FISSION CHAMBERS

Since neutrons are uncharged particles, their detection must be accomplished by an indirect method. Slow (low energy) neutrons may be converted into ionizing reaction products on being captured by an isotope of an element with a high probability of interaction with the neutron, such as uranium-235. The absorption of the neutron causes fission within the uranium atom. The resulting high energy released is approximately 200 MeV per fission, according to Knoll (1). This energy release causes ionization in a gas, which is then detected utilizing normal pulse detection methods. Because of the substantial energy released, a neutron-induced fission reaction can be expected to produce a much greater ionization signal than other reactions, such as gamma radiation or alpha disintegration of the uranium. The extreme ratio of the signal to background allows the use of fission chambers at extremely low background signal, enabling operation at very low counting rates. According to Rossi and Staub (2), fission chambers are typically constructed as cylindrical ionization chambers with the inside surfaces of the chamber coated with a fissile material. For measurement of slow-neutron flux, the usual coating is uranium-235.

The main purposes for which fission chambers are used are:

1. Measurement of the rate of fissions in a given neutron flux
2. Relative measurements of neutron flux of sources with identical neutron energy spectra
3. Investigation of the energy distribution of the fission fragments

For experimental purposes, all three types of measurements are important. For practical commercial uses, fission chambers are used for the first purpose (measurement of the rate of fissions in a given neutron flux) as a part of the instrumentation for measuring the power level of a nuclear reactor. In this instance, the measurement of the neutron flux leaking out of the core of a nuclear reactor is proportional to the power level of the reactor.

In applications in nuclear reactors, fission chambers can be used in several modes of operation. For source-range reactor power measurements, fission chambers can be used in the counting mode or pulse mode of operation. The counting rate from the fission chamber is proportional to the magnitude of the slow-neutron flux from the low pulse counting rates up to a counting frequency at which individual pulses can no longer be differentiated. The fission chamber can also be used in a dc current mode of operation for measurement of full power in a nuclear reactor. The output current from a fission chamber is proportional to the total ionization produced by fission of the coating plus background current associated with gamma radiation and alpha disintegration of the uranium. The useful range of measurement in the current mode of operation is as a linear measurement from 0 to 100% power. Fission chambers can also be operated in an ac signal mode or mean-square-voltage mode of operation. The mean square of the ac statistical fluctuation of the linear current signal is proportional to the slow-neutron flux. This signal is useful for measurements over a fairly wide range of operation, approximately 5 to 6 orders of magnitude from 10^{-3}% power to 100% power.

CONSTRUCTION

Baer and Swift (3) explain that typical fission chambers (see Fig. 1) are constructed as compact cylinders in order to be useful for mounting in close proximity to the neutron flux to be measured. For reactor measurements, these can be from 2.5 cm diameter by 15 cm length up to 10 cm diameter by 115 cm length. The construction is of metal cylinders, preferably with low capture cross section for neutrons and with little activation of the materials. Usually, the construction is with concentric aluminum cylinders, with uranium coated on the inside surface of the cylinder. The outer cylinder is connected as one electrode, and the inner cylinder as the second. The two are separated by ceramic insulators. The spacing between electrodes is approximately 0.25 cm to 0.50 cm. The space is filled with a gas, usually argon mixed with nitrogen at a pressure of 50 kPa to 300 kPa (0.5 atm to 3.0 atm).

ELECTRODE COATING

As explained by Graves and Froman (4), several methods have been developed for providing a uniform coating of fissionable uranium on the surface of the electrode. At least two methods are used commercially by manufacturers of fission chambers. One method, which has provided good uniform results, utilizes a solution of uranyl nitrate suspended in an alcohol-based lacquer. The lacquer is applied in thin coats and then dried and fired in a furnace to drive off the lacquer and fix the uranium to the surface of the metal in the form of uranium oxide. This method produces a very uniform coating, and by applying several coats of lacquer solution, the coating thickness of uranium can be made up to 2 mg/cm^2. The disadvantages to this method include the labor required in applying the numerous layers of lacquer and the care that

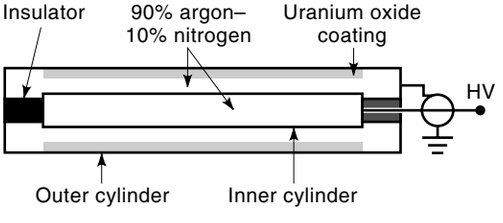

Figure 1. Unguarded fission chamber.

must be taken to ensure that all lacquer residue has been removed in firing in the furnace.

