Geiger Counter Home-Made

Documentation
Bill of Material
Parts

Keywords: activity, Atmel AVR microcontroller, ATMega, beta gamma radiation, CTC-5, equivalent dose, geiger tube, GM counter, radiation, STS-5,

This article describes a home-made Geiger Counter with a CTC-5 (STS-5) tube. The individual disintegrations clicks are counted and computed with an Atmel microcontroller ATMega88. The software was designed with AVR Studio 4 in WinAVR-GCC. The radiation activity in CPM and the equivalent dose rate are calculated and displayed. This portable device is powered from a single Li-ion cell. Recharging facility via USB connection is integrated.

Contents

1 Radiation basics

The human being does not have any sense for radiation. To avoid being harmed by radioactivity, measurement is the only option. The measurement of physical units allows the possibility to determine the medical or biological effects, the destruction of human tissue and DNA. The likeliness of suffering from leukaemia can be calculated.

Through the past century plenty of units have been introduced. Confusion exist about these units. The proper use of conversion tables is difficult.

The SI system (International System of Units [8]) needs only three units for a comprehensive description:

Quantity name	Unit name	Quantity symbol	Unit
Radioactivity	Becquerel	Bq	s^{-1}
Absorbed dose	Gray	Gy	J/kg
Equivalent dose	Sievert	Sv	J/kg

All other units are related or old and should not be used any more.

Brief explanation:

BECQUEREL: means the number of disintegration per second.
Example: If one million uranium atoms disintegrate in one second this equals 1,000,000 Becquerel or 1MBq.

GRAY: for the absorbed dose.
The energy (J) which is absorbed by the mass (kg)

SIEVERT: for the equivalent dose.
This is mainly medical related and indicates the hazard the radiation causes to the human body. If the absorbed dose and the type of radiation are known, the equivalent dose can be calculated.

For Gray and Sievert the dose rate is mostly used. This is the amount of absorbed dose or equivalent dose per time interval. Common intervals are hour or year e.g. uSv/h or mSv/a.

2.0 Features

Schematics around counter tubes are mainly related to the high voltage generation. Examples are widely spread in the net. A special issue of this counter is beside the generation of the high voltage, the microcontroller computing the clicks and display the data on an LCD. Here the main features of this design:

- Microcontroller ATMega88, Software in AVR-GCC
- Software controlled speaker pulse width “click”
- Display of CPM and nSv/h
- Display of Li-ion and tube voltage
- Charging facility from a USB port
- Step up converter to a stable 5.0V
- Auto-power-off after 10min
- Li-ion accu deep discharge protection
- PWM-output for an external analog meter

Nevertheless a stable 5V is useful in combination with a controller and an LCD. Unfortunately the contrast varies with the supplying voltages. The usage of a standard 3.7 V Li-ion rechargeable battery is a solution to the portability and capacity. The annoying effect of self-discharging like regular nickel metalhydrid accu is avoided by usage of li-ion technology. Recharging is supplied with a simple USB cable from any computer interface.

3 Block diagram

The “click” signal of the Geiger tube triggers an interrupt input of the controller. An output of the controller feeds the speaker. The pulse length is fixed by software. Four modes of display are selectable with the toggle mode switch:

1) CPM radiation activity in counts per minute
2) nSv/h radiation dose equivalent in nano -sievert per hour
3) mV voltage of battery
4) HV voltage of tube high voltage

The “Battery / USB” selects the source of power. The push button “Power ON” turns the counter on. In case a USB connection is made, the li-ion battery is charged automatically. Another output pin of the controller drives a PWM signal for an analog instrument. This may be connected externally. See the simplified block diagram in figure 1.

