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IRRADIATION OF PIN DIODES – EXPERIMENT & SIMULATION

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Abstract: Developments in electronic dosemeters have been made recently for photons and neutrons using pin-diode. In this paper the response of the sensor is modeled by applying appropriate simulation codes for the pulse height distribution (energy response) for photon irradiations. Good agreement between experimental data and model calculations for narrow spectra x-ray and standard radionuclides was found. The important interaction regimes are interpreted correctly.

Keywords: dosemeters, irradiations, radionuclides

1. INTRODUCTION

Recently there have been some developments in electronic dosemeters for photons using pin-diodes. For the evaluation of the feasibility of active dosimetry and the assessment of existing methods and further developments, it is necessary to model the response of the sensor by applying appropriate simulation codes. Computer models have been applied to simulate the pulse height distribution (energy response) for photon irradiations of these pin-diodes. It was found that only low energy photons can be registered within the active layer of the detector itself due to escape of higher energy quanta out of the active layer. Hence, the thickest possible pin diodes were used for irradiation experiments to obtain as much energy information as possible. Good agreement between experimental data and model calculations for narrow spectra x-ray irradiations and standard radionuclides was found. The important interaction regimes (Photo effect and Compton scattering) are interpreted correctly.

2. THE MODELING PROCESS

2.1. Detector response for photons

To understand the measured pulse height distribution of pin diodes a Monte Carlo based simulation of the energy deposition in the active part of the detector was carried out. The influence of incident photons on the resultant detector response (pulse height distribution) was simulated as energy dependent function. Different incident photon spectra (radiation qualities) from monoenergetic photon fields to realistic x-ray (multi-energy) and radionuclide radiation qualities were studied as well. The physical mechanism of energy transfer from photons to the active layer (Si) of the detector is relatively simple. In the relevant energy regime (20 keV to some 100 keV) the following two effects are dominant:

- Photo effect
- Compton scattering

2.2. Simulation techniques

The energy deposition in the active layer of the diode caused by incident photons was simulated by the **EGS4 code system**. EGS4 is a general purpose package for the Monte Carlo simulation of the coupled transport of electrons and photons with energies above a few keV up to extremely high energies of a few GeV (The *EGS4 Code System*, by W.R. Nelson, H. Hirayama, and D.W.O. Rogers, SLAC-S65 [1985]).

2.3. Pin diode irradiation simulation with mono energetic photon radiation

A commented pulse height distribution of a simple pin diode irradiated with monoenergetic 100 keV photons is given in fig. 1 as a representative example. All significant peaks and edges are commented according to their origin. Due to the thin layer design of the diode some peaks (A) or edges (C) result from this special geometry. These structures in the spectrum are caused by the increased multi scattering probability for the 90° scattered photon. A diagram of additional simulation results is given in Fig. 2.

