



NEUTRON MONITOR

2222A

Users Manual

Serial number 2222.xxxx

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Upon delivery

BF3 manufacturing certificate
Performance test certificate
Neutron calibration certificate

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Neutron Monitor 2222A

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1 Description

The Neutron Monitor 2222A is a portable instrument developed for monitoring radiation in the areas surrounding reactors, accelerators and other neutron producing equipment and neutron sources.

The instrument measures the neutron dose rate in mSv/h with approximately correct rem dose response within the thermal neutron energy range up to 17 MeV. The neutron dose rate can be measured over a broad range, from 0.001 mSv/h to 999.9 mSv/h.

The instrument can also measure the accumulated dose displayed in μSv or mSv.

The 2222A is a complete monitor comprising a neutron detector and an electronic unit. The monitor is equipped with a pulse port for external pulse counting and an RS-232 communication interface.

A battery eliminator can also be provided for the instrument.

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2 Description of functions

2.1 Panel

Around the display are the four buttons who can be used by the user to set the instrument, see Figure 2.1.



Figure 2.1 2222 A Panel

ON/OFF: Only for turning the instrument on and off.

INT: The main function is to switch on and switch off the integral monitoring function, see also Section 2.10.

PRT: For printing content of data memory, see 2.5.

Light button: Activates the background lighting for the display.
See also Section 2.6.

INT+PRT: Simultaneously pressing these two buttons will take you to a loop with three options: setting the date and erasing the memory. These three are presented as "Date", "Clr" and "SET ALARM". See also Section 2.7.

Pressing all of the buttons activates a sound signal.

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2.2 Startup

To start the instrument press the button ON/OFF. A sound signal indicates that the instrument is on. At the same time all segments on the display light up for 5 seconds, showing that all segments are operational. The program version is then displayed for a further 5 seconds. This is done to ensure that the high voltage and electronics become stable and prevent incorrect pulses. The instrument emits a prolonged tone when it starts measuring.

After the instrument is initiated it actively starts to present the dose rate. If the integral mode is selected, the dose is updated every 100 seconds.

If both the battery and the external power supply should fail, the backup battery will become activated and maintain the RAM and the clock. The instrument cannot be started using the backup battery alone.

2.3 Software calibration

When the instrument has been calibrated with known pulses and a measurement with a known neutron source shows a certain deviation a software factor can be added. The software factor is initiated to 1.00.

This calibration factor is burnt into the internal EEPROM of the microcomputer and is reached by activating switch 1 at SW1 on the presentation board. The calibration value (01.00) and the current integrated dose (514.9 μSv) are shown on the LCD:

01.00
514.9 μSv

Always wait with calibration until the first dose value after 100 seconds. Increase the calibration factor with INT and decrease with PRT. The dose will be updated all the time with the new calibration factor.

Finish by deactivating SW1/1 and the new calibration value will be burnt into the EEPROM.

Note 1:

If this factor deviates from 1.00, the value on the display will deviate from the value which can be calculated by counting the number of pulses on the BNC-connector "PULSE OUT" as these pulses are taken out before the microcomputer.

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Note 2:

If the light button is pushed when SW1/1 is activated, the background light is not switched off as both these functions are handled by interrupts. If the light button has been pushed SW1/1 must be deactivated and the instrument switched off.

2.4 Data collection

Total collected pulses during 5 minutes (calculated in uSv/h) are saved in the RAM memory together with current date and time for the measurement. These data are stored in a spill over memory, which means that when 200 measurements (16 ²/₃ hours of continuous measuring) are stored in the memory the oldest one will disappear.

2.5 Printout of memory

Pressing the PRT button does printout of up to 200 measuring values. This means just copying the memory to the RS-232 port and will not erase or change the values in any way. A printout looks like this:

```
37.87 uSv/h 979416 10:30  
38.12 uSv/h 979416 10:35
```

If the dose rate exceeds 999.9 mSv/h the printout will be as follows:

```
999.9 mSv/h 979416 10:40 Overflow
```

2.6 Background lighting

To light up the display for 4 seconds, press the light button. The light-up time is limited to 4 seconds to prevent too much current being used.

2.7 Selecting the menu

Pressing INT + PRT will take you to a menu loop that can be used to set the date, to erase the memory or set an alarm. The menu, which automatically comes up, is 'dAtE'.

INT: Alternates between the three menus.

PRT: To select, press the PRT button.

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Light button: In the main loop, you can exit the menu at any time and return to monitoring by using this button.

Note:

If this menu is selected, you should avoid carrying out important integral measurements at the same time, since the CPU can detect that INT has been activated shortly before you press PRT and it will terminate the integral measurement.