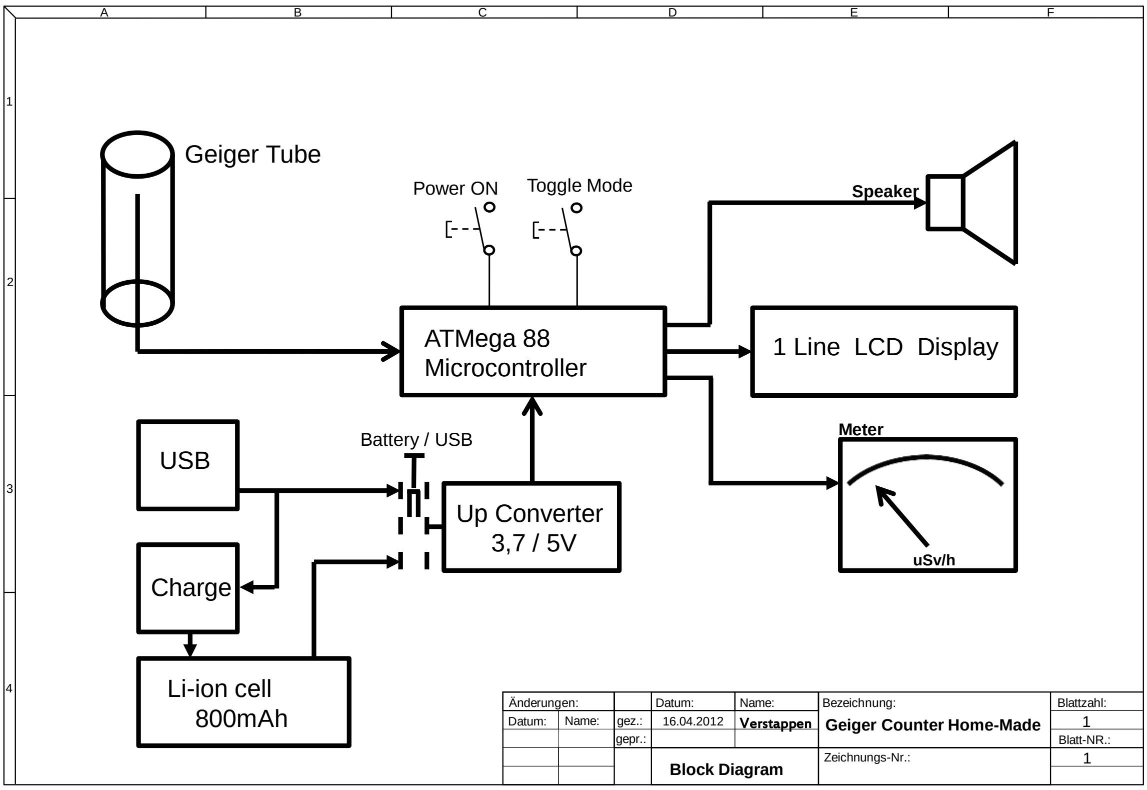

Figure 1: Block diagram of the Geiger Counter Home-Made

4 Schematic high voltage generation

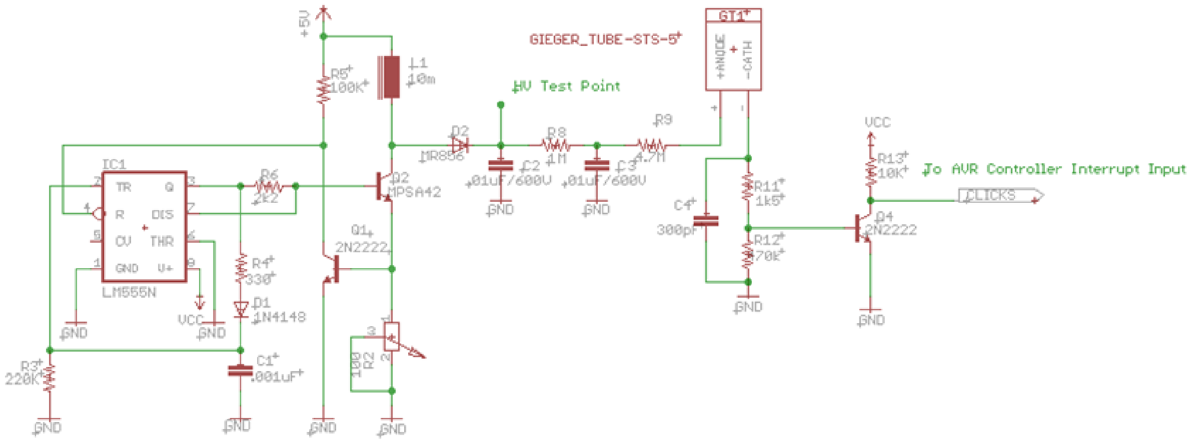

Figure 2: Schematic of the high voltage generation

The advantage of this high voltage circuit is the very low supply current consumption and the independence of the supplying voltage. R9 is the anode resistor for the tube. C2 and C3 are storage capacitors for high voltage. R4 and C1 determine the on-time (30us), C1 and R3 the off-time (3ms). During the on pulse, the current in the coil increases with about 1mA / ms. R2 and the U_{be} limits the current at 25mA and switches the Q2 off. In this moment the L1 in combination with stray capacitance creates a 1/2 sine voltage wave about 2us long and >400V high. This is passed by D2 to the storage capacitors C3 & C4.

This is an unwanted effect when switching a relay coil with a transistor. This spike destroys the transistor if a freewheeling diode across the coil is not implemented. For a more detailed description see John Giametti [2] and Tom Napier [1].

In case the Geiger Tube detects radiation disintegrations, the current increases for about 200us. This pulses are amplified an inverted by transistors Q4. These CLICKS feed the interrupt input of the controller.

4.1 Geiger tube CTC-5

CTC-5 type is Russian production and sensitive to beta and gamma radiation. For a proper indication the tube should be operated with 400V. See appendix for detailed data.

The tube detects about 25 pulses per minute at normal background equivalent to approximately 0.1 uSv / h.

Verification of CPM was check with square waveform from a signal generator into the R/C combination of the controller interrupt input. A 50 Hz signal resulted in a display of 3000 cpm. Total satisfying result.