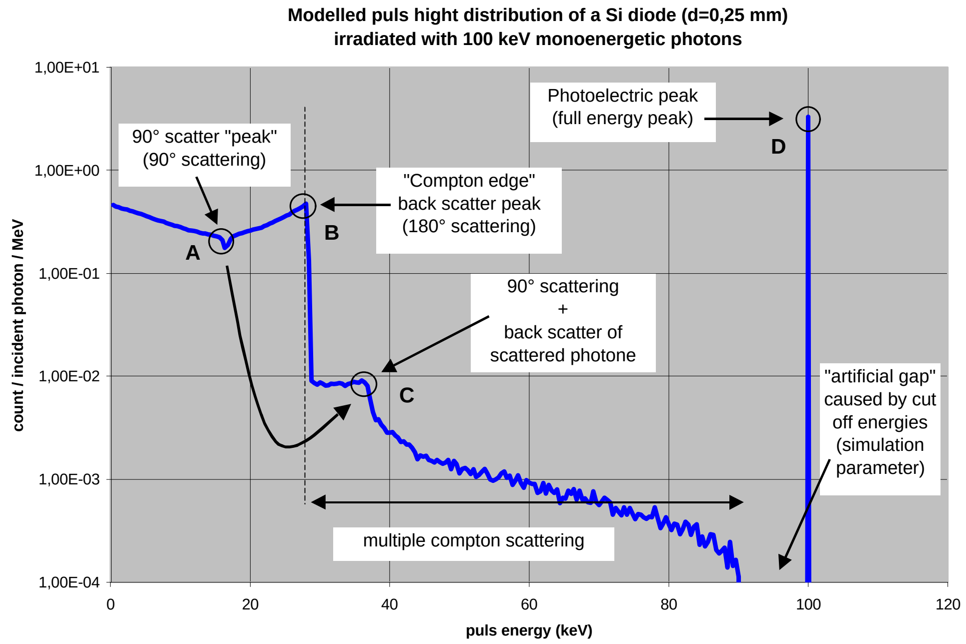

Figure 1. Simulated pulse height distribution in a 250 µm thick Si diode. All peaks and edges are commented according to their origin

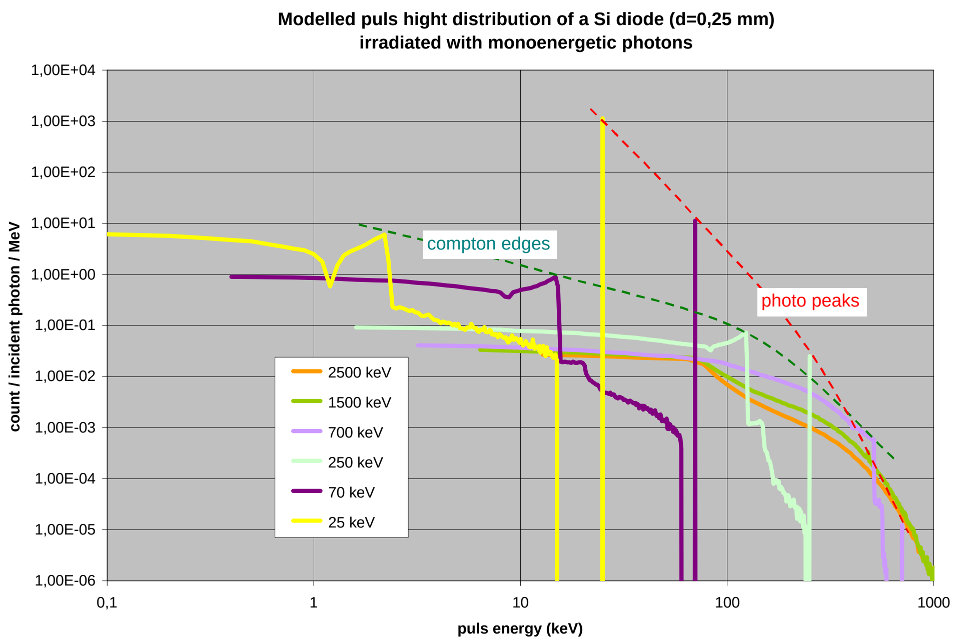

Figure 2. Simulated pulse height distribution of a Si diode (250 µm) for different monoenergetic photon irradiations from 25 – 2500 keV

2.4. Pin diode irradiation simulation with realistic calibration qualities

A more ambitious goal in establishing the feasibility of the model, calculations of realistic diodes and realistic irradiation qualities were necessary. Simulated data for the detector response of diodes with an active layer thickness of 250 µm and an aluminum housing for “realistic” photon spectra were generated.

The following radiation qualities were used for the simulations:

- standard x-ray beam qualities (ISO-N-Series)
- radionuclide emissions (^{137}Cs and ^{60}Co)