2.7.1 Setting the date

All information relating to the built-in real time clock is saved in the following format: 970114 15:10, i.e. ten minutes past three in the afternoon of January 14, 1997.

When you select this menu, three figures will be displayed which, in normal cases, display the rate meter value:

00 1

where the two on the left are date/time and the right is a control figure as shown in Table 2.1.

- 1 - the year, e.g. 97
- 2 - the month, e.g. 01
- 3 - the day, e.g. 14
- 4 - the hour, e.g. 15
- 5 - minutes before or after the hour, e.g. 1

Table 2.1 Setting the date

Use the following buttons to change the setting:

INT: Increases the figure on the left, i.e. by ten years/months etc.

PRT: Increases the figure on the right, i.e. by one year/month etc.

Light button: Confirms that the right value is entered which causes the program to move forward to the next entry. When confirming the minutes it returns you to the main menu.

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2.7.2 Erasing the RAM

When 'Clr' is displayed, the RAM can be completely erased. When you press PRT, the LCD is blank for half a second. This confirms that the RAM is erased and returns you to the main loop.

2.7.3 Setting of alarm level

In this sub-menu an alarm level can be set. After choosing the menu 'SET ALARM' with the PRT button the current dose rate alarm is shown on the display.

Step through the 5 eligible pre-stored alarm levels with the INT button, according to table 2.2 (all in mSv/h).

0
0.010
0.100
1.000
10.00
100.0

Table 2.2 Eligible alarm levels

'0' means that the alarms function is switched off. Selection of desired alarm level is done with the PRT button and the user is once more in the loop. If the instrument detects that the alarm level has been changed 'SET ALARM' will change to 'ALARM SET' during ½ second as a confirmation of changed alarm level. This will not happen if the same alarm level has been chosen.

2.7.4 Setting print parameters

In this sub-menu baud rates and wait time can be set. After choosing the menu "Baud" by means of the PRT button the current baud rate is shown on the display.

Step through the four eligible pre-stored baud rates with the INT button, according to table 2.3.

9600
4800

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2400

1200

Table 2.3 Eligible baud rates

Choose baud rate with the light button. Now "wait" will be displayed. This is the wait time between the lines, when the memory is printed out. Increase the wait time if the printer is missing characters in the end of the printout.

2.7.5 Pulse Out

When Port is displayed on the first row of the display. Switch the port on/off with the PRT button. The status of the Signal Out is displayed on the second row.

2.8 Alarm

When the dose rate exceeds a set alarm level the instrument alerts with a sound 2 times/second and lights the 'ALARM' segment on the LCD. The buzzer can be switched off by activating the light button. A lower dose rate or a higher alarm level can only switch off the light on the 'ALARM' segment.

2.9 Presentation of dose rate

The LC display is divided in a logarithmic analogue scale and a digital presentation. Both are steered by the same data and show the same value. Collection of measuring values is based on the demands in the standard IEC 1005. The presentation is based on an update every 2 seconds and a maximum standard deviation on 20%. At such low dose rates that the standard deviation is not reached the instrument alerts by beeping at every update of the display until the standard deviation is below 20%. At dose rates above 0.017 mSv/h the values is presented and not used further. If the dose rate is below 0.017 mSv/h up to 15 latest measurement values (30 seconds) are used for a mean value calculation. If there are no pulses during a measurement period 0 is added to the mean value calculation and the mean value decreases. If there are no pulses during 3 subsequent measurements the dose rate is set to zero even if the mean value shows different.

Note:

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At a dose rate of 0.001 mSv/h the IEC standard 1005 can not be fulfilled due to the theoretical exchange between neutrons and detector pulses. Thus the instrument beeps constantly in a 0.001 mSv/h radiation field to indicate that the statistical error is above 20%.

2.9.1 Analogue dose rate

In the region 0.001 to 100 mSv/h, the analogue dose rate is presented with a logarithmic scale. Should the value exceed 100 mSv/h, the scale shows full deflection, i.e. 100 mSv/h. The presented value is rounded upwards, i.e. if the digital doses rate presents 0.16 mSv/h (0.14) the analogue shows 0.2 mSv/h (0.1).

2.9.2 Digital dose rate

The digital dose rate is built of 4 figures with a selectable decimal. That means that the value can be presented between 000.0 mSv/h via 0.001 mSv/h, up to 999.9 mSv/h. If the dose rate exceeds 999.9 mSv/h, 999.9 and OVERFLOW will start to blink with 1 Hz.

