Proceedings of the Korean Nuclear Society Autumn Meeting
Seoul, Korea, October, 1998

Fuel Failure Monitoring System Design Approach for KALIMER

Soon-Ja Song, In-Koo Hwang, Kee-Choon Kwon

Korea Atomic Energy Research Institute
150, Dukjin-dong, Yusong-gu,
Taejon, Korea 305-353

Abstract

Fuel Failure Monitoring System (FFMS) detects fission gas and locates failed fuels in Liquid Metal Reactor. This system comprises three subsystems; delayed neutron monitoring, cover gas monitoring, and gas tagging. The purpose of this system is to improve the integrity and availability of the liquid metal plant. In this paper, FFMS was analyzed on detection method and compared with various existing liquid metal plants. Sampling and detecting methods were classified with specific plant types. Several technologies of them was recognized and used in most liquid metal reactors. Detection technology and analysis performance, however, must be improved because of new technology when liquid metal plant is built, but the FFMS design scheme will not be changed. Thereby this paper suggests the design to implement KALIMER(Korea Advanced LIquid MEtal Reactor) FFMS.

1. Introduction

A Liquid Metal Plant generally employs Fuel Failure Monitoring System (FFMS) to detect fission gas and locate breached pins. FFMS is not classified as safety related. But this system should inform plant staffs about the status of the core in the reactor[1]. FFMS comprises one of KALIMER (Korea Advanced LIquid MEtal Reactor) integrity monitoring systems[2]; Radiation monitoring, Fire protection monitoring, Impurity monitoring, Refueling neutron flux monitoring, Loose parts monitoring (LPM). FFMS generally consists of three systems; delayed neutron monitoring, cover gas monitoring and locating failed fuels. Each system is functionally divided into fuel failure detection and location. Methods for detection are delayed neutron monitoring, cover gas monitoring and those for locating are selective valve, tagging, or sipping.[1,2] The purpose of integrity monitoring is to improve the availability of the plants and maintain safety status to be informed about plant status. FFMS provides information to operator from detector and instrumentation in the reactor to keep fuel integrity during power operation.

To detect fuel failure, delayed neutron monitoring system was used in EBR-II, JOYO, CRBRP, PRISM and cover gas in EBR-II, JOYO, PRISM. Most liquid metal plants use these two methods to detect fuel failure to date. On the other hand, gas tagging for locating failed pins was not considered to adopt because of cost and different fuel assembly. However, experimental and prototype LMR used gas tagging to locate failed fuel pins to detect specific isotopes from each fuel assembly. For failed fuel location, selective valve method was adopted in PFR in UK and sipping in JOYO.

This paper provides conceptual and technical design information and criteria to implement KALIMER FFMS since various LMR plants were grouped by detection and location method. In KALIMER, FFMS will comprise three subsystems; 1) Delayed Neutron Monitoring, 2) Cover Gas Monitoring, and 3) Gas Tagging/Tag Recovery and Analysis. The Delayed Neutron Monitoring will be used four detectors in each IHX and one Cover Gas Monitoring in the reactor. A nominal failure rate for metal fuel is a lot lower than oxide fuel so that the metal fuel for KALIMER is expected to be very reliable. In this reason, FFMS for KALIMER will not change the basic design although the gas tagging will not be used later.

2. Functions and Methods of FFMS[4]

The strategy of LMR operation for failed fuels is to continue to operate in run-beyond-cladding-breach (RBCB) mode to improve plant availability. The function of the FFMS is to detect failed fuels and locate them. Each function has several methods to deal with failed fuels. For detection, delayed neutron monitoring and cover gas monitoring methods have been used and for location, selective valve, tagging, or sipping.[1,2] To detect fuel cladding breach, LMRs employ delayed neutron monitoring system for exposure sodium and fission gas monitoring system for identifying fuel elements. The locating failed fuel is to detect and analyze fission gas when the tag gas is released with fission product gas. The breached assembly is identified by mass spectrometric analysis of the reactor cover gas.