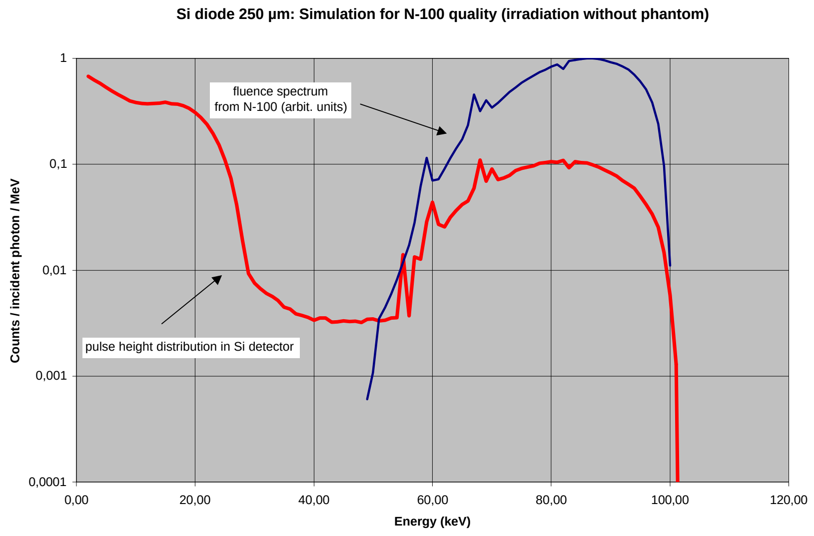

Figure 3: Simulated pulse height distribution of a Si diode (250µm) for N-100 and corresponding fluence spectrum (used for the simulation)

Fig. 4 shows a simulated pulse height distribution for different photon calibration qualities. Compared to the results with monoenergetic photons (fig. 3), both the photopeak and the Compton edge is less well pronounced. This is caused by the spectral photon energy distribution of the calibration beam qualities.

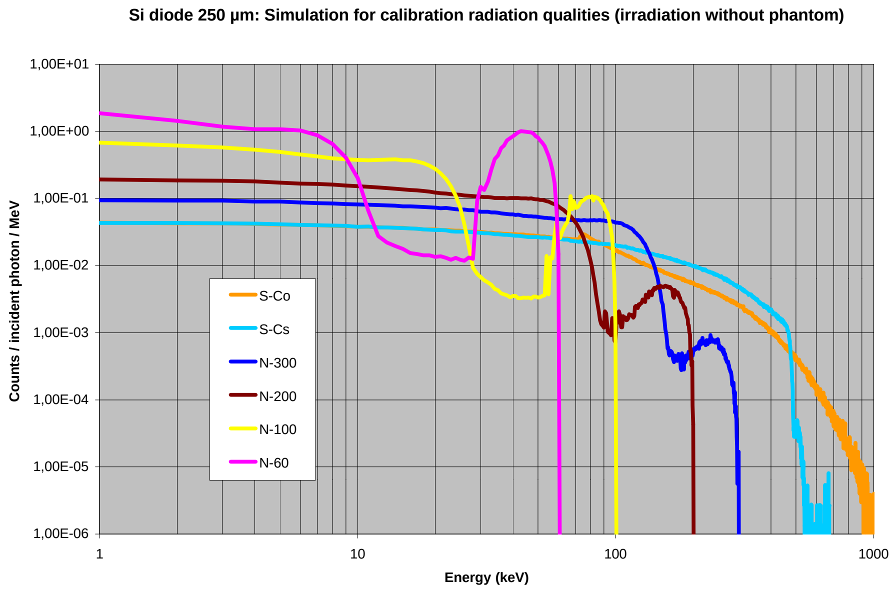

Figure 4. Simulated pulse height distribution of a Si diode (250µm) for different photon calibration qualities

3. IRRADIATION WITH PHOTONS

The aim of the irradiations was to achieve experimental results under the same assumptions applied to the simulated data of the modeling process. For the analysis of the detector response for photons, irradiations in well defined photon fields are necessary. Both the radiation quality and the applied dose needs to be well known.

The described photon irradiations were performed in the dosimetry laboratory at the Research Center Seibersdorf. All irradiations were performed using the following standard beam qualities:

- standard x-ray beam qualities N60 to N300 (narrow spectrum series as defined by ISO 4037-1)
- gamma rays from ^{137}Cs and ^{60}Co radionuclide sources collimated with a standard ISO 15 ° collimator

The irradiation facilities at the Austrian Research Center where the irradiations were performed are shown in Fig. 5.

Figure 5. Irradiation facilities at the dosimetry laboratory in Seibersdorf. The filter assembly for the 320 KV x-ray facility and the 15° ISO collimator for the nuclid souces can be seen.