2.10 Integral dose display

If selected, the integral dose is displayed at the very bottom of the LCD. To do this, press the INT button. This action also deactivates the function. Every 100 seconds, this value is updated. The value is completely based on the values displayed in dose rate.

2.11 Communication through the serial port

The instrument is prepared to communicate with the PC-program "WinPig" as well with a terminal program. The communication is working when the switch SW1/3 is in position on. The Neutron Monitor 2222A sends and receives using the following settings:

9600 baud
8 bits
1 start bit
1 stop bit

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2.11.1 Operator controlled messages

The operator can by pressing PRT copy the RAM memory through the serial port in the form

1.234 mSv/h 971213 14:15

By setting SW1/2 the instrument will send the dose rate through the serial port once every 2 seconds on the format 1.234 mSv/h.

2.11.2 Automatically sent messages

At 'OVERFLOW, 'LO BATT' or 'ALARM a message is automatically sent through the serial port the first time it occurs, for example

LO BATT 971213 14:20

ALARM 7.661 mSv/h 971213 14:22

2.12 External pulse port

The pulses at the external pulse port, are the same as those read by the CPU and the pulse port can be used to connect a scaler to read the number of pulses from the detector. Note that external pulse port not is calibrated in Sv/h as on the display. To get calibration factor look at enclosed calibration certificate.

See note 1, 2.3.

NB:

In order to avoid affecting the electronics, all equipment connected to the external pulse port must have a load of over 10 kohm.

2.13 Power supply

2.13.1 Battery operation

Six LR14 1.5V batteries are required. The battery capacity is about 80 h.

To replace batteries, remove the hood by undoing the 3 screws and gently lift the hood. The two battery tubes, each containing 3 batteries, are

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located under the circuit boards. In order to mount and de-mount the tube hood easily, hold the back of the battery holder.

2.13.2 Low voltage

The instrument gives a warning when the voltage is too low. The 'LO BATT' segment is lit up in the upper left corner of the display. During battery operation, it is recommended that the batteries be changed as soon as possible after this warning is displayed.

Warning:

The instrument seems to work properly after 'LO BATT' is displayed, but since the high voltage is not at the right level, the detector response drops and the user might be in a higher radiation field than the instrument displays.

Note:

Setting up the e.g. the date when 'LO BATT' is displayed, might lead to shut down of the instrument.

2.13.3 External battery eliminator

An external power supply can be plugged in via the 'External Power' connector with a battery eliminator (accessories). This gives at least 10V at load. At connection of the external power supply the batteries are disconnected automatically, as the external source has a higher potential than the internal batteries and thus no further actions are needed before the external power supply is connected. At disconnection the batteries automatically takes over the power supply.

Note:

The voltage regulation on this instrument leads to that the incoming voltage is adjusted to +5V via a voltage controller. If the incoming voltage is above +12V these circuits will be warm and the length of life will be radically shorter.

Therefore a *regulated* +12V battery eliminator is recommended.

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3 Construction of the instrument

3.1 The detector unit

The detector unit consists of a BF_3 proportional counter with a high sensitivity for neutrons. The counter tube is surrounded by polyethylene and boron plastic. The anode support of the BF_3 tube has been minimised and thus made it possible to reduce the overall length of the detector without any impact on the dose sensitivity. Together with a slightly higher pressure in the counter it has been possible to improve the characteristics of the instrument. The shape of the polyethylene and boron plastics surrounding the counter gives the instrument a neutron sensitivity that looks like the biological damage effect on humans neutrons. The response is independent of the neutron energy. The instrument can thus be used to measure the dose rate regardless of the neutron spectrum. Figure 5.1 shows the construction of the detector unit. The thickness of the polyethylene layers and the configuration of the holes in the boron plastic layer have been chosen to obtain the proper rem response.

Figure 5.2 shows the energy response of the detector compared to the reference curve given by ICRP. The curves correspond well over the energy range 0.025 eV up to 17 MeV. The dose sensitivity can't be changed within the angles 0-90° and 270-360° as shown in figure 5.3. The lower sensitivity at 120° and 255° comes from the presence of electronic circuits and batteries.

The use of a BF_3 counter for neutron detection has the advantage that it can effectively discriminate a background of gamma radiation. The monitor, with the proper discriminator level adjusted, is practically insensitive to gamma radiation up to 2 Gy/h. The operating voltage of the BF_3 counter is +2600 V at normal use. This voltage level is 100 V up on the high voltage plateau of the counter tube. The sensitivity of the detector varies between 3,5-5 cps at a neutron dose rate of 10 $\mu\text{Sv/h}$. With the discriminator level at 2.0 V, the contribution from 10 mSv/h gamma radiation is less than 10 $\mu\text{Sv/h}$. The instrument has been tested in accordance with the requirements in the standard IEC 1005.

