THE PHOSWICH DETECTION SYSTEM (P.D.S.) FOR THE SAX SATELLITE.

REQUIREMENTS FOR PHASE A STUDY

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FOREWARD

This report summarizes the main requirements given to Laben during the time period ranging from June to December 1983 concerning the phoswich detection system for the SAX mission.
Several discussions and meetings have taken place where the subject has been discussed in more detail.

1. INSTRUMENT DESCRIPTION

1.1 DETECTOR

It consists of 4 detection units (see Fig. 1). Each of them is made of a NaI(Tl) square scintillator crystal of surface 141x141 mm^2, 3 mm thick, optically coupled to a CsI(Na) square scintillator crystal which has the same front surface as that of the NaI(Tl) crystal and 50 mm of thickness. This phosphor sandwich (phoswich) is seen, through a light pipe of quartz 6 mm thick, by a 5" photomultiplier tube (PMT). The PMT has a transparent window and a high quantum efficiency at about 4100Å. The PMT selection should be made taking into account the effects of radiation, experienced by SAX along its orbit, on construction materials.

The X-ray entrance window is beryllium 5 mm thick.

As the scintillation time constant of NaI(Tl) is equal to .22 μs at about 20°C, it is temperature dependent and is different from that shown by the CsI(Na) crystal ($\approx$ .65 μs), energy losses in the NaI(Tl), used as main detector, can be discriminated by the energy losses in the CsI(Na) alone or in both crystals by analyzing the output pulse shape from the PMT through a preamplifier circuit.

The active side shield is realized by surrounding the phoswich detection units and their collimators by sheets of CsI(Na) crystals 10 mm thick, seen, through light guides, by eight 2" PMTs. Energy losses in this shield give gate signals that veto simultaneous phoswich events.

To increase the rejection efficiency to spurious events, anticoincidence of each NaI(Tl) signal with simultaneous signals from other phoswich units must be performed.

An active shield of NE102 plastic scintillator 3 mm thich on the top of the collimators, seen by four 2" PMTs, must be considered in order to reject the charged particles entering directly into the detector field of view. The signals from this shield will anticoincide contemporary signals from the phoswich units.

1.2 COLLIMATOR

The field of view of the instrument is fixed at $1^{\circ}.5 \times 1^{\circ}.5$ Full Width Half Maximum (FWHM). This is realized by means of two independent collimators mounted above two detection units. Each collimator is made of a bonded matrix of tubes having an exagonal section and a length of 20 cm. The basic material of the walls of the tubes could be tungsten ($\approx 60\ \mu m$ thick) or tantalum ($\approx 75\ \mu m$ thick). A layer of tin ($\approx 150\ \mu m$ thick) should come about half way up the internal walls of the tubes. On this layer a further layer of copper ($\approx 90\ \mu m$ thick) should be deposited. The role of these materials is to shield the X-ray flourescence emission of the most internal materials.

In order to have an almost conical response, with a flat top of about 10 arcmin, to the pointing of celestial X-ray sources, the tubes of each collimator should be assembled with a small offset angle (5 arcmin) in respect of the detector axis.

1.3 ROCKING COLLIMATOR SYSTEM

The collimator block (called A) surmounting a pair of phoswich units will rock at the same time and independently of the other collimator block (called B) above the other pair of detection units. The rocking directions will be the same for both sets. The rocking axis for both blocks will be in a plane parallel to the front surface of the detector. The height of the rocking axis with respect to the detection plane level should be as a result of a compromise among different and opposite requirements, e.g. that of having a minimum number of collimator cells, the minimum distance between exact opposite sheets of side shields;minimum mechanical torque of collimators etc.

The surface of each crystal must be covered by collimator cells both in the ON position and in the OFF1 and OFF2 positions (see below). The described rocking mechanism will allow for background measurements in opposite sides of the selected target. The observing strategy would consist of four phases of equal duration: ON source, +3.8 degrees OFF1, ON-source, -3.8 degrees OFF2.