Check of maximum. A signal of 250Hz resp. 15.000 CPM hits the limit of the counter.

5 Schematic microcontroller

The click signal from the high voltage part is active low. On the way to the controller interrupt input it passes a low pass filter R10 and C5. R13 and R14 are the voltage divider for the 400V high voltage. The ratio is 1GΩ by 1MΩ. The high values are necessary since the high voltage is of very high impedance. Lower values would affect the measurement accuracy. The HV signal is connected to the A/D converter ADC1 of the controller. The battery voltage 3.7V is applied to the ADC0 with a divider of R11 and R12. Since the internal reference voltage for the A/D converter is 1.1 volt, a reduction is necessary. A software calibration value will compensate for this.

S2 is the pushbutton for the display mode. The interrupt input INT1 is falling edge sensitive. The RC combination debounces the switch.

The PB2 output drives the SPEAKER signal. T1 decouples and amplifies for the 8Ω speaker. The timer2 output compare (OC1A) pin is the PWM signal for the analog meter. R4 limits the maximum current. For other than 100uA full scale meters the value has to be adjusted. With a current of 100uA full scale the instrument is calibrated to about 4000 CPM respectively 22000nSv/h. For higher currents an additional stage is necessary.

LED1 flashes with 0.5 Hz. A compare match of timer1 toggles the LED and the flag for the main program loop.

S3 selects the power source either from the Li-ion cell or from an USB interface. In this case the battery charges.

X1 is the ISP (in circuit programming) connector.
CAUTION: When programming, keep power button pressed. During programming the reset pin is kept low and the controller switches it own power off. See figure 3.

