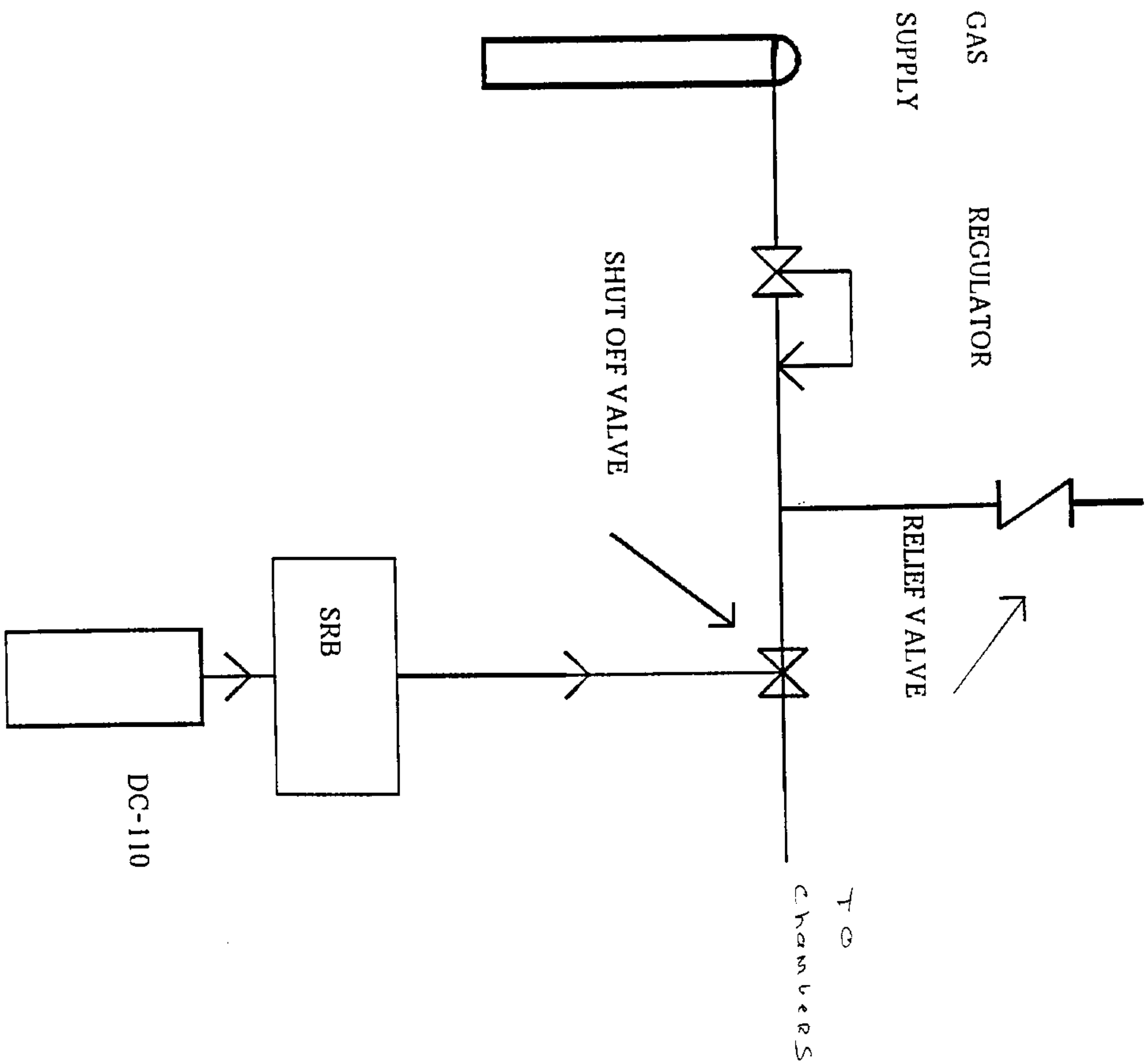
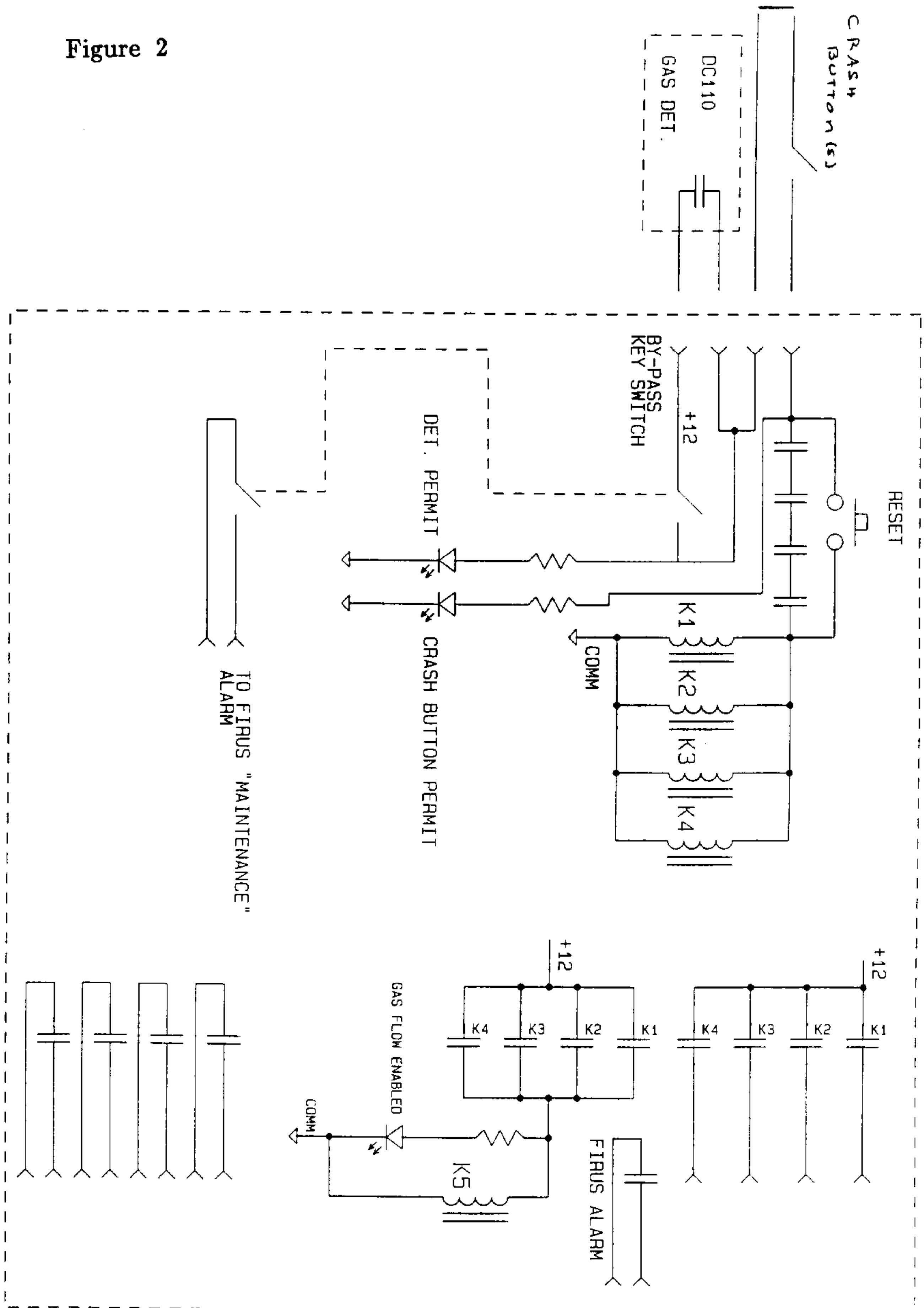

GAS SUPPLY
REGULATOR
SHUT OFF VALVE
RELIEF VALVE
SRB
DC-110
To chambers

**Figure 2**


CRASH Button(s)
DC110
GAS DET.
BY-PASS KEY SWITCH
+12
RESET
DET. PERMIT
CRASH BUTTON PERMIT
K1
K2
K3
K4
COMM
TO FIRUS "MAINTENANCE" ALARM
+12
K4
K3
K2
K1
+12
K4
K3
K2
K1
GAS FLOW ENABLED
COMM
K5
FIRUS ALARM