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3.2 Electronic unit

3.2.1 In general

A block diagram of the instrument is shown in figure 5.4. The pulses from the detector are amplified in the amplifier and the discriminator level is set so that it discriminates background and gamma pulses. This gives that every "neutron pulse" results in a standard pulse, which is sent to a microcomputer (Motorola 68HC11). The microcomputer calculates and presents the dose rate in mSv/h and as an option the dose in mSv or μ Sv. The standard pulses are available at the BNC-connector "Signal Out".

3.2.2 Power supply

The instrument uses 6 batteries (9 V) or a 12 V DC battery eliminator. The contact for the battery eliminator has a inner diameter of 2.1 mm which is a standard and there are eliminators for 110 V/60 Hz and 220 V/50 Hz. If a battery eliminator that has a higher voltage than the batteries is used they are automatically switched off.

3.2.3 High voltage

The high voltage source consists of a variable power supply, a DC/AC, a high voltage transformer and a cascaded rectifier. The power supply is regulated from the presentation board. The high voltage is regulated in three steps (2400, 2500 and 2600 V) using the switch SW3 (see table 3.1). This is done in order to verify that the high voltage plateau is correct. The same function is used to adjust the high voltage of the BF_3 tube at extremely low temperatures. This switch is set at 2500 V upon delivery.

SW3 #1	SW3 #2	HV out
OFF	OFF	2400
ON	OFF	2500
OFF	ON	2600

Table 3.1

3.3 Pulsed neutrons

If the instrument has used for measurements of pulsed neutrons it is necessary to know both pulse length and repetition frequency in order to

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be able to calculate the percentage counting loss at a specified radiation level. Since a moderator encapsulates the detector, a finite time is required for the slowing down and diffusion neutrons. This results in an extended time distribution of about 60 μs in order for the neutron to be detected. It is therefore possible to use the 2222A also for pulsed radiation but with some restrictions especially at low repeated frequencies.

Since each burst of neutrons will have an equal length of 60 μs, the detector will see almost continuous radiation as soon as the frequency is higher than 2×10^4 Hz. This stretched burst has a maximum rate of neutrons between 10-20 μs after the start of the pulse and the time distribution is independent of the pulse width.

If N_τ is the true reading in cps, and N_0 is the measured counts in cps, the calculation error is given by:

$$N_\tau = \frac{N_0}{1 - \tau N_0}$$

The result with $\tau = 0.5 \mu\text{s}$ is shown in picture 5.5, curve 5.

If the burst repetition frequency, f , of the neutron burst, is lower than $f_0 = 2 \times 10^4$ Hz and the length is short (less than 10-20 μs) the true value, N_f , is given by:

$$N_f = \frac{f}{f_0} * \frac{N_0}{1 - \tau N_0}$$

Example	N_0	= 1000 cps
	τ	= 0.5 μ
	f	= 100 Hz
	N_f	≥ 5 cps

The relative errors for different pulse frequencies of $f = 1$ Hz, 10 Hz, 100 Hz, 1000 Hz and ≥ 20 kHz is shown in figure 5.5, curves 1, 2, 3, 4 and 5.

All curves in the figure is given under the same conditions where the impact of the gamma background up to 2 Gy/h is not taken into account.

3.4 Pulse collection

The collection of measuring values is based on the standard IEC 1005.

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The presentation is based on updates every 2 seconds and a maximum standard deviation of 20 %. In order to get the error to be lower than 20 % at least 25 pulses must be collected under a certain time period, according to formula 3.1. 25 pulses under 2 seconds is equal to 0.017 mSv/h and all dose rate over this value is presented every other second and then it is discarded, while dose rates under 0.017 mSv/h are saved and the 15 latest values are averaged for increased statistical certainty.

At those low dose rates, where it takes over 2 seconds before 25 pulses is reached, the instrument gives an audible alarm signal at every update of the display until there are over 25 pulses in the average calculation.

If no pulses are present within a measuring period a 0 is added to the average calculation and the average value gets lower. If no pulses are present under 3 measurements the dose rate is set to zero even if the average value shows anything else.

$$\text{error} = \frac{\sqrt{\text{pulses}}}{\text{pulses}}$$

Formula 3.1

Note:

At a dose rate of 0.001 mSv/h the IEC standard 1005 can't be fulfilled because of the theoretical exchange between neutron and detector pulses. The standard states that a new value must be presented after a maximum of 30 seconds at this dose rate and in the same time the statistical error is allowed to be maximum 20 %. This means that one needs at least 25 according to the discussion in chapter 2.9. In order to display 0.001 mSv/h there must be in average 144 pulses per every 2 seconds. To reach 25 pulses in a radiation field of 0.001 mSv/h it takes 35 seconds to reach statistical certainty. Thus the instrument sounds in a radiation field of 0.001 mSv/h to indicate that the statistical error exceeds 20%.