The main requirements of the rocking mechanism can be summarized as follows:

1. Number of collimator sets: 2
2. Moving mass per unit: 12 Kg
3. Duration of movement: 3 sec
4. Range of movement: $\pm$ 3°8 (max). The rocking angle must be measured by means of some device.
5. Frequency of rocking (max): one cycle every 2 min.

Typical sequences of rocking are the following:

a)

Block A	Block B
ON	OFF1
OFF1	ON
ON	OFF2
OFF2	ON
ON	OFF1
OFF1	ON
'	'
'	'

b)

Block A	Block B
ON	ON
OFF1	OFF1
ON	ON
OFF2	OFF2
'	'
'	'

2. THERMAL REQUIREMENTS

A thermal stability of the instrument is required in order to meet alignment requirements (collimators) and to prevent large decay constant variations of NaI(Tl) crystals. Moreover, short time gradients temperature across the crystals have to be avoided to prevent thermal damage due to thermal shocks.

REQUIREMENTS

Operational (°C)	Non-operational (°C)	MaxGradient across Collimators (°C)
20 ± 10	20 ± 20	10

Time variations of the crystal temperature would be contained to within a few degrees/hour.

3. IN ORBIT ACTIVE GAIN CONTROL AND CALIBRATION SYSTEMS OF THE INSTRUMENT

An active control of the gain of the phoswich detectors within few parts $x10^{-3}$ must be envisaged for the PDS instrument. Four Am^{241} radioactive sources enclosed in thin plastic scintillators or in Silicon surface barrier detectors will be mounted between detection units and collimators (see figure 1).

The X-ray photons of the Am^{241} (lines at 60 keV and 17 keV) will be seen by the phoswich units and will allow for continuous gain control and equalization of the whole detection system and electronics. The alpha particles emitted by Am^{241} contemporeneously with the X-rays, will be seen by the plastic scintillator and then by a small PMT or by the solid state detector. These signals will be used to reject completely the X-ray lines in the pulse-height spectra to be transmitted to the ground. The Am^{241} X-ray lines will be used as gain monitor. If the gain of the instrument varies with respect to the prefixed one, a signal will be generated which would trigger a variation of the H.V. supply until the gain recovered its original value. The Am^{241}

sources can be held permanently in the field of view of the instrument. However, the possibility of an emergency in which the sources are outside the field of view of the phoswich detectors should be discussed during the phase A study.

To measure the absolute gain and energy resolution of the instrument, an X-ray radioactive source or a blend of radioactive sources will be periodically moved in the field of view of the detector, above the collimators. The upper side of the radioactive support could be made of a suitable material to give flourescence K-lines in addition to the source X-ray lines.

In order to avoid an efficiency reduction of the side veto shields, an active gain control of the anticoincidence chain should be studied, using the radioactive lines internally generated in the CsI (Na) crystals.

4. WEIGHT, VOLUME, POWER

Preliminary estimates of weight and external dimensions of the instrument are reported in Table 1. The estimated power is about 30 watts. This does not include power for heaters, if they are required.

TABLE 1

No. of sub-units		Unit Mass	Dimensions	Total Mass	Comments
Detector & Electronics	1	75	540x540x500 mm^3	75 Kg	
Collimator & Rocking Mechanism	2	25	540x540x300 mm^3	25 Kg	
Total	6	100	540x540x800	100 Kg	Incl. Rocking
Internal Weight Contingency				5 Kg	

5. NOMINAL ENERGY RANGE OF THE INSTRUMENT

The nominal energy range of operation of the P.D.S. will be 15-300 keV.

