Evaluation of the Applicability of RTD to SFR

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1. Introduction

In Pressurized Water Reactor, although Resistance Temperature Detectors (RTDs) has low limit temperature and low response time comparable to thermocouples, they have been widely used to measure the temperature for calculating the heat-balance of core. In almost Sodium-cooled Fast Breeder Reactors (SFRs), however, K-type Thermocouples(TCs) have been used to measure temperature and RTDs partially were used.

But Muralikrishna [1] reported that RTDs were ruled out for fast reactors on the recent. He pointed out that they undergo transmutation in the fast neutron and high gamma fields and gamma heating of the resistance element drastically changes the temperature resistance characteristics.

In contrast to his study, however, it was reported that RTD had resistance to radiation damage [2] and thermal neutron flux are responsible for the transmutation but fast neutron reactions, in general, cause very little change in composition [3].

Furthermore, there are some examples that RTDs were used to measure temperature in SFR: the measurement of the exit temperature of coolant in EBR-II [4], of temperature for data on power of the reactor in FFTF [5] and of the inlet and outlet temperature of coolant at the reactor vessel in Rapsodie[6]. RTDs were adopted in above SFRs for their high and inherent accuracy. Also, CRBRP had a plan to measure the temperature of hot leg and cold leg. It was reported that no major difficulties had occurred during tests of the RTDs in FFTF [5].

According to literatures survey up to now, it seems that RTDs could be applicable to SFR in other than Muralikrishna's study. Therefore, the in-depth evaluation for the applicability of RTD to SFR is required.

In this study, the applicability of RTD to SFR is evaluated by 1) whether transmutation in the resistance characteristic of RTD by fast neutron and gamma ray through the extensive literature survey, 2) error analysis of RTD in fast breeder environment, 3) evaluation of the characteristic of SFRs where RTDs were applied.

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2. Evaluation of Applicability of RTD

2.1 Literature Survey

Although extensive literatures were surveyed, the studies about the irradiation effect of fast neutron and gamma ray on RTD had not been found. But some studies about the irradiation effect of fast neutron on TCs were found. However, it is well known that TCs are widely used to measure the temperature in SFR as well as PWR without the problems related with irradiation of fast neutrons. According to the literature survey so far, only Muralikrishna had issued the applicability of RDT to SFR.

Because it is seemed that the study about the irradiation effect of fast neutron and gamma ray on RTD was almost never to be found, the studies about the irradiation effect of fast neutron and gamma ray on platinum, which is the resistance element of RTD, were investigated.

According to the literature survey, the majority of studies on the irradiation effect of fast neutron and gamma ray on platinum were the studies on the differences in the resistivity of metals such as pure tungsten and W-Re alloy[8] or materials such as UO_2 [9], graphite[10] and insulation[11] before and after neutron irradiation experiments and the effects of neutron irradiation on metals such as Pt, Al, Cu, Zr, Ag, Ta, W, Mg at cryogenic[12][13][14] in the experimental reactor such as JOYO and JMTR (Japan Material Testing Reactor) rather than on the influence of the fast neutron or gamma irradiation for platinum in the SFR environment.

Sion [15] recommended the use of type K Chromel-Alumel minerally insulated sheathed TCs including high nickel content in high radiation environment because nickel has a low neutron capture cross section. Also, he added that RTD was avoided in intense radiation environment and he couldn't find the reasons to explain the reluctance to RTD other than that platinum RTD's were not successful in similar environments when measurements were taken at Oak Ridge National Labs.

He insisted that the nickel RTD should be used instead of platinum and transmutation effects would be negligible. However, since the nickel RTD's limit temperature is very low comparable to fast reactor environment, nickel RTD could be not applicable to SFR.

Additionally, according to Westinghouse's report [16], gamma and fast neutron radiation appear to cause the transducer output sensitivity shift and it is believed that fast neutrons (E> 1.0Mev) cause the majority of the RTD damage.

Ehringer [17] compared the EMF characteristic of Chromel-Alumel TCs with Platinum/Platinum-Rhodium. He concluded that for the temperature range 0~1000°C the Chromel-Alumel TCs can be used in up to neutron exposures of at least $5\times10^{20}\,nvt$ and for the range above 1000°C Pt/Pt-Rh TCs cannot be used if the neutron exposure exceeds above $10^{20}\,nvt$.

According to his conclusion, the Chromel-Alumel TCs could be used in PFBR, but Pt/Pt-Rh TCs are not applicable to PFBR because neutron flux in core is about $8.5\times10^{20}\,nvt$ [18] and the temperature of sodium coolant is below 600°C during normal operation.

2.2 Error Analysis

When used for measurement of temperature in Nuclear Power Plants, the major error factors of RTD to be considered are as follows: Self-Heating of RTD's resistance element, Gamma heating of RTD and thermowell and Heat loss through thermowell.

