International Conference
Nuclear Energy in Central Europe 2001
Hoteli Bernardin, Portorož, Slovenia, September 10-13, 2001
www: http://www.drustvo-js.si/port2001/ e-mail: PORT2001@ijs.si
tel.:+ 386 1 588 5247, + 386 1 588 5311 fax:+ 386 1 561 2335
Nuclear Society of Slovenia, PORT2001, Jamova 39, SI-1000 Ljubljana, Slovenia

MEASURING DELAYED PART OF THE CURRENT OF A SELF POWERED NEUTRON DETECTOR AND COMPARISON WITH CALCULATIONS

J. Kópházi, Sz. Czifrus, S. Fehér, G. Pór
Institute of Nuclear Technology
Budapest University of Technology and Economics
H-1111 Budapest, Muegyetem rkp. 9.,Hungary
por@reak.bme.hu, fehers@reak.bme.hu

ABSTRACT

The paper describes the measurement of the delayed signal of a Rh emitter Self Powered Neutron Detector (SPND) separately from other signal components originating from (n-gamma-e), (background gamma-e) and other effects. In order to separate the delayed signal, the detector was removed from the reactor core and placed to an adequately distant location during the measurement, where the radiation from the core was negligible. The experiment was carried out on the 100kW light water tank-type reactor of Technical University of Budapest and the results of the measurement were compared with the results of Monte Carlo calculations.

1 INTRODUCTION

Self Powered Neutron Detectors are widely used in NPPs for in-core flux monitoring. The nuclear processes taking part in this type of detectors have been discussed in details in several publications [1-8], however, extensive investigations - even in simple cylindrical geometries - have not been performed on the relationship between the detector current and the number of electrons born in these processes.

Recently a new idea has been proposed on constructing an SPND of more complex geometry, which could provide information not only on the local neutron flux, but also about its gradient [5]. Such detectors could be used for neutron current measurement, which makes it possible to localize the vibrations in the reactor core [4]. However, the path of neutrons, as well as the path of the electrons born in interactions between the radiation and the detector cannot be followed in a complex geometry by solving conventional differential equations. The neutron, photon and electron transport in the material can effectively and precisely be studied using appropriate Monte Carlo simulations.

The main objective of the research, part of which is outlined in this paper, is to develop a reliable computational model, which makes the precise calculation of the current of the SPND in various detector geometries possible. More details on the computational model and method are presented in Ref. [10]. However, it is vital to test and validate such a new tool by comparing experimental results with calculated ones. As a first step, experiments were performed in a research reactor with conventional SPN detectors of simple geometry. In the present paper, this experiment is reported in details, describing the main characteristics of the physical model for the interpretation of the experimental results and a brief comparison with the calculational results is also given.

2 CONSTRUCTION AND OPERATION OF SPNDS

Although the construction of SPNDs is well known, we summarize its construction and operation below. The majority of SPNDs have cylindrical layout. Their typical cross section is shown in Figure 1.

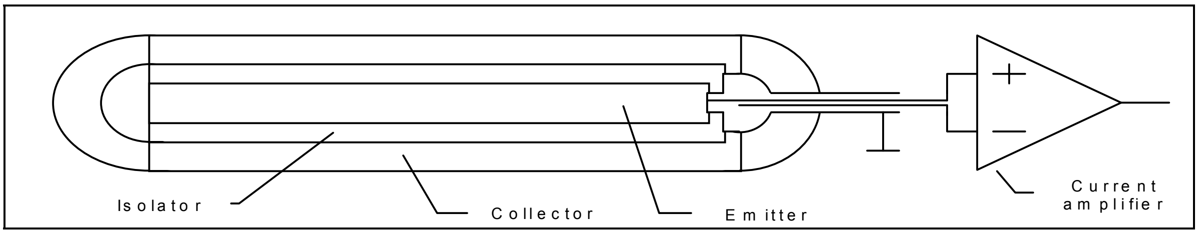

Figure 1: Typical SPND geometry and electrical connection

The most important part of the detector is the cylindrical emitter, which converts neutrons and background gamma photons into high energy e^- radiation.

