

Nuclear reactor instrumentation — Wide range neutron fluence rate meter — Mean square voltage method

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**Instrumentation des réacteurs nucléaires –
Appareillage de mesure du débit de fluence
neutronique à grande dynamique –
Méthode du carré de la tension moyenne**

**Nuclear reactor instrumentation –
Wide range neutron fluence rate meter –
Mean square voltage method**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

NUCLEAR REACTOR INSTRUMENTATION – WIDE RANGE NEUTRON FLUENCE RATE METER – MEAN SQUARE VOLTAGE METHOD

FOREWORD

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This International Standard IEC 61501 has been prepared by subcommittee 45A: Reactor instrumentation, of IEC technical committee 45: Nuclear instrumentation.

The text of this standard is based on the following documents:

FDIS	Report on voting
45A/338/FDIS	45A/346/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

Annex A is for information only.

INTRODUCTION

The response of a fission chamber to a neutron is to produce a pulse of electrical charge and by counting these pulses it is possible to measure the neutron fluence rate. At higher levels the rate of pulse generation increases to the point where pulses merge (a phenomenon known as "pulse pile-up") and the process of electronically counting the pulses becomes impracticable.

An alternative approach to processing is to consider the piled-up pulses as a fluctuating d.c. signal. Using Campbell's theory it can be shown that the mean square of the signal amplitude, measured over a fixed bandwidth, is proportional to the initial pulse rate. At low fluence rate levels the use of this approach is limited to 10^3 to 10^4 fissions per second by background noise in the electronics and in the fission chamber. The limit at high fluence rate levels is in the range 10^{10} to 10^{11} fissions per second because of non linearity caused by space charge effects. This is the most common application of the MSV method.

The use of the mean square voltage (MSV) measurement technique in combination with pulse counting permits the design of a system capable of measuring a neutron fluence rate over a range of more than 11 decades using a single fission chamber with appropriate corrections. It is also possible to use two different detectors.

NUCLEAR REACTOR INSTRUMENTATION – WIDE RANGE NEUTRON FLUENCE RATE METER – MEAN SQUARE VOLTAGE METHOD

1 Scope

This International Standard applies to instrument and measurement channels which generate a calculation of the mean square voltage (MSV) of a signal arising from a neutron detector, in order to extract from it information relating to the neutron fluence rate of a nuclear reactor. After calibration, this information can be used to derive the relative power and the time constant, for example expressed in terms of period, doubling time, decades per minute or percent per second.

The method used to calculate the mean square voltage of the signal is also known as "fluctuation treatment" or "the Campbell method".

Associated with other techniques of measurement, such as pulse rate counting or current measurement, the calculation of the mean square voltage allows the assembly of a series of wide range neutron fluence rate measurements for the simplification of nuclear instrumentation systems in the control of nuclear reactors.

This standard describes the principles, the terminology, the characteristics, the requirements and the testing methods related to instrumentation and measurement of the neutron fluence rate using MSV techniques for nuclear reactor control.

Typical examples of the application of the MSV techniques are given.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60050(101):1998, *International Electrotechnical Vocabulary (IEV) – Part 101: Mathematics*

IEC 60050(393):1996, *International Electrotechnical Vocabulary (IEV) – Chapter 393: Nuclear instrumentation: Physical phenomena and basic concepts*

IEC 60050(394):1995, *International Electrotechnical Vocabulary (IEV) – Chapter 394: Nuclear instrumentation: Instruments*

IEC 60359:1987, *Expression of the performance of electrical and electronic measuring equipment*

IEC 60527:1975, *Direct current amplifiers; characteristics and test methods*

IEC 60650:1979, *Analogue counting ratemeters – Characteristics and test methods*

IEC 60880:1986, *Software for computers in the safety systems of nuclear power stations*

3 Definitions

For the purpose of this International Standard, the definitions given in IEC 60050(101), IEC 60050(393) and 60050(394), as well as the following apply.

NOTE – The principle of the method is based on the variations analysis of the output of a detector and amplifier channel. These variations have many origins: the pulses induced by the reactions of detection and the perturbations internal or external to the channel. To ensure clarity in the document, the terms which characterize the origin of the signal are defined. Generally the term "noise" refers to the signal variations linked to the perturbations.

3.1

fluctuations

random variations of a physical quantity around its mean value

NOTE – In this standard, "fluctuations" means the variations of the measured signal induced by ionizing phenomena inside the detector. These variations are produced by the gamma radiation, by the alpha emission of the sensitive coating or by the neutron reactions induced in the coating. For the considered applications only, the fluctuations from neutron reactions are useful.

