Conducting Research Topics on I&C Division at KAERI: Radiation Measurement Instrumentation and Applications

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1. Introduction

The instrumentation and control (I&C) division for nuclear applications has conventionally been developed as ‘central nervous system’ of a nuclear power plant (NPP) including electrical equipment, modules, sensors, transmitter, redundancies, and so on. Recently these utilities have rapidly changed due to its ageing and obsolete components, particularly transitioning from analog to digital I&C. Additionally, safety issues become more attentive on cyber security and human failures since the Fukushima nuclear disaster was occurred in 2011.

The Nuclear Information and Communication Technology (ICT) Research Division, formerly Nuclear I&C, at KAERI has actively been conducting research on traditional topics and contributing many achievements on academic and industrial fields globally as well as locally; a) The safety-grade programmable logic controller (PLC), named POSAFE-Q which was one of three non-localized technologies in nuclear power plant fields was successfully localized and adapted to APR1400 plants, b) digitally diverse devices against common cause failures (CCF) were developed for safety systems, and c) the state-of-the-art simulator and systems for replicating main control rooms and devices were developed with considering human factors and cyber security issues.

However, these traditional research areas are facing challenges according to rapidly changing technologies, as known as the Fourth Industrial Revolution. The huge transition can be classified into two domains, nano-scale and macro-scale research areas. The nano-scale research topics would contain semiconductor radiation sensor technologies and radiation-hardened circuit systems that can be utilized for more safe plants and the next generation of NPP as well as for other related applications such as cargo scanning and medical tomography instruments. Secondly the macro-scale research topics would cover machine learning algorithms and communication technologies, for instance, big data and internet of things (IoT).

The Nuclear ICT research division at KAERI is responding with speed to the new research era. In this paper, some parts of ongoing research topics of the division are presented and discussed for future collaborations between academia and industry that would actually contribute on human life and safety.

2. Rad-Hard Preamplifier for MPFD

The first research topic is to develop a small-area, low resource-overhead front-end readout architecture that can mitigate radiation impact events, especially for a micro fission detector mounted available to the next generation reactors.

For many decades, various radiation-hardened-by-design (RHBD) techniques have been developed to meet the design requirements of irradiating environment in nuclear power plants. Improvements on the circuit side for radiation sensors in performance, chip size, and radiation hardening ability have been adopted in current plant systems; however, next generation reactors and/or preparation for severe events in existing reactors require advanced circuit structures that can provide relatively long viability in harsh conditions.

Analog front-end circuits are essential components used to bridge two different signal-processing worlds between physical data from sensors and digital expression for human recognition. The positioning of these front-end circuits, for example, preamplifiers should be coupled with sensors as close as possible to minimize any signal interference and noise. The location in or near a reactor pressure vessel requires radiation hardening techniques to prevent signal errors induced from radiation impacts on electronics that cannot be completely protected by standard radiation shielding techniques due to packaging, sizing, and high temperature issues. Therefore specialized RHBD techniques are required to protect circuits from radiation effects in those applications.

The proposed RHBD preamplifier described in this work could maintain its functionalities in harsh radiation environments. In addition, the specialized preamplifiers could be coupled with the new Micro Pocket Fission Detector (MPFD) of INL, resulting in a fully integrated fission detector module containing both sensor and readout circuitry that could be implemented immediately into practical applications such as existing nuclear power plants, material test reactors, advanced fast reactors, and radiation-tolerant military devices.

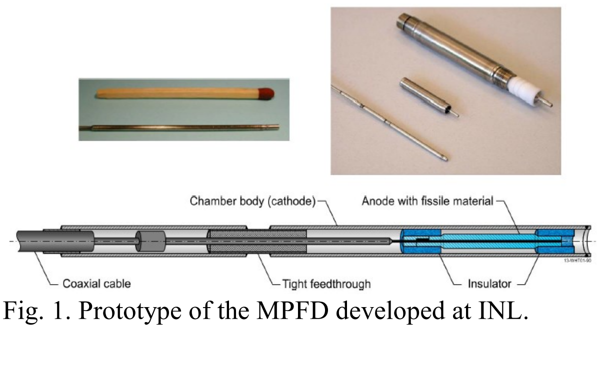

Fig. 1. Prototype of the MPFD developed at INL.