The emitter is surrounded by a layer of insulator, which itself is surrounded by a metallic (typically stainless steel) tube, called collector. A coaxial cable (most commonly with two central wires) is connected to the emitter and to the collector. One of the central wires is connected to the emitter, the other one ends at the entrance of the detector. This serves for g-compensation purposes. The electrical shielding of the cable is welded to the collector. The internal parts of the detector are electrically and mechanically insulated from the outer world.

Neutrons as well as (external) gamma photons can produce high energy electrons in the emitter by various electron creation processes (ECP). The electrons escaping from the emitter through the insulator are made up by electrons flowing through the cable (via a current meter). This current is assumed to be proportional to the neutron flux, since the number of high energy electrons is proportional to this quantity.

Typically, the emitter consists of a cylinder of metal with high cross section of (n,gamma) reaction. Therefore mostly currentsfrom this reaction are considered.

When a neutron is captured in the emitter, a (prompt) gamma-photon is emitted and this photon can knock out one or more electrons from the emitter by either photoelectric effect, Compton-scattering, or pair production. The activated nuclei will undergo beta-decay and emits an electron. One or more gamma photons can be emitted during the beta-decay, and these photons can also knock out electrons from the emitter.

Inelastic scattering can also be significant for some emitter types. Such reactions may also result in nuclei that can produce delayed gamma photons, which in turn can knock out electrons. Not only photons born due to neutrons but also external gamma-photons from reactor background can knock out electrons from the emitter. There are also several other ECPs, which normally have less significance than these.

Based on the origin of the electrons, the detector current can be decomposed into three parts:

- Electrons created immediately after neutron capture produce the “prompt” part of the signal.

- Electron created in delayed beta-decay will contribute to the "delayed" part of the signal. This part can only follow the slow time variations of the neutron flux.
- All the other, non neutron-induced electrons will form the background noise in the signal.

However, the current from an SPND is not simply equal to the sum of the electrons born in the emitter. The current evolves in a more complex manner. The high energy electrons originating in the processes mentioned above slow down in various interactions with the detector material. A portion of these electrons stop in the emitter before they could leave it. The rest enter the insulator. A portion of these entering electrons stop in the insulator, while the remaining part crosses the insulator and reaches the collector. The electrons stopped in the insulator build up an electrostatic field, which affects on the movement of the bypassing electrons and also induces electrical current removing the charge from the insulator[1]. This means that a part of the electrons will return to the emitter. The determination of the current due to the electrostatic field is one of the most demanding modelling/calculational tasks. A simplified solution to this problem is given in Ref. [1].

3 THE EXPERIMENT

SPNDs with Rh and Hf emitters were used in our experiment. Detectors were produced by IKPH of University of Hannover. The main properties of the detectors are given in Table 1.

Table 1. Properties of the detectors

Emitter material	Emitter length [mm]	Emitter diameter [mm]	Isolator width [mm]	Isolator material	Outer diameter of the detector	Collector material	Form
Rh	60	1	0.35	MgO	2.2	Inconnel	Cylindrical
Hf	60	1	0.35	MgO	2.2	Inconnel	Cylindrical

The detector was placed in an aluminum detector holder (see Fig. 2) fixed at the end of a 6 m long manipulator rod. The holder was inserted between the fuel elements of the reactor core of the 100 kW training reactor of the Budapest University of Technology and Economics.