3.2

electronic noise

variation of a signal produced by the thermal agitation of the components of the electronic circuits. It is an internal perturbation of the measuring channel.

3.3

system noise

all variations of the signal with an origin external to the measuring channel

3.4

white noise

random process whereby the power density spectrum is constant and independent of the frequency

3.5

Poisson process

process defined according to the three following hypotheses:

- the number of events noted in a time interval T is independent of time and independent of any events which have already occurred;
- the probability of having one event, and one only, in a time interval T is proportional to T when $T \rightarrow 0$;
- the probability of having more than one event in a time interval T tends towards 0 faster than T when $T \rightarrow 0$.

The law of probability P is:

$$P(K, T) = \frac{(aT)^K}{K!} \times e^{-aT}$$

where

K is the number of considered events;

T is the time interval considered;

a is the mean number of events.

It occurs in all nuclear fission reactions.

3.6

pseudo-random signal

periodic deterministic signal with spectral properties similar to those of Poisson processes. The pseudo-random signal provides a constant amplitude envelope at discrete frequencies within a certain frequency band. (The Poisson random signal tends to give a continuous spectrum.)

3.7

counting rate method

signal processing method which applies to a signal having the form of separate pulses. The useful information representative of the neutron fluence rate is contained in the number of pulses per each unit of time (counting rate).

3.8

mean square voltage method

signal processing method which applies to a random signal. The information representative of the neutron fluence rate is contained in the mean square value of the a.c. part of the detector signal.

NOTE – This method and its application for neutron fluence rate measurement are presented in this standard.

3.9

wide range channel

detection assembly using at the same time several measurement techniques such as counting rate, d.c. measurement, mean square voltage method

4 Abbreviations

cps	counts per second
DMSP	digital mean square processor
DPM	decades per minute
EMC	electromagnetic compatibility
FP	full power
PPS	percent per second
LOCA	loss of coolant accident
MSV	mean square voltage
nv	neutron fluence rate unit. Notation for neutron $\times \text{cm}^{-2} \times \text{s}^{-1}$
OPM	octaves per minute
r.m.s.	root mean square
S/I	source/intermediate
WRC	wide range channel

5 Principle of the mean square voltage method

The principle of the mean square voltage method is to process the signal coming from a neutron detector to estimate the mean voltage induced by the fluctuation. This voltage is proportional to the square root of the neutron fluence rate. For this type of measurement, a neutron detector, in the form of a fission chamber is used. Such a detector consists of one or more polarized electrodes for charge collection, on which the fissile material is deposited. Typically two electrodes determine a sensitive volume filled by an inert gas, partially ionized by alpha, gamma and fission products.

Application of the theory of Campbell, in the case of a band-pass filter amplifier receiving at its input the charge Q (emitted during each fission within the detector) and taking the low cut-off frequency of the amplifier as zero, leads to the expression:

$$\sigma_S^2 = \bar{N} \times \overline{Q^2} \times \frac{R}{2C} = \bar{N} \times \overline{Q^2} \times R^2 \times \pi \times f_c$$

where

σ_S^2 is the variance of the signal;

$\bar{N}$ is the mean counting rate;

$\overline{Q^2}$ is the average of the square of the charge released during each event;

R is the feedback resistance;

C is the feedback capacitor;

f_c is the cut-off frequency of the filter.

The variance is proportional to N and also to B , the width of the pass band.

In that case:

$$B = f_c = \frac{1}{2 \times \pi \times RC}$$

NOTE – The output signal of the amplifier is a fluctuating voltage. Due to the ergodic character of the signal, (similarity between statistical average and time average), the standard deviation and the r.m.s. of the voltage are equivalent.

6 Implementation of the mean square voltage method

The method used to derive the neutron fluence rate can be divided into three main categories as described in 6.1, 6.2 and 6.3.

6.1 Linear analogue method: quadratic amplifier

This concerns a measurement circuit consisting of a narrowband preamplifier which gives an r.m.s. voltage V_1 for which the amplitude is proportional to $\sqrt{N}$, and a squaring circuit followed by a filter, making available an output signal (V_{out}) proportional to N .

Below is a block diagram of this method, as an example.