5.2 LCD

The 16x1 LCD uses a standard KS0073 controller. This single line has to be addressed as two lines with 8 characters each. The microcontroller addresses the LCD in 4-bit IO port mode. Pot. R2 controls the contrast of the display.

5.3 Power management

X2 is the connector for the Li-ion cell mounted underneath the PCB. S3 selects the power source. In USB position the counter is powered from the USB port and the Li-ion cell is charged via the MAX1811. The charge voltage is selected to 4.1V and the max. current to 500mA. LED2 is lit while charging.

Power on sequence:
S4 is a push button and pulls the gate of Q3 to ground. This p-channel MOSFET in a SO-8 case switches the Geiger Counter on. During initializing the controller sets the PC2 output pin high which keeps the Counter switched on.

Power off:
After 10 minutes the counter switches itself automatically off. The POWER ON signal is set to low.

Li-ion accu deep discharge protection:
In case the Li-ion accu drops below 3.5 V, the POWER ON signal is set to low and switches the counter off.

5.4 DC/DC converter

The inputs voltage can vary from 3.5V to 5.5V. A step–up converter with the integrated circuit MC34063A supplies a stable 5V for the complete Geiger Counter.

Across R22 the charging current of L2 is measured. A limiting circuit protects the internal switching FET. C14 determines the oscillation frequency. With 1nF chosen to 33 KHz. With the nominal current consumption of 25mA at 5V the charging inductor of 100uH was selected.

The efficiency was measured at an input voltage of 4V and an output of 5V/25mA slightly above 50% with 200mVss ripple.