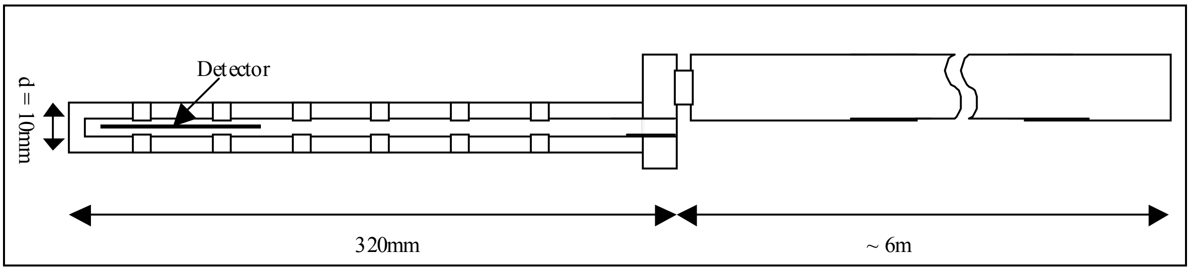

Figure 2. Aluminium detector holder and manipulator rod

The detector output current was measured with the aid of a high sensitivity current amplifier specifically developed for the SPNDs. The output of the amplifier was connected to a 12 bit Advantech PLC-814 ADC data acquisition board. The data acquired were converted to ASCII and later processed by Excel. The amplifier and the ADC were calibrated by a simple current generator. The generator was set up from a 9V battery and a certified 10 GΩ ± 1% resistor.

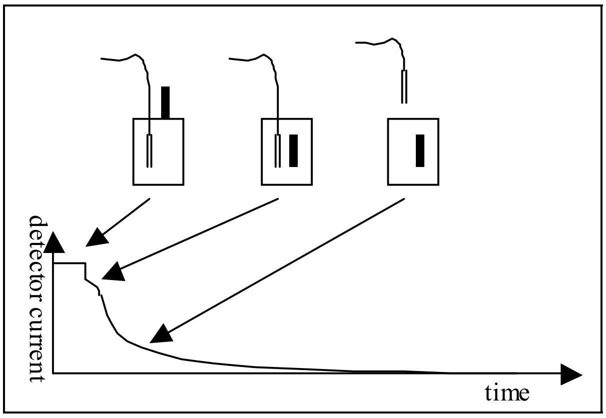

Figure 3. Draft of the experiment

The experiment, the performance scheme of which is shown in Fig. 3., was designed to make it possible to measure a single component (originating from beta-decay) of the detector current. The reactor was steadily operating at 100 kW nominal power. The neutron flux had been constant for a time sufficiently long for the ^{104}Rh activity to reach the saturation state. Obviously, by this time the detector current had also become constant. The reactor was stopped within 500 ms by dropping the control rods, which resulted in a sudden drop of the detector current (second part of the curve in Fig. 3.). Immediately after shutdown, the detector was lifted up to one meter above the core (inside the water pool), while the detector current was measured continuously. The third part of the curve corresponds to the current due to the beta-decay of rhodium.

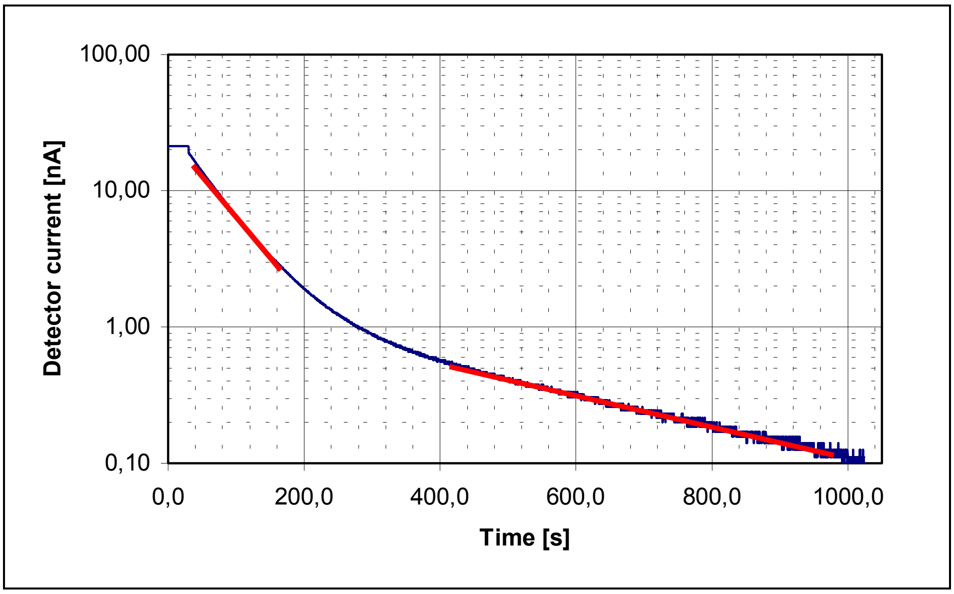

Figure 4. The measured signal of the Rh detector (log-lin scale). The exponential components are marked with red lines.