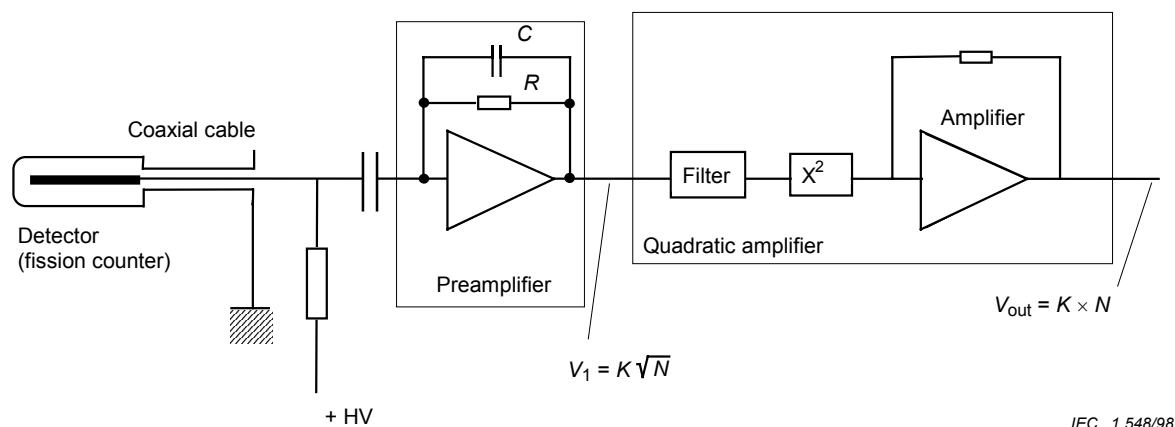


Figure 1 – Schematic diagram of the linear analogue method

The filter placed before the squaring operator permits a better build-up between pulses.

6.2 Logarithmic analogue method: logarithmic amplifier

Similarly to the linear analogue method, the measuring circuit consists of a narrowband amplifier whose output is sent to a logarithmic amplifier. The output is proportional to the logarithm of the neutron fluence rate and hence to the logarithm of the reactor power. A block diagram of this method is shown below as an example:

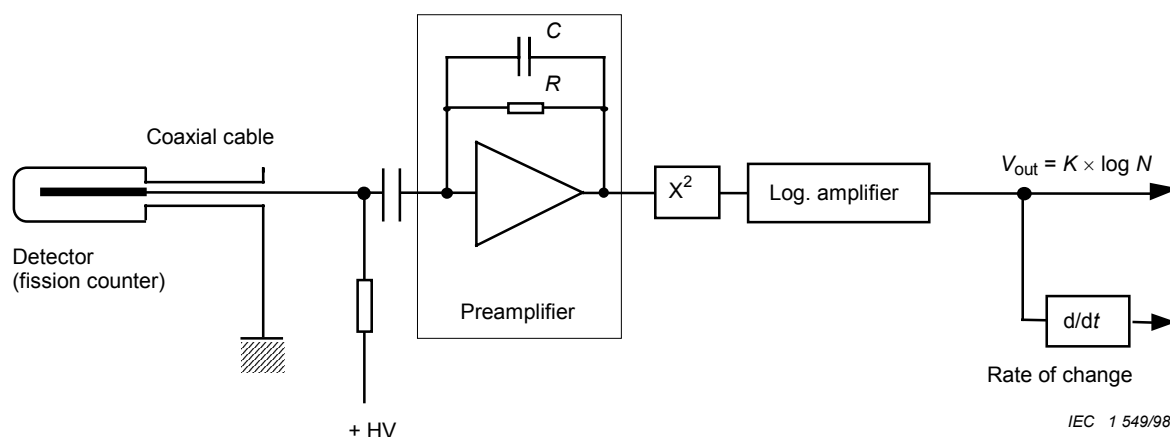


Figure 2 – Schematic diagram of the logarithmic method

6.3 Digital method: digital mean square processor

The measurement circuit consists of a narrowband amplifier followed by a fast sampling circuit and a mean square processor which directly calculates the variance of the signal. This device is coupled with a central processing unit which operates on the digitally derived fluence rate measurement in order to deduce the power of the reactor. When implemented in a safety channel, the software shall be developed according to the recommendations of IEC 60880.