2.1 Fuel Failure Detection

2.1.1 Delayed Neutron Monitoring System

The exposure of fuel to sodium through a breach releases fission product into the primary coolant and the fission products remain in the coolant. These fission products decay with time emitting neutrons. Therefore, the presence of delayed neutron in the coolant indicates a failure of fuel and leakage of fission product from the bleach. This delayed neutron monitoring system for detecting fuel breach is deployed for EBR II, JOYO, CRBRP, PRISM, MONJU.

2.1.2 Cover Gas Monitoring

If a clad failure occurs, fission gases are released from fuel cladding to the upper area through sodium pool and cover gas. A passive diffusion gas monitor takes sample of cover gas and analyzes the gas contents using the gamma ray spectra. It identifies the concentration of selected fission gases to estimate fuel failure. This cover gas monitoring is being used in most of LMRs all around world except CRBRP.

2.2 Failed Fuel Location

2.2.1 Selective Valve method

Coolant samples from fuel assemblies are extracted through the selective small pipes connected to each fuel assembly. The presence of fission products is monitored by delayed neutron measurement and /or gamma detection to locate the breached fuel cladding. This technology is applied to Phenix, Super Phenix, and British PFR.

2.2.2 Pin Gas Tagging

If each fuel assembly is filled with a unique isotopic tag gas, it releases the tag gas along with the fission product gas. If the content of cover gas is analyzed by mass spectrometric technique, the assembly with breached cladding can be identified on the basis of mass spectrum of the tagged gas filled in to the fuel assembly. When helium cover gas is used in ALMR, argon and neon gases are employed for tagging.

2.2.3 Sipping

JOYO plant used sipping method to locate failed pins after reactor shutdown. A coupling pipe is inserted under the fuel assembly and sample of coolant of the fuel assembly is drawn to the top of the reactor to analyze the amount of fission products for locating the breached assembly. For large reactors with many fuel assemblies, it takes long time to perform the sipping test.

Table 1. Method of detecting and locating failed pins [3,5,6]

Method / Plant	DETECTION		LOCATION			
	Delayed Neutron	Cover Gas	Sodium Sampling	Gas Tagging	Dry Sipping	Wet Sipping
EBR-II	DM	CGM	-	GT	-	-
JOYO	DM	CGM	-	-	-	WS
CRBRP	DM	-	-	GT	-	-
PRISIM	DM	CGM	-	GT	-	-
MONJU	DM	CGM	-	GT	-	-
Super-Phenix 1	DS	CGM	SS	-	-	-
Super-Phenix 2	DS	CGM	SS	-	-	-

DM : Delayed Neutron Detection (main pins), DB : Delayed Neutron Detection (by-pass),

DS : Delayed Neutron Detection (special pipework), SS : Sodium Sampling

GT : Gas Tagging, DS : Dry Sipping, WS : Wet Sipping

Table 2. Method of sampling and analyzing primary gas [3,5,6]

Plant \ Method	Kind of Gas	Sampling Method	Analysis Method
EBR-II	argon	grab sample	mass spectrometer
JOYO	argon	Capsule pot	gas chromatography
CRBRP	argon	on-line	gas chromatography
PRISIM	helium	on-line	mass spectrometer
MONJU	argon	off-line	-
Super-Phenix 1	argon	DRG	-
Super-Phenix 2	argon	DRG	-

3. KALIMER FFMS design

KALIMER FFMS will consist of three subsystems. In Figure 1, delayed neutron system is located in one of the IHX having four detectors and cover gas system is equipped just above the sodium level. Gas tag in the core is used with a common tag for all the pins of each fuel assembly. In KALIMER, when a clad occurs, plant will continue to operate in run-beyond-cladding-breach (RBCB) mode to maximize plant availability. According to the reference design technology, nominal failure rate is 0.2 breaches/reactor/year. A nominal failure rate for KALIMER metal fuel similar to PRISIM generally is lower than oxide fuel so that the fuel for KALIMER is expected to be very reliable. In this result, gas tagging may not be used in KALIMER to consider cost and benefit. The basic design scheme is presented [Figure 2]. This FFMS scheme was classified with functions and methods.