The output signal of the ADC was scaled to nA based on the calibration, and displayed in a linear-logarithmic diagram (see Figure 4.). One can see that after the reactor was shut down and the detector was lifted, the signal became a sum of two exponential decays according to Eq. 1.

$N(t) = C\exp(-\lambda_m t) + D\exp(-\lambda t) + B$ (1)

where

$N(t)$	is the number of ^{104}Rh nuclei at time t present in the emitter,
B, C, and D	are constants,
λ_m	decay constant of the metastable state,
λ	decay constant of the ground state.

The delayed current of the detector is assumed to be proportional to the number of ^{104}Rh nuclides (see above the second and third ECPs in Sec. 2). In order to obtain the current as a function of time, a function

$$I(t) = U\exp(-\lambda_m t) + V\exp(-\lambda t) + W \quad (2)$$

was fitted on the measured data. The beginning of the fitting interval was 20 s after reactor shutdown, in order to discard the data acquired during detector movement, due to the fact that moving the detector and cable cause "striction" currents. The decay constants were taken from Ref. [11].

The fitting yielded the result

$$i(t) = 0.0265 + 28.208\exp(-0.01638t) + 1.4022\exp(-0.002662t) \text{ nA} \quad (3)$$

In order to obtain the delayed signal at the equilibrium state of the detector, the time of reactor shutdown (t_0 = 29.4 s) was substituted into Eq. 3:

$$i(t_0) = 18.7 \text{ nA} \quad (4)$$

The total uncertainity, originating from the amplifiers and fitting (about 5%) and from detector positioning, was estimated to be smaller than 2.8 nA.

The prompt SPND (with Hf emitter) was not lifted from the core. Therefore, its signal reflects three different phenomena: the decrease of the neutron flux after shutdown, the delayed signal (approx. 4%) of the Hf detector [7] and the decline of the gamma background (see Fig. 5 and 6.).

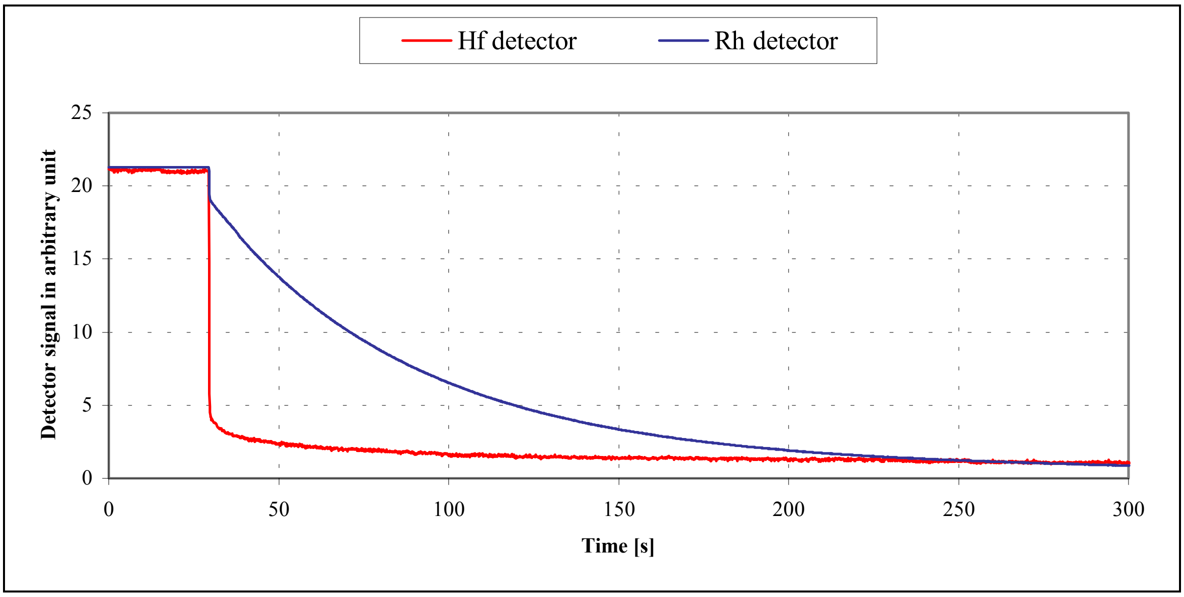

Figure 5. Rh and Hf detector signal (Rh in nA, Hf in arbitrary unit)