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4 Specifications

Microcomputer:	Motorola 68HC11
Software:	C-code stored in external EPROM
Real time clock:	Can be set by the user. Displays the date and time in the following format: 970417 14:41. The backup battery ensures that the clock continues to work even during battery replacement.
Display:	Graphic LCD with optional background lighting at 4-second intervals.
Display of dose rate: Analogue display:	Logarithmic scale in the range of 0.001 - 100 mSv/h. If the value exceeds 100 mSv/h, the instrument will display 100 mSv/h.
Digital display:	In the range of 0.001 - 999.9 mSv/h, above 999.9 mSv/h, 999.9 and OVERFLOW will blink with a frequency of 1 Hz.
Storage of measured values	Every 5 minutes the dose rate value is stored in an external RAM with a spill over function. The entire memory can be erased. The backup battery ensures that the measurement value is stored even during battery replacement
Printing:	Via RS-232 to terminal program. Printout from the memory of the measuring values with time indication. LO BATT, ALARM and OVERFLOW indication are printed out with time indication.
Statistical error:	Maximum 20%. At entrance in a weak neutron field the error can be higher during a short period and the instrument will give an audible alarm.

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Energy range:	0.025 eV - 17 MeV
Neutron sensitivity:	0.35 – 0.50 cps/ μ Sv/h (individual variation)
Gamma sensitivity:	2 Gy/h gives < 5 μ Sv/h
Average background counts: (normal conditions)	Less than 30 counts per hour under a 10-hour period.
Minimum pulse charging from detector: (HV = 2500 V)	$5 * 10^{-14}$ Coulomb
Charge amplification - Amplification:	$2V/10^{-13}$ Coulomb
Differentiation time:	1 μ s
Discriminator range:	About -0.5V ... -3V ¹
External pulse port Amplitude:	about +2.8 V
Duration:	700 ns
Load:	10 kohm min
HV supply - Voltage:	+2200V - 2700V ²
Operation:	1 V/ $^{\circ}$ C
Square wave frequency from DC/AC converter:	50 kHz
Power supply: Internal:	Alkaline batteries 6 x 1.5V IEC LR14
Operating time:	80 h
Battery testing:	Tested electronically. 'LO BATT' lights up on the LCD when there is about an hour left of battery capacity.
External (option):	Through the 'External Power' connector, a 12 VDC eliminator with positive center can be connected. When connected the eliminator will

¹ The exact value depends on the neutron calibration.

² The exact value depends on the individual BF3-tube. HV is normally 2400V at "plateau knee".



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take over the battery function. This eliminator can be connected and disconnected while the instrument is operating.

Power consumption in "Power Off" mode	Max 0.30 mA
Temperature range:	-10°C - +40°C
Dimensions -	
Diameter:	215 mm
Length:	325 mm
Weight:	10.5 kg, including batteries