6. HIGH VOLTAGE REQUIREMENTS AND PARTICLE MONITOR

High energy losses in the CsI(Na) (up to 100 MeV) and passages of the satellite across regions with high radiation fields (near South Atlantic Anomaly) can change the gain of the instrument, cause fatigue effects in the PMTs and cause heavy overloads in the preamplifiers. All this requires the correct design of the voltage divider and the high voltage (H.V.) supply. The H.V. supply of the PMTs would be studied in order to recover quickly the gain of the instrument after high anode current saturation. To avoid PMT fatigue effects it needs to reduce the current due to high counting rates. A particle monitor would be used to switch off (or lower) the PMTs H.V. supply when the environment radiation field exceeds some fixed value, and turn it back on (or raise) when the particle flux drops below the fixed threshold.

A low ripple in the H.V. supply is required to avoid energy resolution degradation and to have efficient discrimination of the pure NaI(Tl) energy losses (see below).

7. γ-RAY BURST MONITOR

Events in the CsI(Na) side shield, if they meet a trigger condition will be recorded at a fixed time resolution. The expected celestial burst rate will be 1 every 3 $\div$ 4 days. However several false trigger conditions can occur.

Preliminary requirements of the burst monitor are:

1. Alternative integration times for trigger decision: 4 or 32 or 256 msec.
2. Trigger threshold: variable (depending on the integration time).
3. The absolute time of the burst triggering is required.
4. An on-board clock periodically syncronized with a reference on-ground clock.

8. FRONT-END ELECTRONICS AND DATA HANDLING

8.1 The main requirements of the front-end electronics are:

a) A pulse-shape analysis of the pulses coming from each phoswich unit, which would permit the recognition of events due to interactions of X-ray photons within the NaI(Tl) crystals only.

b) The signals recognised as pure NaI(Tl) events, which are not vetoed by the anticoincidence logic, must be analyzed in amplitude if they correspond to photons in the 15-300 keV energy range.

c) The coincidence/anti-coincidence logic should reject events if they meet at least one of the following conditions:

i. contemporary signals from phoswich units and from CsI(Na) side shields;

ii. contemporary signals from phoswich units and from the plastic scintillator;

iii. contemporary signals from two or more phoswich detectors.

d) We would require to have the possibility to release by Telecommand one or more of the previous conditions i., ii., iii.

e) Electronic flags to have information on the time occurrence of the events which meet one or more of the previous conditions.

f) Analysis of the γ-ray burst events in a pre-fixed energy band, with requirements given in section 7.

g) Pulse-height analysis of the events occurring in the lateral shield crystals and in the CsI(Na) crystals of the phoswich detectors. Lower energy thresholds: 60 keV for both crystals; upper energy thresholds: about 500 keV for the lateral crystals; about 1 MeV for phoswich crystals.

8.2 EXPECTED VALID EVENT RATES

8.2.1 RATES FROM THE WHOLE DETECTOR

i. Minimum event rate(background + weak source): 40 counts/sec
ii. Typical event rate (BKG + source): 80 counts/sec
iii. High event rate (BKG + strong source): 380 counts/sec
iv. Rare event rate (BKG + an X-ray flare from a source like Cygnus X-1); 1000 counts/sec.

Table 2 shows details of the expected background rates

TABLE 2 - BACKGROUND COUNTING RATES

$E_1 \div E_2$ (KEV)	COUNTS/cm^2 sec keV	COUNTS/sec
15 ÷ 30	3.1×10^{-4}	3.72
30 ÷ 40	2.3×10^{-4}	1.84
40 ÷ 80	1.7×10^{-4}	5.44
80 ÷ 200	1.1×10^{-4}	10.56
200 ÷300	1.2×10^{-4}	9.6
15 - 300	1.40×10^{-4}	31.16