A summary of measured pulse height distributions (spectra) for other radiation qualities is shown in Fig. 6**.** For all x-ray irradiations (photon energy < 300 keV) the typical photo peak and the Compton region can clearly be identified. Due to pile up effects, pulses with higher energies than the maximum x-ray energy are found.
Gamma irradiation from a ^{137}Cs source only shows the Compton region with a significant Compton edge. No photo peak is found in this case.
Gamma irradiation from a ^{60}Co source shows only the Compton region. No Compton edge and no photo peak is found .

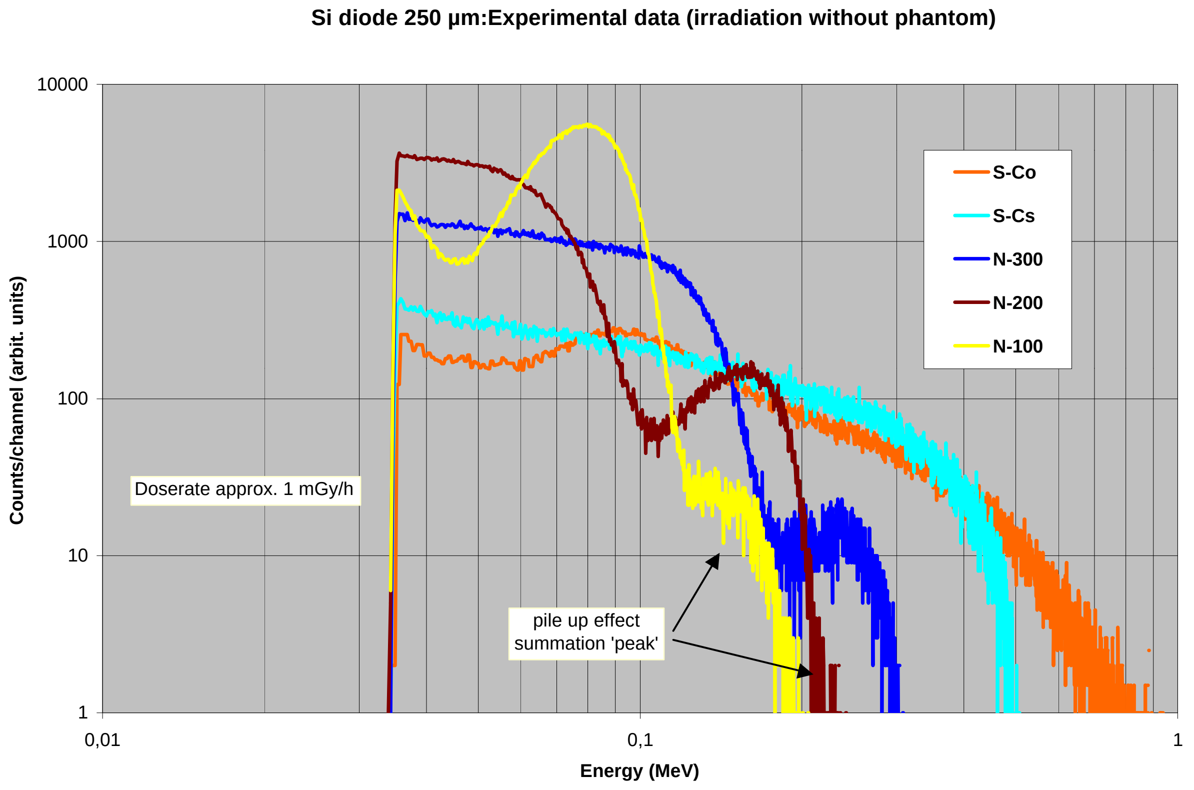

Figure 6. Measured pulse height distribution of a Si diode (250 µm) for different photon calibration qualities. The applied air kerma rate was approx. 1 mGy/h.

