Characteristics of an Ex-Core Detector for the Design of SMART ENFMS

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1. Introduction

The Korea Atomic Energy Research Institute (KAERI) has been developing a system-integrated modular advanced reactor for a seawater desalination and electricity generation with a 330MW thermal power. A study is being processed for the design of an Ex-Core Neutron Flux Monitoring System (ENFMS) of SMART with an integrated wide range fission chamber and has found several technical problems to be solved in installing the Ex-Core detector caused by the integral reactor type [1].

This paper describes the technology of ENFMS applied in commercial Pressurized Water Reactors (PWRs) and discusses the characteristics of various detectors. In addition, it will be expected that this study provides valuable information as basic data for the design of ENRMS of SMART.

2. Ex-Core Neutron Flux Monitoring System in PWRs

Figure 1 show a typical location for an out-of-core neutron detector of a PWR during an operation at a rated power. In this figure, the detector is also outside the reactor vessel. In today's power reactors, the neutron flux inside the core boundary is always greater than 10^{11}nv (nv is flux unit, n/cm^2-sec). Consequently, it is current practice to define an out-of-core detector as one that is not exposed to a neutron flux greater than 10^{11}nv. However, an out-of-core detector can be located inside the reactor pressure vessel, e.g., in the region of the thermal shield, provided the neutron flux does not exceed 10^{11}nv.

2.1 Conventional ENFMS

In PWRs, ENFMS is used to protect the core from an excessive thermal power and to control the thermal power level and flux distribution within the core. At low power levels, it is used to confirm that the core remains subcritical during refueling periods. In addition, it is used to ensure that the rate of change in a reactor power remains within acceptable limits during a reactor startup and shutdown.

To perform these functions, the systems must operate over a range of about 10-decades of power. Many systems cover this range with '3-subranges', each with a different detector type and associated electronics. Typically, the source range covers the lowest 6 or 7-decades of power. The intermediate range covers about 10-decades, which are equivalent to about 10^{-8} to 200 percent of the power, depending on the design of the reactor. The source and intermediate range instruments are usually designed so that they would overlap for about 2-decades of power. The power range covers the top 2 or 3-decades and indicates the flux (and infers thermal power) linearly. Typically 2 or 3 detector elements per a detector assembly are used in each quadrant to obtain the radial and axial flux distributions.

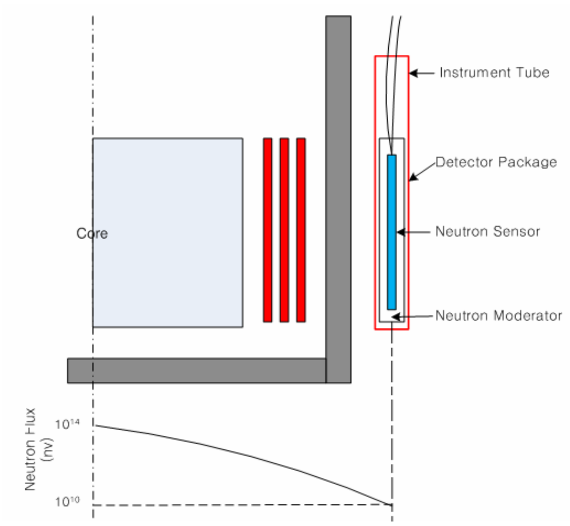

Fig. 1. Typical neutron flux for neutron sensors in PWRs at full power.

The 3-subranges, historically, have resulted from technological constraints on a detector's range, sensitivity and accuracy [2]. Detectors for the power range, typically an uncompensated, boron-lined ion chamber, generate an electrical current in response to the interaction of the boron and the neutron flux. However, they induce an excessive 'error' current at low power levels.

Ion chambers that compensated for this error were applied in the intermediate range. (In early plants, some of the power range channels shared compensated ion chamber detectors with the intermediate range channels.) Source range detectors required a higher sensitivity, resulting in the widespread use of proportional counters, either boron-lined or with boron trifluoride, BF_3, as the fill gas. Source range channels counted the pulses from the detectors, to measure the rate of an interaction between the neutron flux and the boron. Thereafter, a fission chamber is employed for the intermediate range and in its later plants, for the power range in the United States [3]. Figure 2 shows the conventional nuclear instrument ranges of the ENFMS in PWRs.