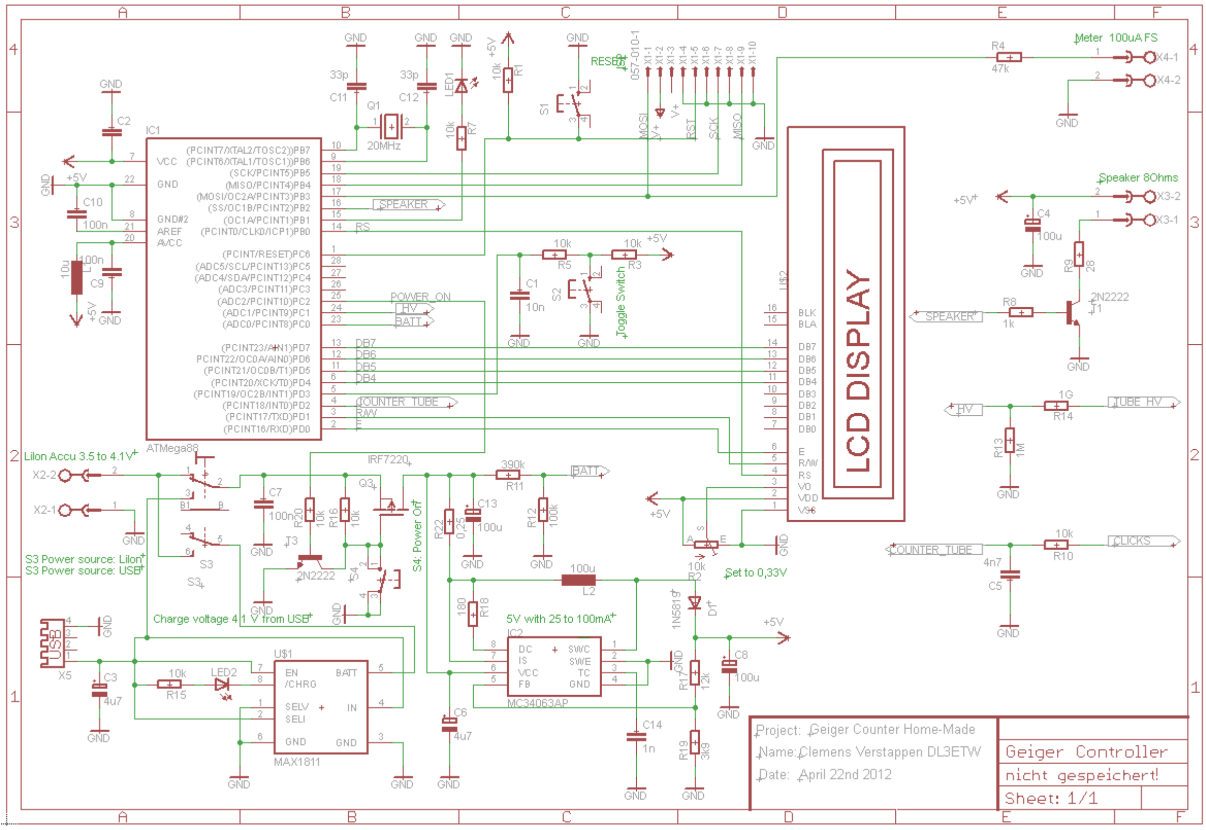

Figure 3: Schematic microcontroller

6 Construction on a perfboard

Components are easy to identify, see figure 2. A standard perfboard of 100mm by 160mm (eurocard) was used. All components are fixed onto the PCB, nothing is attached to the enclosure.

A 6.3 x 32mm fuse holder avoids soldering the contact of the Geiger tube. The left 8 pin IC is the dc/dc converter the right one is the timer for high voltage generation. The red resistor (1GΩ, 5watts) belongs to the high voltage divider. Underneath the LCD is the ATMega88 microcontroller located.

On the soldering side are integrated circuits for charging the li-ion cell and the FET as power switch, both SMD devices. See photo#3. Figure 4 shows the socket of the controller before the LCD was mounted.