5 Appendix

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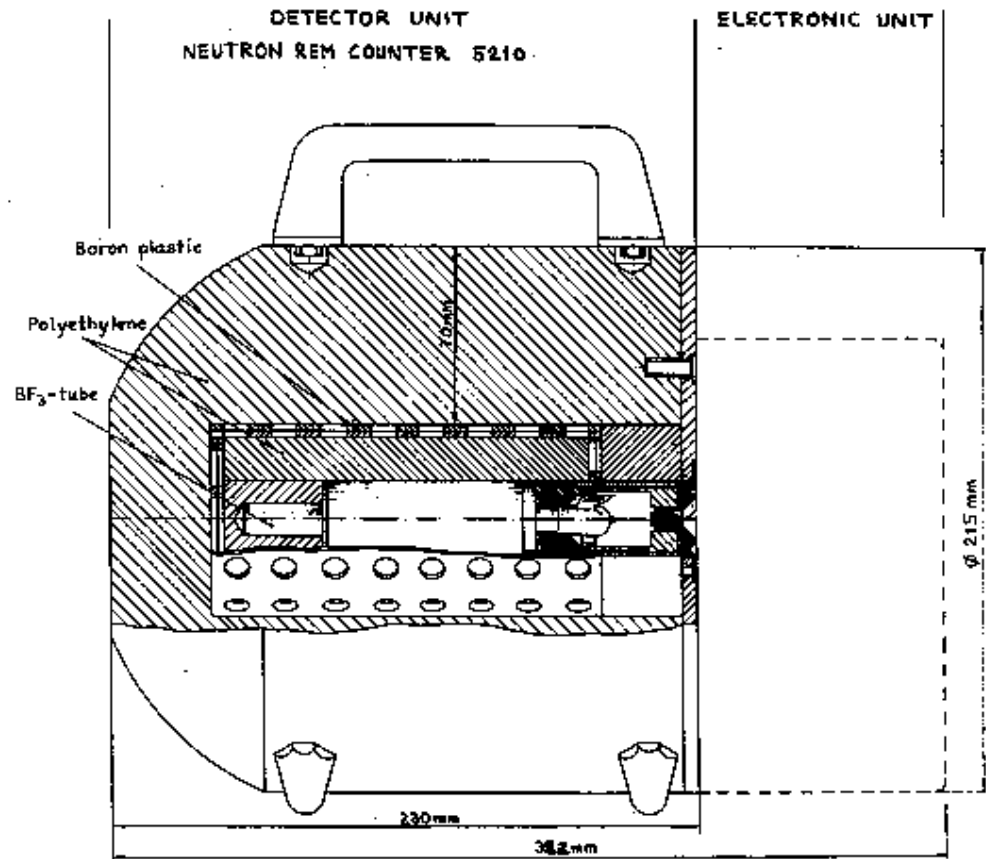