8.2.2. EXPECTED COUNTING RATES FROM THE γ -RAY BURST MONITOR

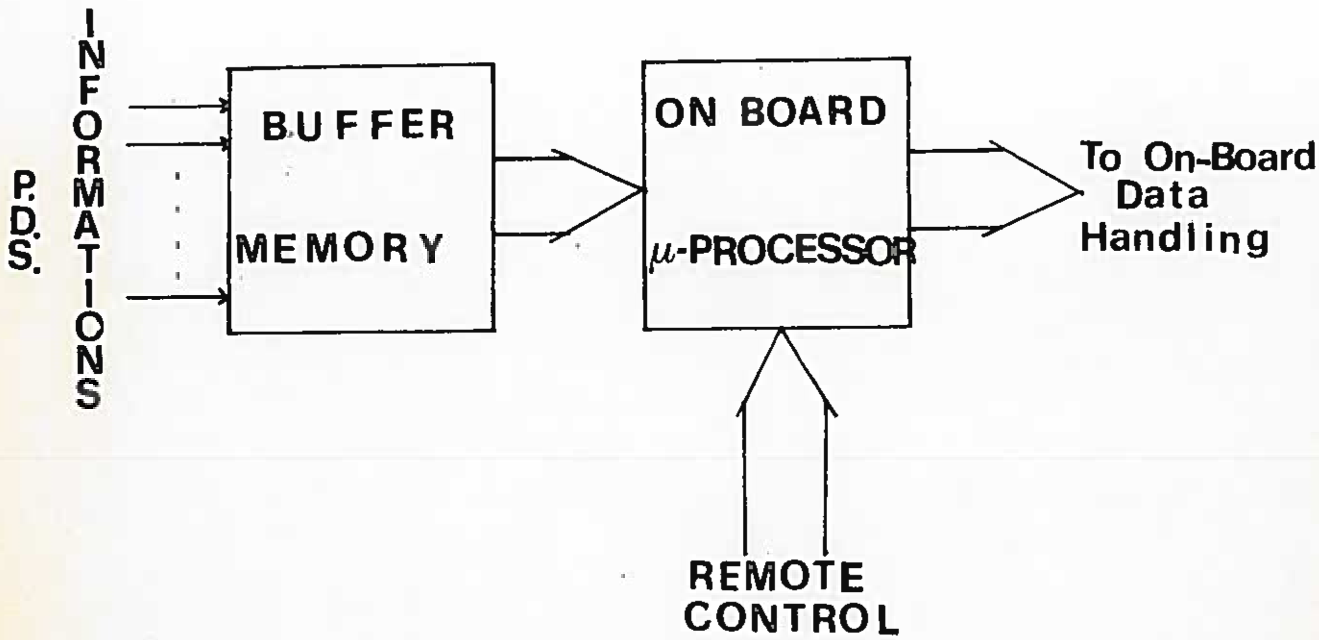
Maximum counting rate : 4×10^6 sec $^{-1}$

Typical counting rate : 8×10^4 sec $^{-1}$

8.3 DATA FORMATTING AND COMPRESSION

8.3.1 GENERAL PHILOSPHY

In order to permit the maximum flexibility of data formatting and the highest data throughput, the maximum information on each qualified event should be sent to a buffer memory. An on-board processor will format and compress the information on the basis of the observation program, the event rate and the available bit rate. Formatting and compression of the information should be selected by remote control from a menu of possible formats and compression modes.



8.3.2 INFORMATION TO BE SENT TO THE BUFFER MEMORY

a) For each valid event in the main detector in the energy range 15-300 keV

i. Sub-range of energy (two sub-ranges: 15-180 keV; 180-300 keV); 1 bit;
ii. Energy in each band: 8 bits
iii. Rise time spectrum: 7 bits
iv. Identification of detection unit: 2 bits

v. Further TBD information: 4 bits;

Depending on veto signals not used one or more of these 4 bits could be employed to give flags on occurrence of coincidence events. Therefore:

a) One bit for NaI(Tl) events in coincidence with the plastic scintillator;

b) One bit for NaI(Tl) events in coincidence with the CsI(Na) external shield;

c) One bit for NaI(Tl) events in coincidence with CsI(Na) events of other Phoswich units;

d) One bit for NaI(Tl) events in coincidence with NaI(Tl) events of other Phoswich units.

vi. Time of occurrence: 10 μsec of time resolution (For example, 15 bits are required to have this time resolution if a clock reference signal is in the format every .32 sec).

