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Fission chambers designer based on Monte Carlo techniques working in current mode and operated in saturation regime

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ABSTRACT

Fission chambers have become one of the main devices for the measurement of neutron fluxes in nuclear facilities; including fission reactors, future fusion ones, spallation sources, etc. The main goal of a fission chamber is to estimate the neutron flux inside the facility, as well as instantaneous changes in the irradiation conditions. A Monte Carlo Fission Chamber Designer (MCFCD) has been developed in order to assist engineers in the complete design cycle of the fission chambers. So far MCFCD focuses on the most important neutron reactions taking place in a thermal nuclear reactor. A theoretical model describing the most important outcomes in fission chambers design has been developed, including the expected electrical signals (current intensity and drop in potential) and, current-polarization voltage characteristics (sensitivity and saturation plateau); the saturation plateau is the zone of the saturation curve where the output current is proportional to fission rate; fission chambers work in this region. Data provided by MCFCD are in good agreement with measurements available.

Contents

1. Introduction

The advent of the new nuclear fusion facilities based on magnetic confinement, like ITER [1], has shown the absence of suitable instruments for on-line, in-core measurement of neutron fluxes in these facilities which are characterized for having high and fast neutron fluxes [2]. The signal provided by the fission chamber is used as a basis for monitoring and calculating some of the most critical parameters, such as power, in-core energy distribution, fuel burn up and damage of structural materials, among others.

Cylindrical fission chambers consist of a pair of electrodes, one of which usually the anode, is coated with a fissile material, usually U235 but other fissile isotopes, such as U238, Pu242 can be used according to the neutron spectra is intended to analyze. The space between the electrodes is filled with inert gas, often argon, sometimes with a small percentage (4%) of nitrogen or other gases.

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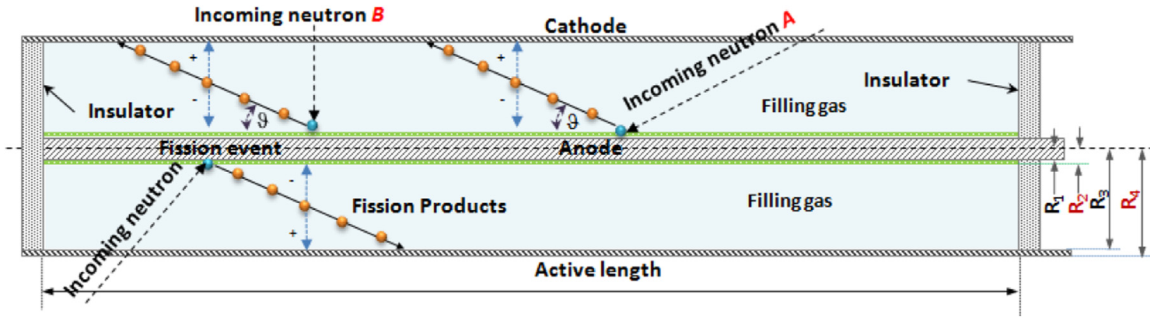

Fig. 1. General scheme of a fission chamber.

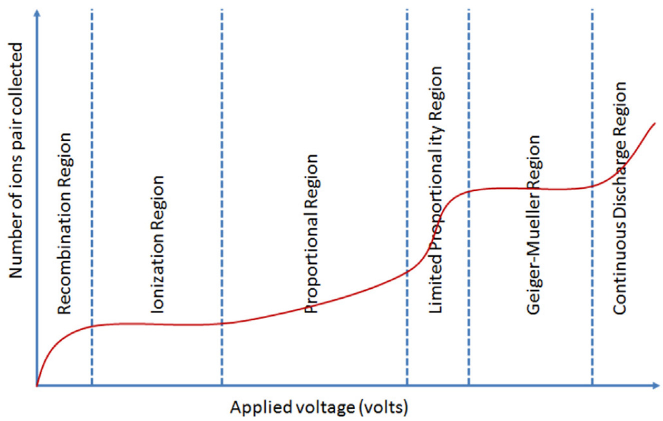

Fig. 2. Six-region curve for gas-filled detectors. Fission chambers are expected to work in the 'ionization region' or saturation plateau.