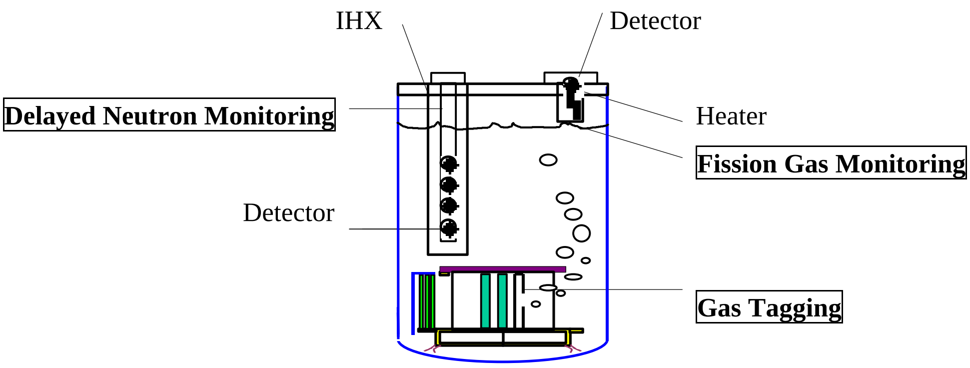

Figure 1. Location of FFMS Subsystems

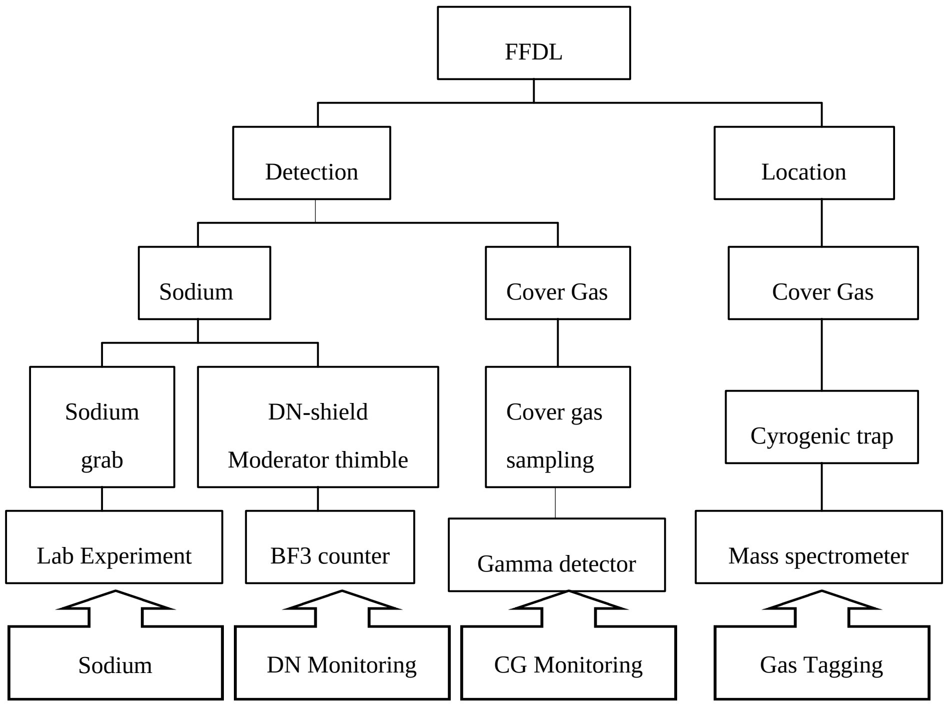

Figure 2. KALIMER FFMS design scheme

3.1 Delayed Neutron Monitoring

KALIMER reactor has two stations in reactor. For delayed neutron monitoring, each station has four detectors inside IHX drywells. The vertical displacement of the detectors inside thimble is optimized so that the transport-delay time for primary sodium between adjacent detectors is approximately 5% of the transport time to the first detector. Signals from each delayed neutron monitoring are processed to continually provide several diagnostic parameters that are used to indicate the amount of fuel to sodium exposure. These diagnostic parameters include the sodium transport time for the DN emitters, and the isotopic holdup time which is a measure of the relative aging of the DN precursors between their birth in the fuel and their release to the coolant. These signals are processed with signal processing and are sent to alarm annunciator for operators and plant staffs to maintain the plant.