Below a block diagram of this method is given as an example:

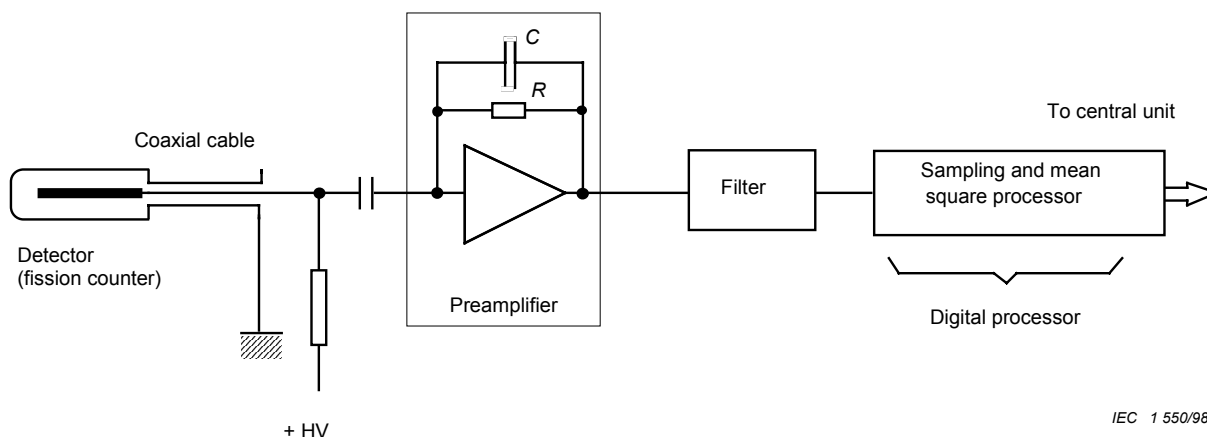


Figure 3 – Schematic diagram of the digital method

7 Structure of a wide range channel

A WRC is obtained by combining counting rate and MSV circuits. Depending upon the functional requirements the combination may be implemented with a single or a double detector. In the second case, the sensitive elements can be separate or located in the same housing.

A WRC generally consists of two types of electronic circuits:

- the conditioning circuits which include preamplifier, amplifier and HV supply. The conditioning circuits produce the high-level signals necessary to perform the functional processing;
- the functional processing circuits which include the rate of change calculation, the comparison against set points and the display management.

Depending upon the technology (analogue or digital) the division between the electronic functions (conditioning and processing) can vary.

7.1 Single-detector WRC

A single-detector WRC is the basic combination of a counting rate processing and MSV processing. A typical block diagram is shown below.

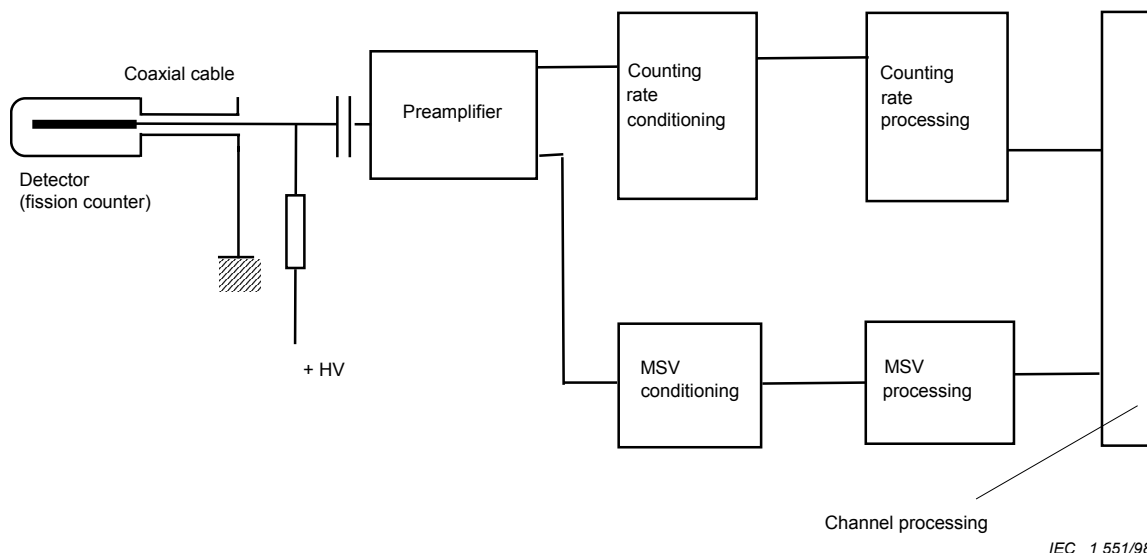


Figure 4 – Block diagram of a single-detector WRC

The preamplifier is common to the counting rate processing and the MSV processing circuits. Such an arrangement with a single-detector has a range of operation of 11 decades or more when it includes corrections to take into account the non-linearity which may occur at high fluence rates.