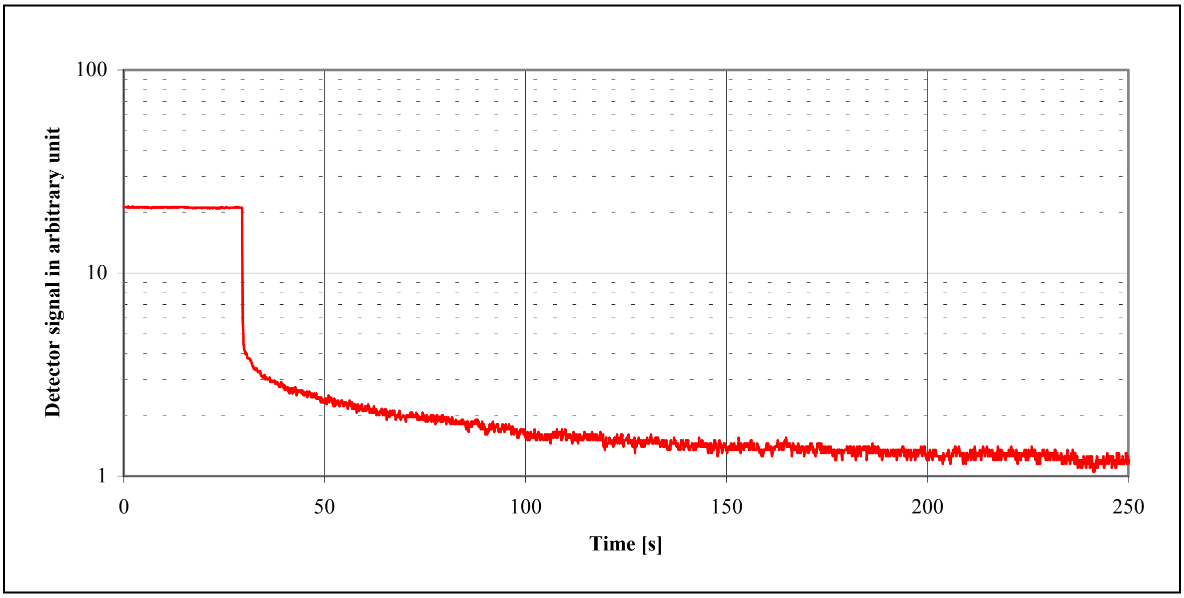

Figure 6. Hf detector signal in log-lin(in arbitrary unit)

4 MONTE CARLO CALCULATIONS

A detailed MCNP model of the INT BUTE reactor, which includes the detector as well, was set up with all of the 369 fuel elements, describing exactly the geometry of fuel assemblies and graphite reflector. A KCODE simulation was performed in order to obtain the spatial distribution of the neutron capture rate in the emitter using a series of tallies with appropriate multipliers.

In the case when the detector is removed from the reactor, i.e. when no external neutron or gamma radiation is present, the rate of high energy electron creation in the rhodium emitter can be determined by accounting for the following two processes: (1) beta-decay and (2) interaction of gamma photons either emitted by the nuclei which have undergone beta decay or by excited nuclei produced earlier upon interaction with neutrons, such as inelastic scattering. In the computational model we have only taken into account the first process, i.e. the electron birth directly from beta active nuclei.

Since the measurement was performed after reactor shutdown and the detector was lifted up above the core, the detector current was “extrapolated back” to a hypothetical situation in order to compare the measurement with the calculation. In this hypothetical situation the detector would be in the reactor (see Eqs. 3 and 4), but only the electrons from delayed processes would yield the detector signal.