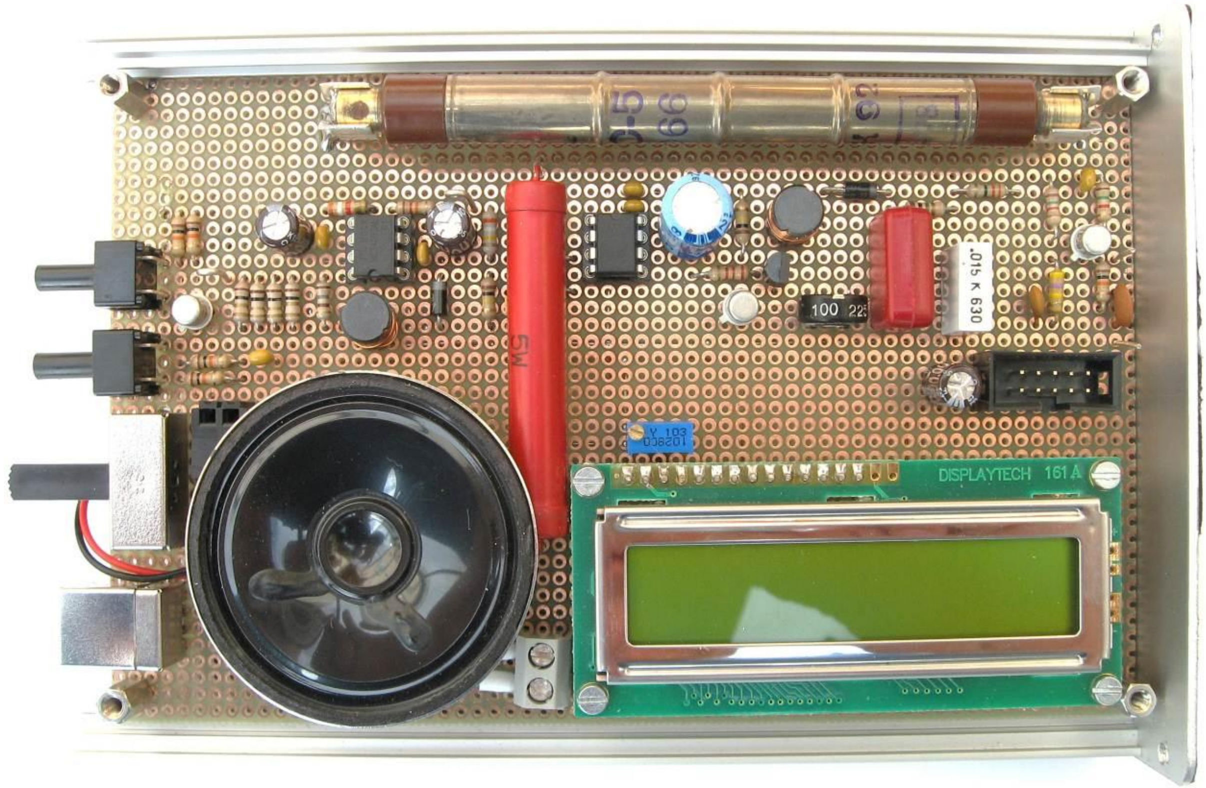

Figure 4: Photo component side

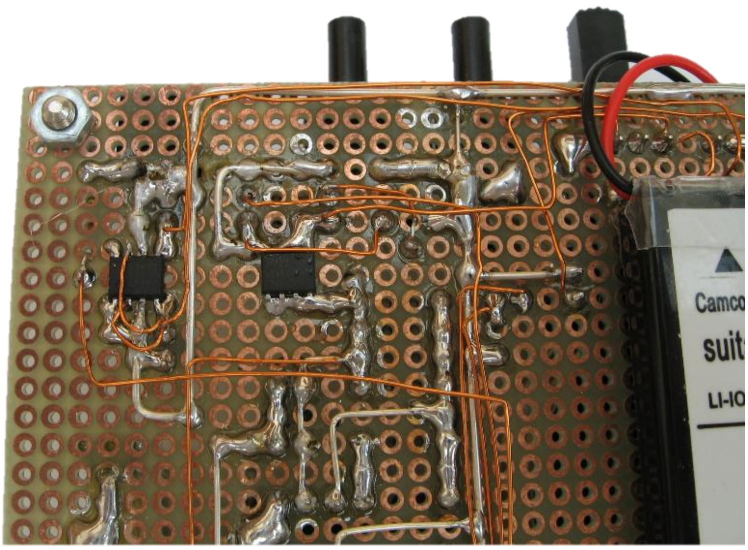

Figure 5: Photo PCB, SMD components on the solder side

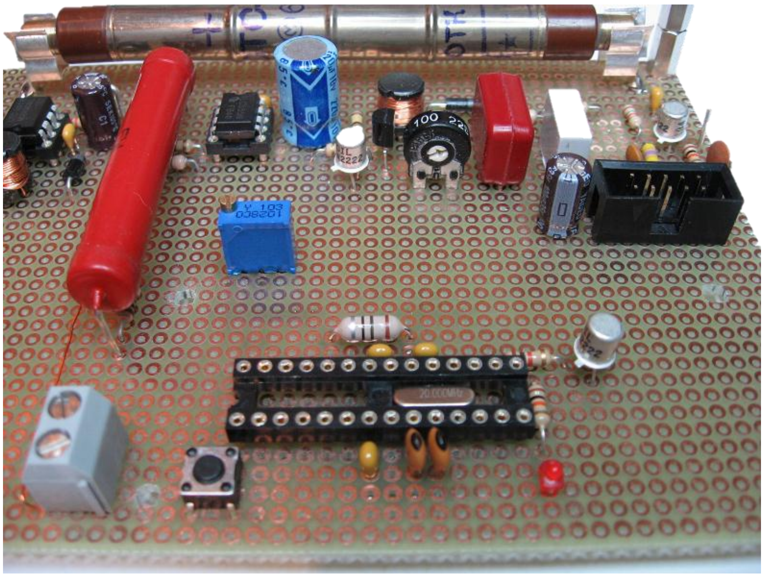

Figure 6: Photo PCB, Controller underneath LCD

7 Software

The source code was designed with Atmel AVR Studio 4 in WinAVR-GCC. The software is under GNU license, for details see header of source code. The lcd.h from Peter Fleury made the control of the LCD easy. The intension was to keep the source code as simple as possible. Float variables were not used, numbers on the LCD were kept in integers. Here is plenty of room for modifications and improvements.