4. RESULTS

The aim of the experiments was too verify the model of the Monte Carlo simulation. To be comparable to the simulation results, the experimental pulse height distributions were transformed into the unit count/Mev/incident photon. For this transformation the following parameters of the irradiations were necessary and had to be established:

- Dose (or doserate and irradiation time) in terms of air kerma
- Detector thickness (250 µm)
- Detector area (200 mm^2)
- Mass energy transfer coefficient (depending of the incident radiation quality)

The comparison between simulated results and experimental data in fig. 7 shows good agreement in the photo peak and in the Compton region for energies up to 300 keV. The model reflects the characteristic features detailed and correctly.

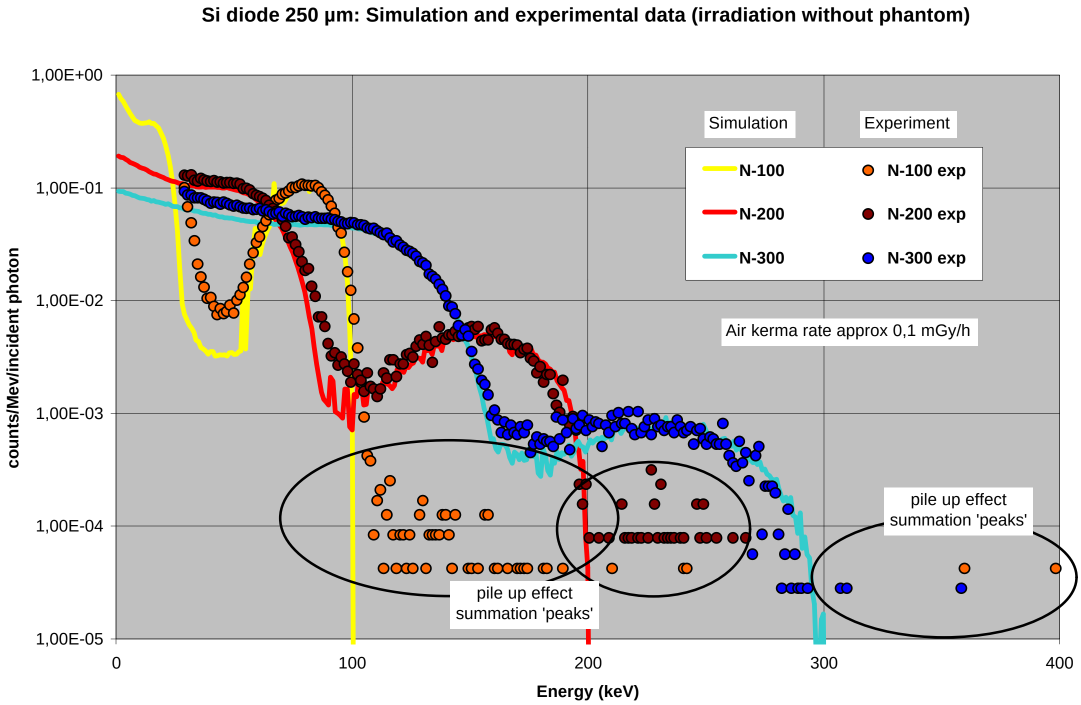

Figure 7. Comparison between Simulation and experiment for a 250 µm Si diode. Good agreement in the photo peak region and in the Compton region.

In the transition region between Compton edge and photo peak the agreement is less good due to detector system dependent energy resolution and pile up effects.

The simulated values are somewhat smaller than the experimental data. Nevertheless it is not intended to change the simulation model for further investigations to achieve – in this respect - more realistic results since the energy resolution and the pile up effect is not a detector property but is caused mainly by the readout circuitry and other electronic reasons. Correction of summation effects (artificial peaks) might also help to enhance the agreement simulation vs.experiment.

5. CONCLUSION

An important step in the development cycle is simulation and modeling. The modeling of the detailed photon interaction mechanism and subsequent simulation is the approach chosen for the improvement of radiation detectors. The detection element of choice has been a commercially available pin-diode with an active region of 250 µm. The EGS4 computer code has been selected for the Monte Carlo simulations of the photon and electron interaction. All distinct features of experimental data can be explained through the model and discrepancies interpreted by features of the actual sensor and read out electronics. Excellent agreement is found for the lower and higher energy regime. Inaccuracies in the intermediate energy regions might further be reduced by applying corrections to the experimental data summation peaks.

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