Development of Thermal Transient Flow Rate Sensors for High Temperature, Irradiation, Corrosive Environment

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ABSTRACT

In an advanced very high-temperature reactor (VHTR), the coated particle fuel is burned in a graphite-moderated reactor that is cooled with special coolants. One type of coolant material that has been actively researched is liquid fluoride salt, which unfortunately is very corrosive to structure material. Coupled with the extreme operating environment imposed by the reactor, including high radiation level and temperature (outlet temperature up to 1000°C), most existing instruments will fail to function reliably. In order to improve monitoring capability and system reliability in a liquid- or gas-cooled nuclear reactor, research and development of salt-wetted instrumentation for both operation and maintenance is required. This proposal addresses one such equipment that is used to perform on-line, long term measurement of coolant flow rates essential for determining the maximum power required by the plant operation and for monitoring the safe operation of the plant.

Coolant flow rate can be measured by various types of sensors, and the technique that measures thermal transient flow rate is by far the most promising one in a harsh environment caused by high irradiation, pressure, temperature, and corrosive media. Basically, the transit time of natural random temperature fluctuations in processes, like the coolant flow in a nuclear reactor, can be obtained by the cross-correlation calculation of flow temperatures recorded by two separate temperature sensors. Provided that the cross-sectional area of the pipe through which the liquid flows is known, the flow rate can be readily derived. Although simple in concept, in practice, accuracy of this method is often severely compromised due to the wide peak generated from the cross-correlation calculation and sometimes even additional false peaks. This serious problem has been successfully solved by the PIs' group by introducing a new adaptive signal processing algorithm to better estimate the sensor system's impulse response function. The main peak obtained using the new algorithm is much narrower than that using the classical cross correlation method, and the sidelobes (additional peaks) are considerably suppressed in the proposed method.

Although significant progress has been made in developing a flow rate meter for nuclear reactors over the past a year a half, yet there remain a number of serious research challenges: (1) the new signal processing algorithms and sensing configuration have to be carefully verified and validated, and thus fine-tuned in a harsh reactor environment with real, or close to real, physical and environmental effects (e.g., pipe diameter, thickness of pipeline, corrosion effects, radiation effects, sensor reading drift over the time, and so on); and (2) acceptable performance of the sensors using different shielding materials under different operating scenarios need to be quantitatively determined.

To meet these challenges, several research tasks will be performed: (1) calibration strategies based on conventional stainless steel shield thermal couples will be developed, (2) irritation testing of the sensor using the facility available in a DOE lab will be performed, (3) corrosive testing of the sensor using the facility

available in the PIs' home university will be performed, (4) the theoretical foundation of and practical guidelines to flow rate measurement employing a novel sensor configuration with multiple (or array of) temperature sensors (>2) will be developed; and (5) different types of sensors, including fiber optic thermal senor, platinum resistance thermoelectric sensor, and SiC (silicon carbide) temperature sensor, will be thoroughly investigated to determine their suitability for a harsh nuclear reactor environment.