The second method that is used commercially is electroplating a solution of uranyl nitrate and ammonium oxalate in water. The electrodeposition of uranium is accomplished through the use of a platinum electrode, a plating voltage of 8 V to 10 V, and a current density of about 120 mA/cm^2. The electroplating is carried out to completion; thus the quantity of uranium in solution becomes the quantity of uranium plated. Since the coated area is fixed, this provides good control over coating thickness.

FILL GAS

Several gas mixtures have been used in the design of fission chambers. Argon gas at atmospheric pressure and mixtures of argon with 1 to 10% nitrogen have been used with commercial success in fission chambers, for certain magnitudes of the neutron flux to be measured. According to Colli and Facchini (5), the ionizing potential of the gas and the drift velocity of electrons in the gas have greatly favored the use of argon for the fill gas in fission chambers. The drift velocity, however, is greatly influenced by the presence of small amounts of impurities in the gas (6). If aluminum is used for the construction of the electrodes in the fission chamber, the surface of the aluminum and the surface of the uranium coating trap oxygen. Under operation at temperatures above 90°C (200°F), the oxygen mixes with the argon fill gas, causing changes in the electron drift velocity, and greatly affecting the output pulses from the fission chamber. The use of 1% to 3% nitrogen stabilizes the pulse output by reducing the effect of free oxygen within the argon fill gas. Using this combination, fission chambers have been used at temperatures up to 200°C (400°F). At higher temperatures, other materials such as titanium, nickel, or other high-temperature metals must be used in the construction of the fission chamber. In fission chambers used in-core in research reactors or in power reactor applications, where neutron flux levels nv reach 10^{14} cm$^{-2} \cdot$ s^{-1}, pure argon must be used as the fill gas because of the tendency of nitrogen to disassociate under these high radiation fields.

ELECTRODE SPACING

Numerous experiments have been performed to test the effects of electrode spacing on fission chamber performance. One study is examined by Aves et al. (7); the testing involves measuring the pulse height versus count rate for various test conditions. The effects of electrode spacing, fill gas pressure, and coating thickness are then measured versus output sensitivity. The effects on output pulse height from varying coating thickness from 0.1 mg/cm^2 to 3.0 mg/cm^2, electrode spacing from 1.25 mm to 7.6 mm, and fill gas pressures from 750 mm Hg to 2400 mm Hg have been tested. At a fill gas pressure of 760 mm Hg, the output pulse height increases with electrode spacing up to a spacing of approximately 4.0 mm. Above this spacing, the pulse amplitude does not increase significantly, indicating that most of the ionization of the gas by fission fragments occurs within the first 4 mm of gas space. By then varying the coating thickness, a set of output pulse amplitudes versus coating thickness was obtained, which indicates that the counting sensitivity increases directly with coating thickness up to a value ranging from 1.5 mg/cm^2 to 2.0 mg/cm^2. Above this thickness, the output count rate increases significantly more slowly versus coating thickness, indicating that for thick coatings most of the energy of the fission fragment is lost before the fission fragment exits the uranium coating, while for thin coatings the fission fragment exits with most of its energy remaining to be given up within the fill gas.