Note 1. As an alternative to the i. and ii. information, 9 bits for energy in the range 15-300 keV could be used.

b) γ-RAY BURST INFORMATION

If a trigger decision has occurred, the following information should be sent to a dedicated memory:

i. Absolute time of burst triggering (accuracy : better than .1 msec);

ii. Counts of side CsI(Na) shield accumulated for 0.5 msec and 10 msec;

iii. Maximum content/channel: 11 bits;

iv. Maximum number of channels of the multiscaler : 20000 + 12000 = 32000

v. Time required for γ-burst memory unload: 4 hours.

c) STATUS INFORMATION (Rocking, source calibration, etc.)

d) COUNT RATEMETERS (CRM). Integration time of one minute or less.

e) "ROVING" PHAs (Pulse-height spectra of CsI(Na) lateral shields; pulse height spectra of the CsI(Na) of each phoswich detector; rise time distribution of each phoswich detector including CsI(Na) events as well).

f) DEAD TIME MEASUREMENTS FOR PULSE HEIGHT/PULSE SHAPE ANALYSIS.

g) HOUSEKEEPING DATA (temperature, voltages, etc.)

8.3.3 ACQUISITION AND COMPRESSION MODES

Compatibly with the event rate and telemetry capacity, the basic mode of data acquisition and recording is the total content of the buffer memory.* If the basic mode is incompatible with telemetry bit rate, different modes of compression at experimental level to be selected from remote control, have to be foreseen.

9. TELECOMMANDS

The exact number of commands will be defined in a further phase. Two different types of commands will be required for the remote contraol of the PDS instrument:

i. DIGITAL WORD COMMAND

ii.DISCRETE COMMANDS

i. Digital word commands will be used for subsystems of PDS which should operate in more than two configurations.
Examples of digital commands are the following:
 a. Selecting modes of operation of the rocking collimator (rocking frequency, rocking sequency, etc.);
 b. Selecting procedure of source calibration (frequency, time duration, etc.);

c. Selecting format and compression mode of the information in the memory buffer;

d. Selecting the operative mode of recognizing a true γ-ray burst (trigger threshold, integration time for analysis of counting rate variations, etc.).

ii. Discrete commands will be required for subsystems of PDS which have two operation modes.

Two examples of discrete commands are:

a. Lateral shield anticoincidence : ON/OFF

b. Plastic shield anticoincidence : ON/OFF.

10. CLOCK STABILITY REQUIREMENTS

The clock stability is fixed on the basis of the frequency of comparison of the on-board clock time with an on-ground absolute reference clock time (very stable). In the hypothesis that the comparison is performed every orbit the stability of the clock on-board is required to be better than 1.0×10^{-9}/orbit.

11. RELEVANT POINTS TO BE STUDIED IN THE PHASE A STUDY

i. Time tagging

ii. Automatic gain control/H.V. power supply

iii. Collimator

iv. Rocking mechanism

v. Source calibration

vi. Particle monitor strategy

FIGURE CAPTIONS

FIG. 1 (a and b). Two views of the mechanical sketch of the P.D.S.

Number meaning:

1. Phoswich unit;
2. Phoswich PMT;
3. CsI(Na) side shield;
4. Side shield PMT;
5. Sub-collimator;
6. Plastic Scintillator;
7. Plastic PMT;
8. Periodic calibration system;
9. Continuous calibration system;
10. Electronics box;
11. Rocking system;
12. Mechanical frame.