Mainly interrupt routines were used to control the program. All three timers of the ATMega88 are used.

7.1 Interrupts

INT0
In case radiation disintegration is detected by the tube, the falling edge of the signal "COUNTER_TUBE" generates an interrupt on INT0 (SIGNAL (INT0_vect)). In the corresponding routine the output signal "SPEAKER" is set to high. Timer0 starts immediately and this event increases the counter.

INT1
A falling edge on the INT1 inputs toggles between the four display modes. In the interrupt routine (SIGNAL (INT1_vect)) the display mode is increased.

7.2 Timer

Timer0 determines the length of the dc signal of the "SPEAKER." A compare match interrupt on timer0 (SIGNAL (TIMER0_COMPA_vect)) switches the dc off again. The prescaler of 1024 and 20MHz oscillator frequency, the timer increases in steps of about 51us. The compare match is programmed in OCR0A to 4 produces a nice click of 200us.

Timer1 generates a compare match interrupt (SIGNAL(TIMER1_COMPA_vect)). This generates the flag for the main program loop. Only once per second all calculations are performed and the LCD is updated.

Timer2 produces the PWM signal for the external connected analog meter.

7.3 A/D converters, average and display

In the main loop every second the numbers of clicks are copied into the average_array[]. Each second this array is shifted by one element. The average of all elements in a time frame of 15 seconds, multiplied by 4, results into the desired CPM.

The ADC0 is connected to the battery voltage of the Li-ion cell, the ADC1 to the high voltage of the tube. Each second an A/D conversion for one of these values is started, the third value is stable and used. A calibration value of 67/13 for battery A/D gives the voltage in mV. The A/D value of the HV corresponds directly in volts.

7.4 Power related functions

The usage of a Li-ion cell makes the monitoring of the voltage mandatory. A complete discharge damages the cell. In case a value of less than 3.5V is detected the Geiger counter switches itself off. An auto power off function switches off after 10 minutes as well.

8.0 Calibration with a professional equivalent dose meter

A reference measurement with a professional fully calibrated equivalent dose rate meter (Berthold TOL-F) was made in order to verify the accuracy of activity measurement. More over an attempt was made to find a calibration value in order to indicate the equivalent dose in nSv/h. The latter can only be a rough reference since the type of sensor is different. The accurate value depends on a variety of parameter e.g. tube high voltage.

For the first test the probe measured the surface activity of a small piece of broken ceramic plate with uranium glaze [7]. The instrument read 36 IPS (or 2340 CPM) See figure 7 and 8. The same shard was held at the same distance above the Geiger counters tube. The reading was 2196CPM. This was an unexpected good match.

In the second step the dose rate equivalent was selected on the TOL-F. The meter indicated 13uSv/h. This resulting calibration value of 0.33 uSv/h per one IPS was taken over from the TOL-F. Refer to chapter 10. Appendix and abbreviations

Figure 7: left, Geiger Counter Home-Made and professional equivalent dose meter
Figure 8: right, The probe and a broken piece of ceramic plate

9.0 Parts and distributers

Distributor: Reichelt Elektronik [4]