3.2 Fission Gas Monitoring

This function operates by diffusion and contains a central tube close at the upper end, but opened to the cover gas at its lower end. The upper portion provides a field of view for the detector which is shielded from the remainder of the cover gas and the sodium pool below. Heat below colliator creates a temperature inversion in the tube to prevent convection and maintain the static gas column. This also maintains the tube temperature above that of the sodium pool to prevent sodium condensation. KALIMER is designed to detect fission gas of cover gas with Gamma ray detectors. These detectors have a preamplifier, an amplifier, a high voltage supply, an ADC and a signal processing system. This system can be used in some commercial parts of the previous light water plants.

3.3 Gas Tagging/Tag Gas Recovery and Analysis

KALIMER has selected argon-neon gas tagging . The main reason is that the argon-neon system is lower in cost, less prone to in reactor compositional changes, and more readily compatible with the sealed reactor cover gas operation. To execute tag gas recovery and analysis, the reactor is shutdown and the cover gas vehicle is connected to the reactor, and the reactor is charged with fresh helium. For these functions, an off-line, plant-wide approach is employed. This system is related to fuel design department to select the use of gas tagging for KALIMER. Because there are some issues about gas tagging, this tagging will be drafted until fuel design will be set. Nevertheless, integrity monitoring systems of KALIMER should not change the basic fundamentals which is modularized and executed individually when some parts is changed.

To design the Fuel Failure Monitoring System, proven technologies should be adopted. Table 3 and 4, shows KALIMER sampling and detecting method. This result suggests and provides technical information to design and implement FFMS.

Table 3. Method of detecting and locating failed pins for KALIMER (Draft)

PLANT	DETECTION		LOCATION			
	Delayed Neutron	Cover Gas	Sodium Sampling	Gas Tagging	Dry Sipping	Wet Sipping
KALIMER	DM	CGM	SS	GT	-	-

* refer to Table 1.

Table 4. Method of sampling and analyzing primary gas for KALIMER (Draft)

PLANT	Kind of Gas	Sampling Method	Analysis Method
KALIMER	argon nitrogen	on line	gamma detector, mass spectrometer

4. Conclusions

In this paper, the FFMS of various liquid metal plants was classified into sampling fission gas, detecting failed fuel pins, and locating breached pins. In the result of classifying liquid metal plants (LMR), The fuel detection and location technology of CRBRP and PRISM were based on the experimental plant, EBR-II, and in these two plants, the recent FFMS technologies had tested and suggested for liquid metal fuel plants. To design the Fuel Failure Monitoring System in KALIMER Integrity Monitoring System, those tested and designed functional requirements should be adopted. However, sampling and detecting gas technologies may be changed. Particularly the technologies related to detector signals must be changed. This paper suggests the functional fundamentals to design and implement FFMS.

Acknowledgements

This work has been carried out under the nuclear research and development program by Ministry of Science and Technology.

References

1. NUREG/CR-1368, "*Preapplication Safety Evaluation Report for the Power Reactor Innovative Small Module (PRISIM) Liquid-Metal Reactor*", April 1994.
2. GE, "*Modular Liquid Metal Reactor (LMR) Design Technology*".
3. IAEA, IWGFR/80, "*LMFBR Plant Parameters*, 1991.
4. PNC Technical Review No. 73, "*Research and Development Activities on Instrumentation and Control*", pp95- 96, Mar. 1990.
5. CRBRP PSAR 7&8, June 1976.
6. GEFR-00793, Vol. 2, Chapters 5-8, "*Preliminary Safety Information Document*", Nov. 1986.