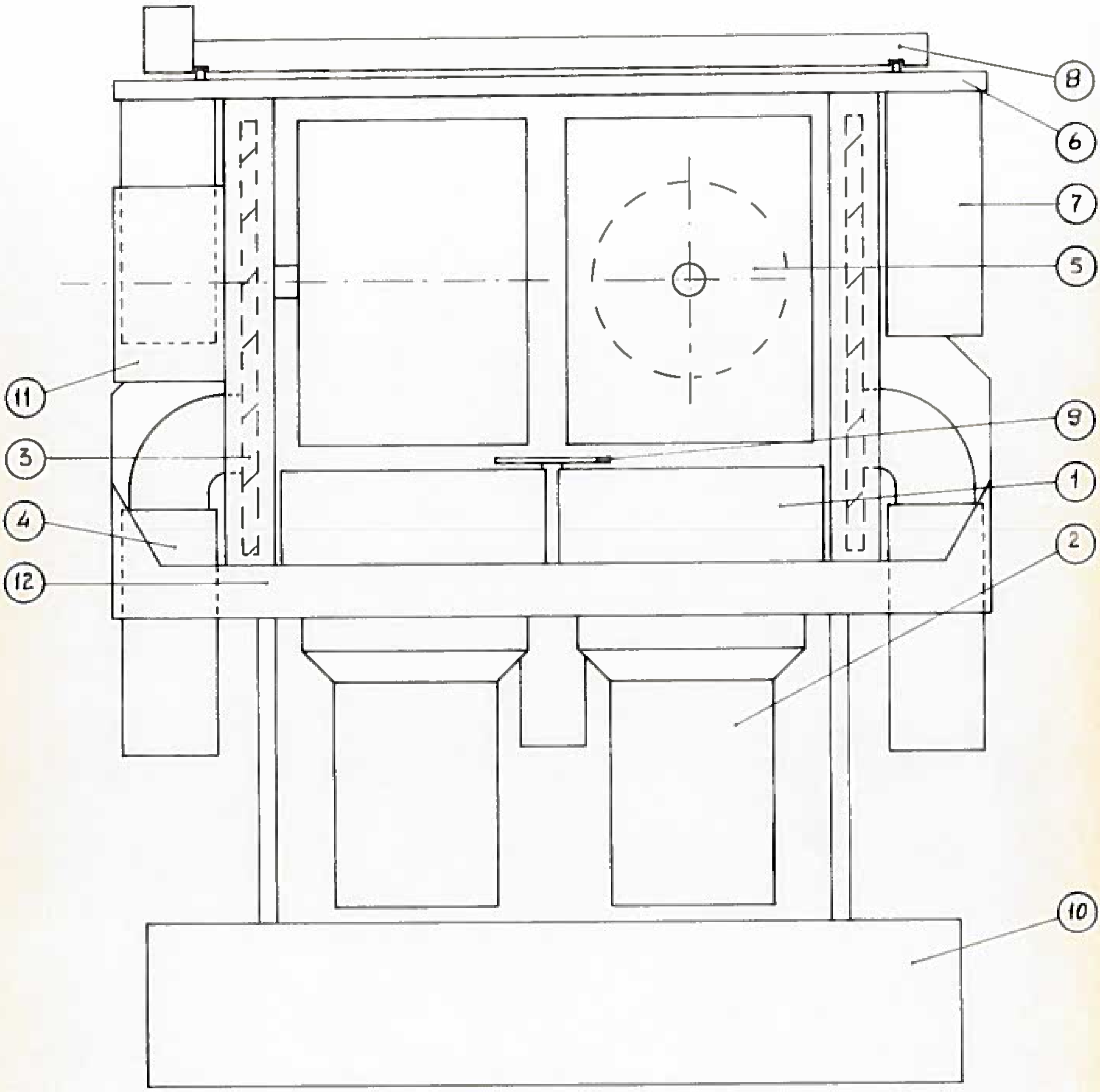


Fig. 1 a