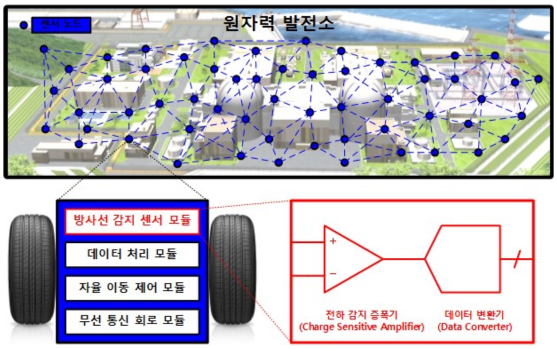

Fig. 2. Conceptual diagram for the proposed radiation sensor network.

3. Rad-Hard Sensor Network and Deep Learning

The sensor network system might be required to monitor and manage severe accidents because people cannot access the accident site even robots cannot without radiation hardened electronic systems. With the grouped sensors which are developed with RHBD circuits would provide necessary information regarding radiation dose and sources.

For this purpose, ultra-small and low-power sensor-bot system will firstly be developed with RHBD circuit design techniques to prevent signal errors and circuit malfunctions due to radiation impact events on electronics. Moreover, low noise system for receiving small signals from radiation sensors will be developed as well for analog front-end circuits and ADC. These circuits should be sustainable in low power operation to form a wireless sensor network.

Secondly, sensor big data algorithms will be developed with deep learning coupling to short distance wireless technology for communication. Wireless data transfer algorithms related to big data techniques will be exploited for information transferred from tens of radiation sensors.

Finally, radiation map for severe accident NPP site will be constructed where people could not access due to high radiation environments. By developing image signal processing algorithms such as segmentation, optimization, and deep learning numerous data from sensors through wireless network could be properly treated for the radiation map.

Through the research activity, the results provide users who should promptly perform follow-up action to mitigate the accident situation by using radiation map in the site where radioactive substances is hidden by structures or buried in ground. Additionally, radiation hardening techniques be developed by the research for electronics could be used in applications of robots/drones/systems for commercial NPPs and decommissioning processes. Furthermore, deep learning/ big data/ wireless sensor network algorithms could be used to the Fourth Industrial Revolution as well as national security and military systems.

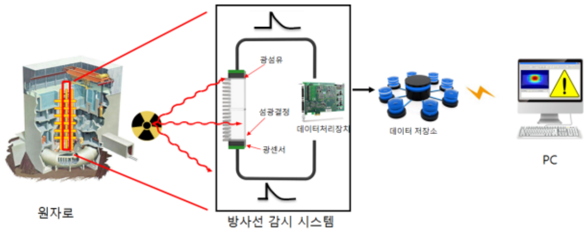

Fig. 3. Conceptual diagram for the proposed reactor monitoring system for managing severe accidents.

4. Reactor Monitoring against Severe Accidents

The last research topic is to develop radiation-hardened-severe-accident-instrument components to monitor core/reactor damage status in real-time. According to IAEA and TEPCO reports, one of the main reasons of the Fukushima accident why the accident could not be mitigated immediately is no reactor monitoring method due to harsh environments in terms of high temperature, high radiation and no electricity. In order to overcome these ultimate conditions, a new radiation detecting system with scintillator detectors has been proposed to sustain high radiation and temperature that would be mounted next to a reactor.

Through this technique, operators could monitor a reactor in real time, resulting in early responses actioned to prevent aggravation of severe accidents.

5. Future Work

Researchers know that successful scientific/industrial accomplishments require a diverse set of skills and capabilities, and that takes a substantial period of time. Under these circumstances, close collaboration between related fields even academia and industries is necessary for drawing innovative ideas. The Nuclear ICT research division is open to all experts for future works.

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