ELECTRODE GEOMETRY

In order for fission chambers to be used for experimental purposes, the operation of the chamber is of primary importance (8). For this purpose, flat electrodes provide the ultimate theoretical performance, by providing a uniform electrical field between them. In that case, output pulses due to fission events can be measured with good correlation. For instrumentation applications in a nuclear reactor, however, the fission chamber must be designed to fit within as small a volume as practicable, necessitating the use of alternative construction geometries. For such purposes, the fission chambers generally are cylindrical. The use of cylindrical electrodes produces a varying voltage gradient between electrodes; however, for electrode spacing less than 20% of the chamber diameter, the voltage gradient across the chamber is sufficiently uniform that there is no significant degradation in performance.

Associated Instrumentation

Fission chambers operate as pulse ionization chambers (see Fig. 2), that is, they detect the ionization in a gas caused by the fission of the uranium coating on the electrode of the fission chamber. As explained by Pare (9), when the chamber is operated with a high potential between electrodes, the ionization of the gas produces a pulse of current. According to Taboas and Buck (10), this pulse of current can then be amplified in a high-gain pulse amplifier to produce an output voltage pulse corresponding to each fission event within the fission chamber.

The output voltage pulses are then passed through a level detector, such that all pulses greater than a threshold height produce a digital output, but smaller ones produce no output. This produces an output digital pulse that has been discriminated to eliminate background signals caused by electrical noise in the amplifier and to eliminate electrical noise caused by other sources of ionization of the gas within the fission chamber. These digital pulses can then be counted directly to produce an output count rate proportional to the neutron flux. This is the basis of source-range neutron flux monitoring instrumentation for power reactor applications. For more information on this instrumentation, see Ref. 11.

The output pulses from the fission chamber can also be summed into a linear current amplifier to produce an output signal proportional to the neutron flux. The output current

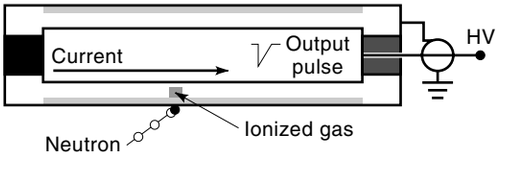

Figure 2. Operation of fission chamber.

signal for each pulse is approximately 1×10^{-13} C (ampere-seconds); thus the output current is only relatively accurate for neutron flux levels *nv* above 10^8 cm$^{-2} \cdot$ s^{-1} due to the inherent alpha background current from the naturally radioactive uranium coating. (Typical dc alpha background currents from large fission chambers are of the order of 10^{-9} to 10^{-8} A.) This current measurement from fission chambers is the basis for some power-range neutron flux monitoring instrumentation for power reactor applications.

The output pulses from the fission chamber can also be amplified in an ac voltage amplifier to produce an ac output signal that is statistical in nature. According to the statistical theory of noise, the fluctuation of the output signal is proportional to the square of the signal produced by the fission chamber. If this statistical output signal is then passed through a squaring circuit and then through a logarithmic amplifier, the final signal output will be proportional to the logarithm of the neutron flux. This technique is useful in monitoring neutron flux over a fairly wide range, and this is the basis for intermediate-range neutron flux monitoring instrumentation for power reactor applications. For additional information, refer to the study performed by Valentine et al. (12).

From the above examples it may be seen that, if desired, the various signals from a fission chamber can be used to provide inputs into several different instruments, providing the capability to measure the neutron flux over a wide range. By using a combination of counting, statistical noise measurement, and linear current measurement, the range of detection can cover more than 11 orders of magnitude, covering reactor operation from shutdown (zero power operation) up to full power.

In boiling water reactors, three different types of miniature fission chambers are located within tubes inside the reactor to monitor source-range, intermediate-range, and linear-power-range neutron flux. In pressurized water reactors, fission chambers are located within holders placed outside the reactor vessel to provide similar functions for source range and for intermediate-range neutron flux monitoring instrumentation and, in some reactors, also for power-range instrumentation. Major benefits for this application include high signal-to-noise ratio, good rejection of the signal caused by gamma radiation in comparison with the signal caused by neutron flux, and good usable signal over a wide range of operation.

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JAMES F. MILLER
GAMMA-METRICS

FLASHOVER. See VACUUM INSULATION.