When a neutron interacts with an atom of the fissile material and produces fission, a couple of fission products are released resulting in an ionizing trajectory through the filling gas. A polarizing voltage applied to the electrodes, prevents the ions and electrons from recombining. Electrons travel towards the anode and ions towards the cathode producing a pulse of current and potential. Ionization tracks have different angles and they produce different pulse shapes. Each neutron causing fission produces a pulse. All pulses occurring randomly in time add together. As neutron flux and hence pulse-rate increases, accumulation occurs when pulses begin to coincide in time, and are counted as one by the electronics connected to the chamber. Fig. 1 shows a schematic design of a fission chamber; in this picture a possible neutron absorber coating is also shown. This absorber could be use to filter the neutrons entering the chamber. Fig. 2 shows the six regions in which a gas-filled detector can operate according to the polarization voltage applied:

I. Recombination region; in this region the charges produced by the passage of radiation quickly recombine to form neutral molecules due to the low voltage applied.
II. Ionization region; the collection efficiency of electron-ion pairs in the recombination region increases with applied voltage until all the charges that are being produced get collected. In this region further increasing the voltage does not affect the measured current since all the charges being produced get collected by the electrodes. This zone is also called the "saturation plateau". Fission chambers work in this region.
III. Proportional region; if a high enough electric potential exists between the electrodes so that the charges could attain very high velocities, charges produced during primary ionization have enough energy that they can produce additional electron-ion pairs, a process called secondary ionization.
IV. Limited proportional region; as the bias voltage increases, more charges are produced inside of the detector. Since heavy positive charges move much slower than the electrons, they form a cloud of positive charges between the electrodes. This cloud acts as a shield to the electric field and reduces the effective field seen by the charges. As a consequence the proportionality of the total number of charges produces to the initial number of charges is not guaranteed.
V. Geiger-Mueller region; increasing the voltage further may increase the local electric field to such high values that an extremely severe avalanche occurs in the gas, producing very large number of charge pairs. Consequently a very large pulse of several volts is seen in the readout electronics.
VI. Continuous Discharge; if we continue increasing the bias voltage a breakdown process can occur, leading to a process of continuous discharge. In this region, electric arcs can be produced between the electrodes, which may eventually damage the detector.

Fission chambers can be operated in: pulse mode, current mode, and mean square voltage mode (MSV mode), also called Campbelling mode [3].

Several works have been carried out in order to qualify fission chambers in different nuclear facilities [2,4–6] all of them have taken advantage of the existing tools to accomplish this task: MCNP, SRIM, GEANT4… using them at different stages of the design process. However this makes the design and analysis of sensitivity tedious and slow that is reason we have developed an integrated tool capable of dealing with the entire design and simulation process. As nuclear fusion facilities and new generation fission reactors are not in place yet, improvements in fission chambers performances will be needed. Thus, an integrated development tool for their design and outcomes simulation is of outstanding interest. During the last four years the present work has settled down the first stone for a software suit intended to give an integrated tool for the design of fission chambers capable of operating in such harsh environments Monte Carlo Fission Chamber Designer (MCFCD), which takes advantage of Monte Carlo methods. From the point of view of computing performance, Monte Carlo methods are generally easily parallelizable, with some techniques being ideal for use with large CPU clusters but presents higher CPU consumption. The results obtained from Monte Carlo calculations are based on probability decisions; hence the results obtained need a statistical analysis before taking a final decision. However Monte Carlo allows modeling the complete physical processes occurring in the fission chamber, thus it renders many intermediate data which can be very useful for a complete understanding of the device. Other efforts have been made in the fission chambers community in order to develop appropriate software for the design of these detectors using GARFIELD suite [4] or for the estimation of the γ-ray contribution to the signal [7].