1	ATMEGA 88-20 PU	ATMega AVR-RISC-Controller
1	LCD 161A	LCD-MODUL 16X1
1	MC 34063 A	Schaltregler, DIP-8
1	MAX 1811 ESA	MAXIM-IC, SO-8 // Laden von LiIon Akkus S
1	ICM 7555	Timer, DIP-8 = ILC 555 siehe Datenblatt
1	IRF 7220	Leistungs-MOSFET P-Ch SO-8 12V 11A
1	MPSA 44	Transistor NPN TO-92 400V 0,3A 0,625W
1	MR 856	Fast-Recovery-Gleichrichterdiode, DO27,600V,3A
1	MUR 160	Ultrafast Diode, DO-15 / DO-204AC, 600V, 1A
2	2N 2222	Transistor NPN TO-18 60V 0,8A 0,5W
1	1N 4148	Planar Epitaxial Schaltdiode, DO35, 100V, 0,15A
1	VAP VFL002	LiION Camcorder-Akku 3,7V 1050mAh

1	L-07HCP 100µ	Stehende-Induktivität, 07HCP, Ferrit, 100µ
1	L-07HCP 10M	Stehende-Induktivität, 07HCP, Ferrit, 10m
1	64Y-100	Präzisionspoti. 25 Gänge, stehend, 100 Ohm
1	VIS K 50-8	VISATON Breitbandspeaker, 5cm, IP 65, Metall

1	GEH EFG 1A	Euro-ALU-Flachgehäuse 168 x 113,5 x 31 mm
1	LCD FRONT 1	LCD-RAHMEN für 1x 16 Zeichen, schwarz
1	AKL 182-02	Wannenstecker für AKL 169, 2-pol, RM3,5
1	GS 28P-S	IC-Sockel, 28-polig, superflach, gedreht, schmal
2	GS 8P	IC-Sockel, 8-polig, superflach, gedreht, vergold.
1	TASTER 3305B	Kurzhubtaster 6,6x7,4mm,Höhe:8,35mm,12V,horiz
1	USB BW	USB-Einbaubuchse, Serie B, gew., Printmontage
1	PICO 1,0A	Feinsicherung, Picofuse, flink, 1,0A
1	UP 832EP	Lochrasterplatine, Epoxyd, 160x100m
1	PL 137000	Sicherungshalter, 6,3x32mm, max. 6,3A-250V

Distributor: Conrad Elektronik [9]

1	Miniatur-Print-Taster (L x B x H) 20 x 10 x 7 mm Schwarz gerade 24 V 0,01 A
1	Schiebeschalter 2 x Ein/Ein/Ein 50 V 0,3 A

Source for 1GΩ:

1 R14 GΩ Resistor amazon, search:
"1G Ohm 3w 5% Resistance Glaze High Voltage Resistor"

10. Appendix and Abbreviation

Technical characteristics of Geiger-Mueller Counter STS-5 [3]:

Radiation Source	- Cs;
Gamma radiation sensitivity: MED	- 0.28mkR·s-1;
Operating voltage	- 390V;
Power bills start	- 280V-330V;
Length of the counting characteristics	- not less than 80 V;
The slope of the counting data	- no more than 0.125%/V;
Own background	- not more than 0.45 s-1 ;
The maximum operating MED	- 2500 s-1, 30mkR·s-1,k.n.± 20%;
The maximum permissible MED dose	- at least 50R· h-1 ;
Dimensions	- 12x12x110mm;
Weight	- 10g.

Berthold TOL-F equivalent dose rate meter:

Measurement Instrument:	Dose Rate Power Meter
Type:	TOL/F LB1320
Manufacturer:	Berthold Technologies GmbH& Co.KG
Detector:	LB1321
Measuring Range:	
Low dose range:	0.1uSv/h – 10mSv/h
High dose range:	10mSv/h – 100.0Sv/h
Energy range:	10 keV – 7 MeV ±30%
Calibration Factor:	0.33 uSv/h / ips

Abbreviations:

CPM	counts per minute
nSv / h	equivalent dose rate in nano sievert per hour
IPS	Impulse per second
R	Roentgen
Gy	Gray
eV	Electron volt

10.1 References

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