Figure 5.1 Construction of detector unit

Neutron sensitivity

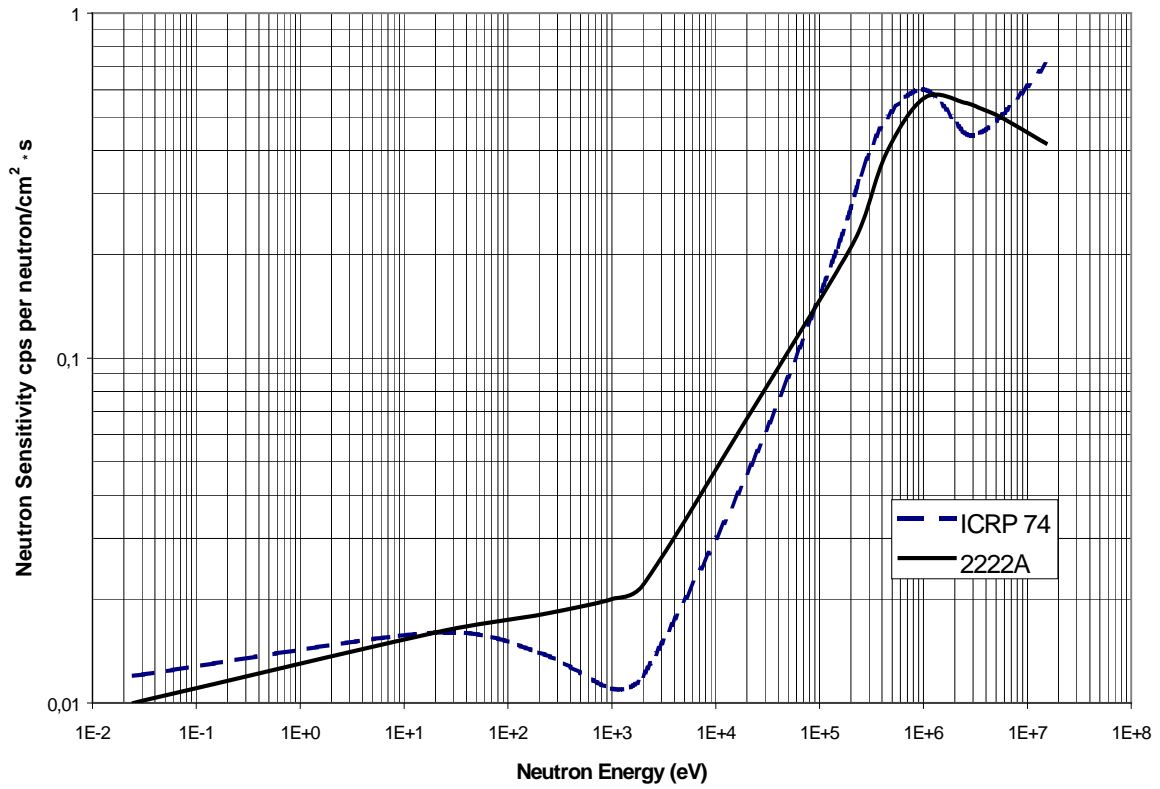


Figure 5.2 Neutron sensitivity

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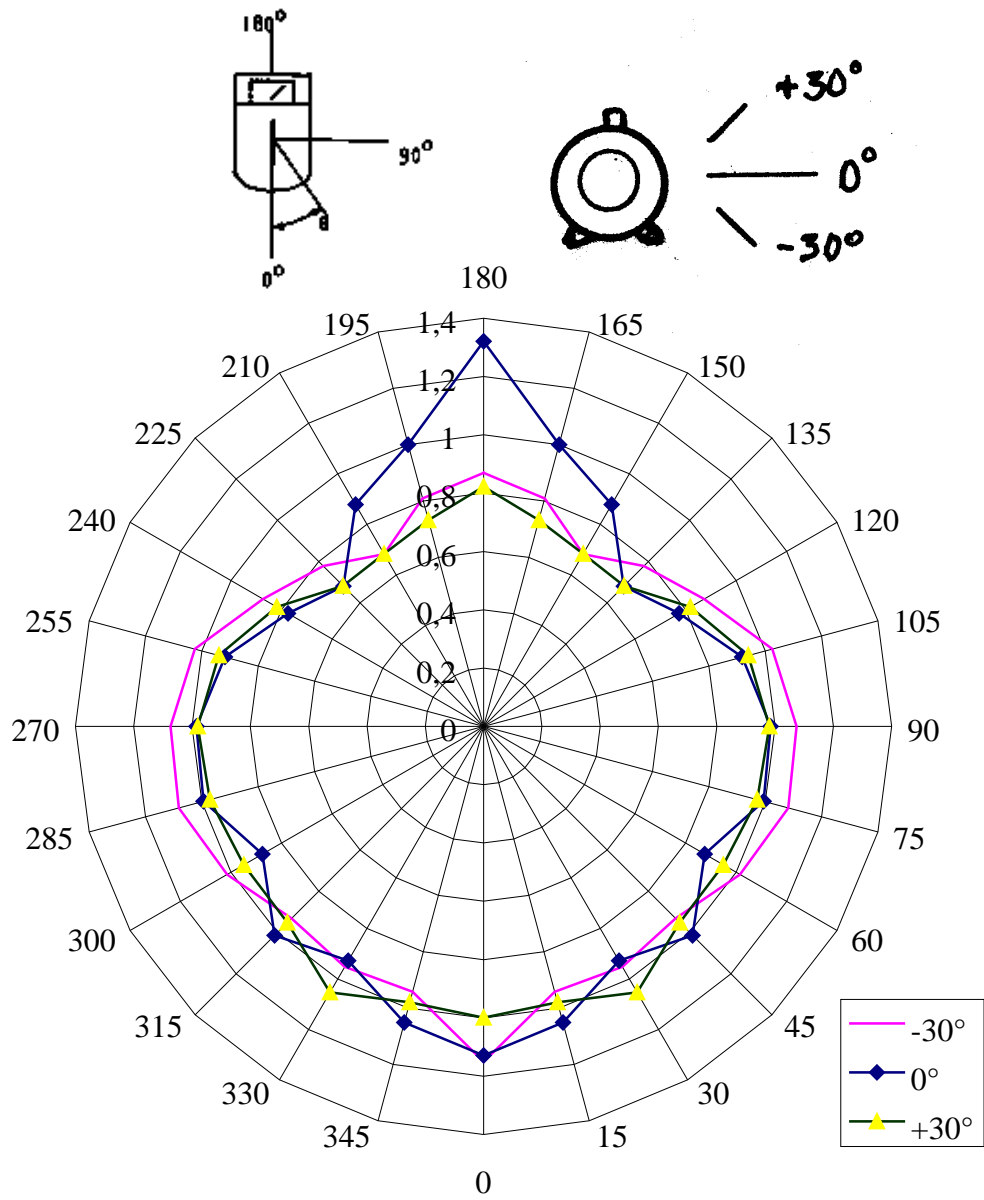


Figure 5.3 Angular dependence relative to count rate

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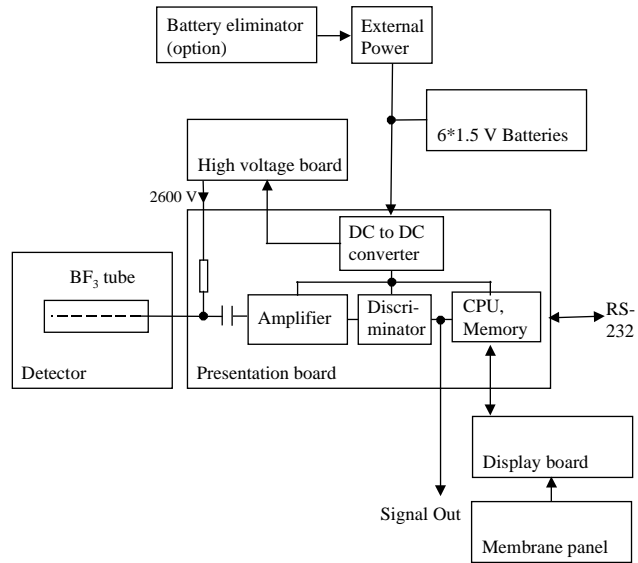