A reduced MCNP model containing only the detector was set up. The spatial distribution of the electron source inside the emitter was defined corresponding to the result of the previous neutron calculation. The energy distribution was sampled from the “Fermi” equation of β-decay [1]. The calculation was carried out in coupled electron-photon mode, with particle current electron tallies installed on the outer surfaces of the emitter, insulator, and collector. The calculated high energy electron current through the outer surface of the emitter was 13.6 nA and through the inner surface of the collector was 6.7 nA. The estimated uncertainity of these results was 4%.

5 COMPARISON WITH MEASUREMENTS

According to the considerations given in the last paragraph of Sec. 2, for the hypothetical situation described in Sec. 4 the measured detector current should be smaller than the calculated high energy electron current through the outer surface of the emitter (13.6 nA) and should be greater than the calculated current through the inner surface of the collector (6.7 nA). Since the measured value is 18.7 nA, this means that the calculated value is less than the measured one by approximately 30 to 35 percent.

From the discrepancy described above it seems that modelling the (n,gamma) reactions is probably not sufficient to calculate correctly the delayed part of the SPN detector signal. Comparison of the results of calculations and measurement shows that at least 30% of the total current is originated from other processes, which have not been taken into account in our MCNP calculations. Further investigations, implying the development of the model, which include the effect of other reactions, should be carried out in order to disclose the reasons for the discrepancy. Since MCNP is not capable of accounting for external electric fields and conductivity phenomena, during the future development of the computational model, it will be necessary to work out some specific computational tools.

ACKNOWLEDGMENTS

Authors wish to express their gratitude to IKPH for SPND detectors and for preamplifiers, and personally to Dr. J. Runkel for valuable suggestion in their testing.

REFERENCES

[1] H.D. Warren: *Calculational Model for Self-Powered Neutron Detectors*, Nucl. Sci. Eng., Vol. 48, pp. 331-342, 1972

[2] Bernd Hellmich, *Experimentelle Untersuchung zur energieabhängigen Kalibrierung von SPN-Neutronenflussdetektoren*, (Diplomarbeit) Institut für Kerntechnik und Zerstörungfreie Prüfverfahren, Universität Hannover, Hannover, 1998

[3] K. Pytel: *A Monte Carlo calculation of the neutron and gamma sensitivities of self-powered detectors* Atomkernenergie – Kerntechnik, Vol. 39, pp. 31-37, 1981

[4] I. Pázsit: *On the possible use of the neutron current in core monitoring and noise diagnostics*, Ann. Nucl. Energy, Vol. 24, No. 15, pp. 1257-1270, 1997

[5] P.Lindén, J.K.-H. Karlsson, B. Dahl, I. Pázsit, G. Pór: *Localisation of a neutron source using measurements and calculation of the neutron flux and its gradient*, Nucl. Inst. Methods in Phys. Res. A, Vol. 438, pp. 345-355, 1999

[6] S. Avdic, P.Lindén, I. Pázsit: *Measurement of neutron current and its use for the localisation of a neutron source*, Nucl. Inst. Methods in Phys. Res. A, Vol. 457, pp. 607-616, 2001

[7] Personal communication with Dr. Todt

[8] H.D. Warren, N.H. Shah: *Neutron and Gamma-ray Effects on Self-Powered In-Core Radiation Detectors*, Nucl. Sci. Eng., Vol. 54, pp. 395-415, 1974

[9] A.C. Mao, J.S. Hewitt: *Detailed Analyses of Self-Powered Detector Responses by Monte Carlo Methods*, Trans. Am. Nucl. Soc., Vol. 24, pp 390-392, 1976

[10] S. Feher, J. Kophazi, G. Por, P. F. A. De Leege: *MCNP Coupled Neutron-Gamma-Electron Transport Calculations of Self-Powered Neutron Detectors (SPND)*, American Nuclear Society Winter Meeting, 2001, Accepted

[11] G. Erdtmann: *Neutron Activation Tables*, Verlag Chemie Weinheim-NewYork, 1976