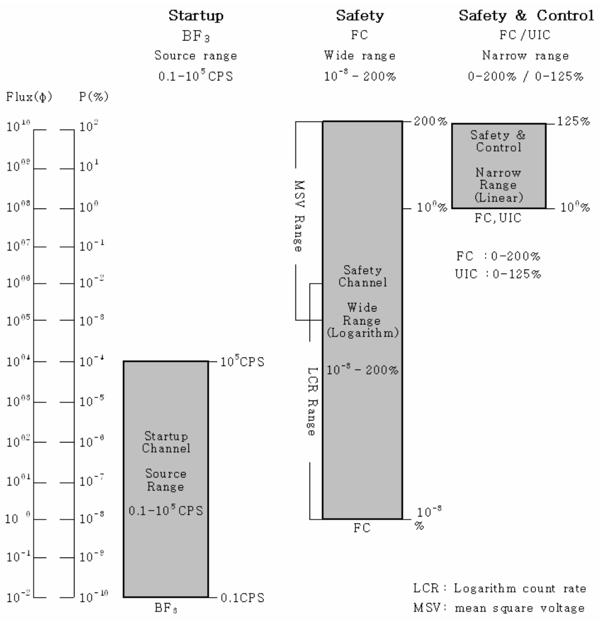

Fig. 2. Conventional nuclear instrument ranges of the Ex-Core neutron flux monitoring systems in PWRs.

2.2 Modern ENFMS

In the United States, most commercial PWR power plants have installed a new ENFMS employing fission chamber detectors. A primary motivation was the regulatory requirement for a post-accident monitoring of a neutron flux [4]. In response to the accident at Three Mile Island, new requirements for the instrumentation for Light Water Reactors (LWR) have been promulgated in Regulatory Guide 1.97. A major objective of these requirements is to ensure the quality and reliability of a plant's status information available to the control room operating personnel both during and after an accident. It is imperative that the instrumentation operate in the most severe conditions produced by an accident. Furthermore, the range of a measurement must be wide enough that the instrument is on scale at all times, even under abnormal conditions.

Fission chamber detects thermal neutrons by producing an electrical pulse in the detector when a uranium atom captures a neutron. The energy transmitted to the detector's gas from the fission is significantly greater than the energy from a gamma photon and the energy ratio is much higher than in a detector using boron as the neutron-sensitive element. Thus a fission chamber, in conjunction with good system design practices, is inherently better at rejecting gamma signals than other common detectors. This rejection is essential for systems that are expected to measure a neutron flux accurately in the presence of a high gamma radiation, e.g., after a design basis accident.

Consequently, a fission chamber can be used over a wide range of reactor powers. Fission chamber produces pulses at low power levels and operates in the mean square voltage (Campbelling) mode at higher power levels, both with a negligible effect from gamma. A common, modern PWR channel with a fission chamber detector assembly covers the same range as the original system.

Thus two detector technologies (proportional counter and compensated ion chamber) are no longer needed to cover the full range of a flux. This consolidates and simplifies a channel's design. Fission chambers are also used as an ion chambers to produce a current linearly and proportional to a flux. With a proper design, one fission chamber assembly can cover the entire range of a neutron flux with output signals suitable in accuracy and response time for the Reactor Protection System

3. Ex-Core Neutron Flux Monitoring System in SMART

Table 1 shows the comparison of the ENFMS in a reactor. Nowadays, an integrated wide range fission chamber is being considered for the ENFMS of SMART. Although there are some technical problems to be solved, it seems that an integrated fission chamber which can cover the entire range of a neutron flux is the most favorable neutron detector for SMART.

Table 1: Comparison of detector in reactor type

	KSNP	WH	SMART
Meas. Range	entire	entire	entire
Safety Ftn.	trip variable LPD/DNBR	trip variable	trip variable LPD/DNBR
Control	power range	power range	entire range
Monitoring	entire range	entire range	entire range
Calibration	fixed incore	Mov. incore	fixed incore
Det. Type	SR- BF_3 IR - FC PR- FC	SR- BF_3 IR - CIC PR- UIC	SR- FC IR - FC PR- FC
Det. No.	Startup- 2 Control- 2 Safety - 12	Startup- 2 Control- 2 Safety - 8	Startup- 2 Control- 2 Safety - ? DPS - 2

Acknowledgements

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