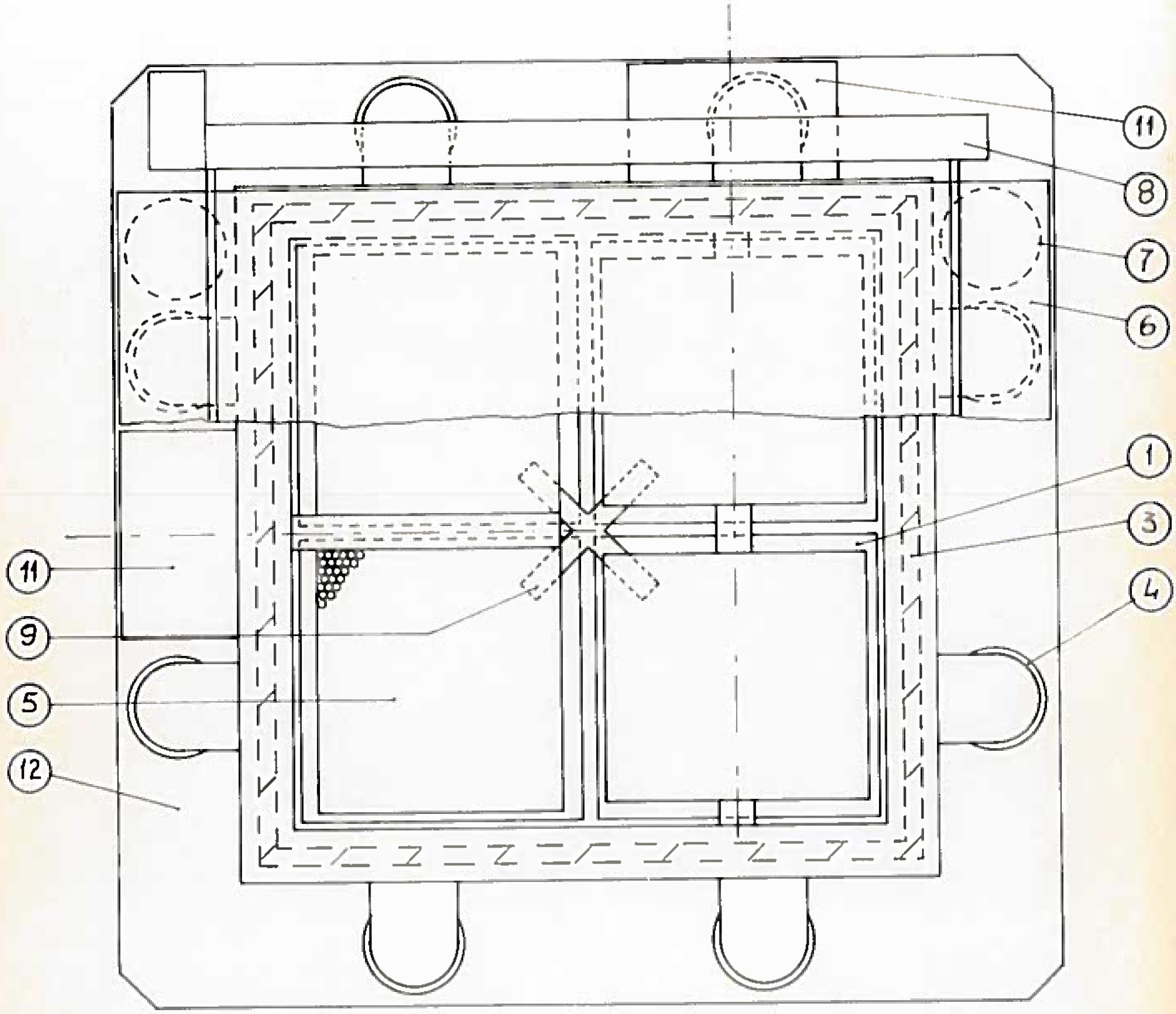


Fig. 1b