In this analysis, only the effects of gamma-heating are considered excluded those of self-heating and heat loss, which are same factors considered in PWR.

Gamma rays are electromagnetic waves with high energy interacting with a materials by photoelectric effect, Compton scattering and pair production. If an RTD and a thermowell are exposed to a gamma field, they will absorb some of the energy carried by the gamma radiation.

The absorbed energy in RTD and thermowell cause the increase of the temperature of the RTD assembly and result in the RTD measurement errors.

Maximum gamma ray is about 10Gy/h in bottom of Safety Vessel of PFBR [18] and about 300Gy/h in JOYO [19]. If RTD and thermocouple are irradiated at 300Gy/h gamma field, they absorb the following energy:

$$300\frac{Gy}{h} = 300\frac{J}{kg\cdot h} = \frac{1}{3600}\frac{J}{s\cdot kg} = 0.0833\frac{W}{kg}$$

Assuming the mass of the thermowell is 3kg (the mass of RTD is small relative to the thermowell and can be neglected) and all gamma energy is deposited in the thermowell without heat-loss, then the heating power is:

$$0.083\frac{W}{kg}\times 3kg = 0.25W$$

It can generate about 1.9℃ temperature error based on the self-heating data of Rosemount 176KF[20], 7.67℃/W. Considering that general tolerance error of RTD is about 1℃at 400-500°C, the above calculated error due to gamma heating couldn't be negligible. However, it is necessary to calculate the gamma heating based on gamma flux distribution of the prototype SFR because the above calculated gamma heating value was based on the maximum gamma ray filed of JOYO.

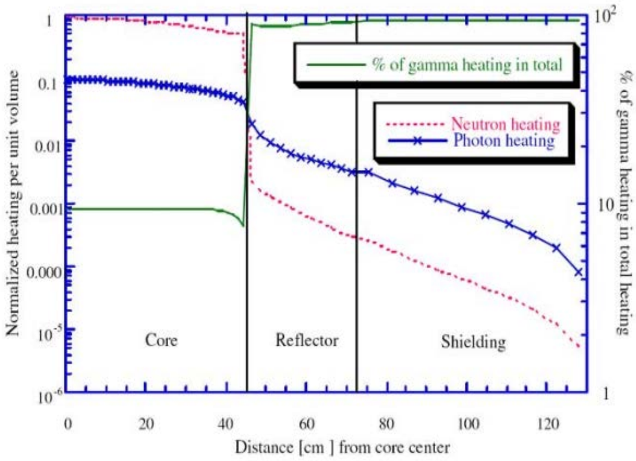
2.3 Characteristic of SFR

So far, the application of fast reactors utilizing RTD had been identified: for measurement of coolant exit temperature monitoring in EBR-II, of the temperature measurement associated with the reactor power n FFTF and of temperature at the reactor vessel entrances in Repsodie. CRBRP had a plan to measure the temperature of hot leg and cold leg by RTDs.

Above fast breeder reactors where the measurement of temperatures were accomplished or to be planned by RTD were all loop-type reactor except the EBR-II. According to the EBR-II operating experience report [21], 10 RTDs installed to monitor the exit temperature of coolants were all damaged. Although other reports on RTD operating experience of loop-type or pool-type were not reviewed, it is seemed that the cases normally operating with RTDs in pool-type SFR were extremely rare. Therefore, in-depth reviews are required to apply RTD to the pool-type SFR.

As shown in Figure 1[22], neutron heating has a great part of responsibility for nuclear heating inside the core and decreases rapidly as it passes over the reflector and shielding. The ratio of gamma heating is only 10% in nuclear heating inside core and gamma heating decrease but slightly than neutron heating outside core.

Therefore, the loop-type fast breeder reactor where the important temperatures are measured outside the reactor vessel has a high potential of applicability of RTD.



3. Conclusions

In this study, the applicability of RTD to SRF was evaluated by the literature survey, the analysis of RTD's error factor and of characteristics of SFR where RTD was applied.

Firstly, the studies on the applicability of RTD to SRF hardly have been found and it was not taken up as an important issue yet. However it make sure that RTD is not recommended in high radiation area.

Secondly, errors due to gamma heating inside core of SFR in comparison to by gamma heating at PWR is significantly greater than the tolerance of RTD itself. Therefore it is not recommended to use the RTD in strong gamma ray area.

Thirdly, RTD could be used outside reactor vessel for loop-type SFR, and it is advisable to limit the use of RTD inside reactor vessel for loop-type SFR as well as pool-type.

In conclusion, it is judged that the use of RTD is to be limited inside reactor vessel of SFR, but RTD could be allowed to be used outside the reactor vessel at the location verified by the neutron flux and gamma radiation level assessment.

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