Typically, in the case of an ex-core instrumentation using a fission counter with a sensitivity of 1 cps/nv, the functional ranges are as follows:

- range for pulse processing: 1 cps to 10^6 cps corresponding to a fluence rate from 1 nv to 10^6 nv;
- range for MSV: 10^4 cps to 10^{11} cps (or more) corresponding to a fluence rate from 10^4 nv to 10^{11} nv (or more).

The overlapping between pulse processing and MSV shall be one decade as a minimum.

As an example, the output signals from a single-detector WRC may be as follows:

- the counting rate;
- the MSV processing signal;
- the level of power and the rate of change corresponding to the combination of counting rate processing and the MSV processing;
- binary outputs from trip set points.

The power level is expressed either in relative power (percentage of FP or P/FP) or directly in count rate units. The change of rate is expressed in term of decades per minute (DPM), octaves per minute (OPM), doubling time, period or percent per second.

7.2 Double-detector WRC

To increase the functional range, two separate detectors may be used. For counting rate processing it is more convenient to use a high-sensitivity counter and a low-sensitivity fission counter for the MSV processing.

The high-sensitivity counter can be either a fission counter or a proportional counter. The functional circuits are similar to those used for the single-detector WRC, but each detector has its own preamplifier.

The characteristics of the detectors shall be selected to optimize the total range of operation and to guarantee the overlap between the operating ranges of the two detectors.

As an example, the block diagram of a double-detector WRC may be as follows:

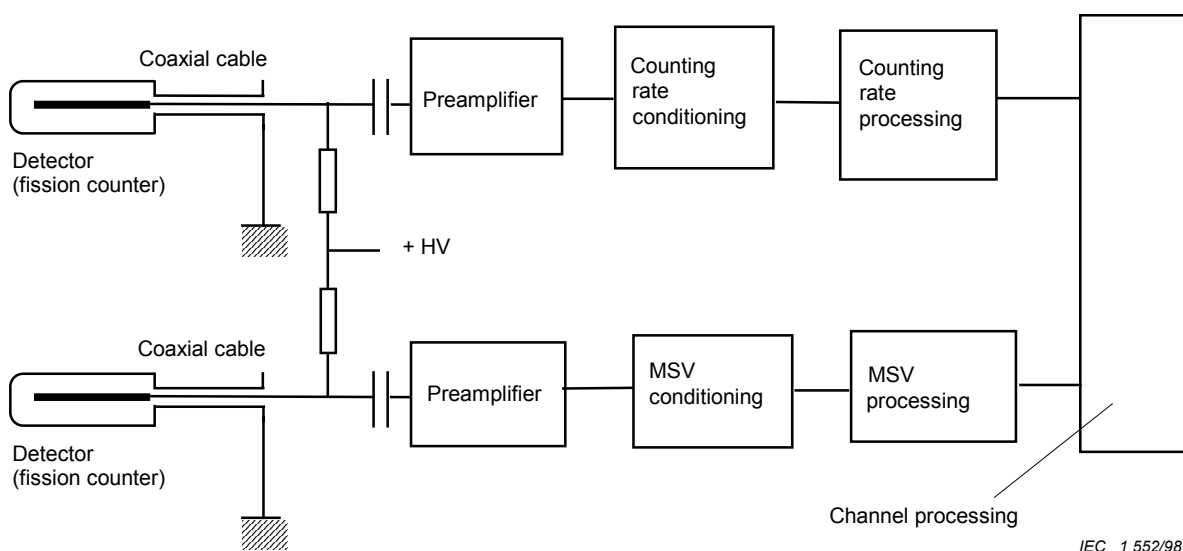


Figure 5 – Block diagram of a double-detector WRC

Some other arrangements are possible in order to improve performance.

A double-detector WRC should have a functional range of 12 decades. The overlap between the pulse processing and the MSV shall be a minimum of one decade.

The output information given by a double-detector WRC may include the following:

- the counting rate and the rate of change corresponding to the first detector;
- the power level and the rate of change corresponding to the MSV processing;
- binary outputs from trip set points.

8 Technology of WRC

The technology of WRC can be either analogue or digital. Each technology is similarly applicable to single- or double-detector WRCs. To simplify, only the single-detector WRC is presented.