Figure 5.4 Block diagram

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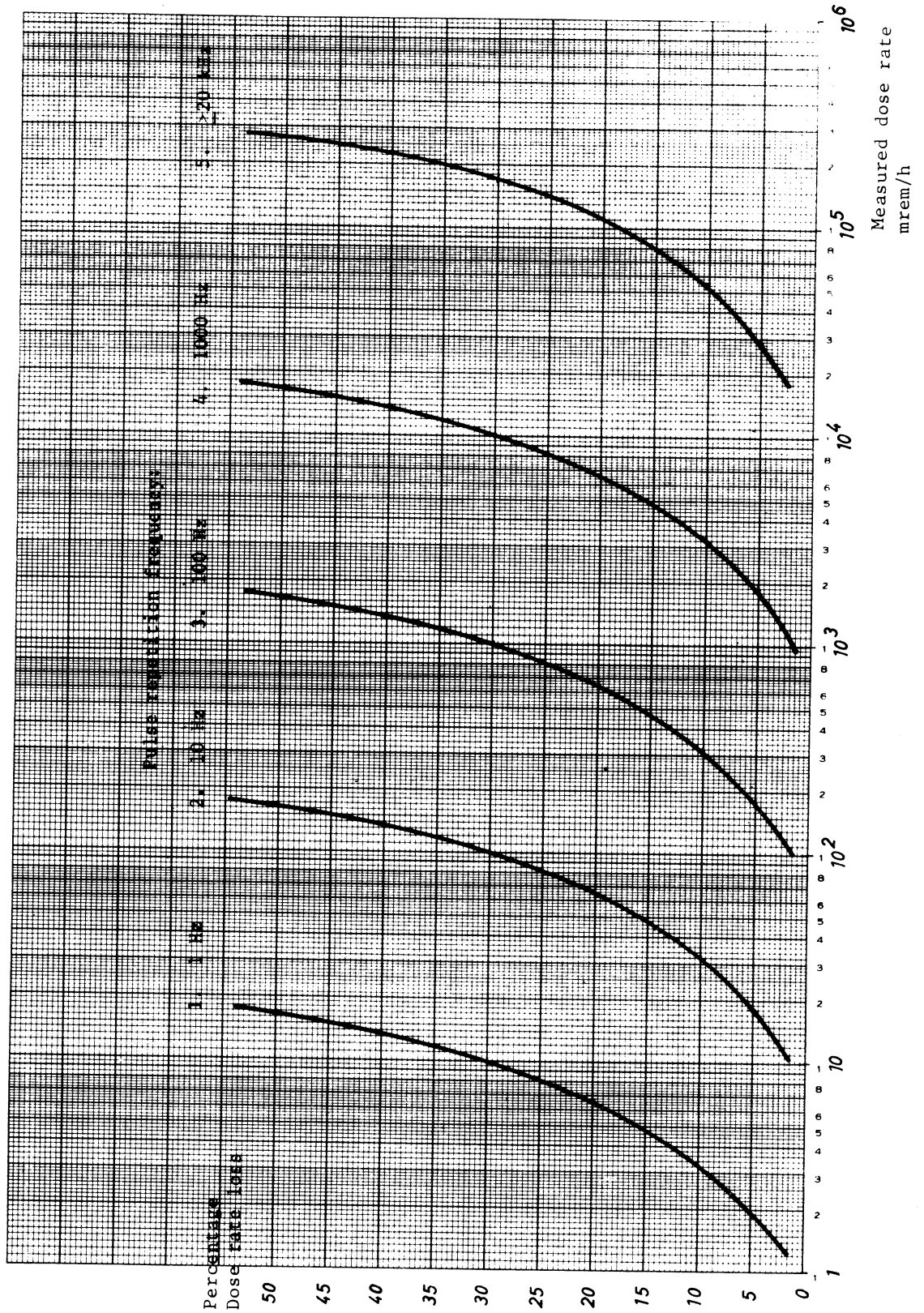


Figure 5.5 Loss of counts at different pulse repetition frequencies