Long-lived Hybrid Incore Detector for Core Monitoring and Protection

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Ⅰ. Introduction

The signal production mechanism in a rhodium (Rh) fixed in-core detector emitter relies primarily on the beta particles resulting from neutron absorptions in either of two Rh isotopes to produce an electric current. As the neutron transmutation process depletes the Rh isotopes, the signal output per unit neutron flux from an Rh detector emitter will decrease. A vanadium detector is primarily sensitive to neutrons, but with a somewhat slower reaction time as that of a Rh detector. The benefit of vanadium over rhodium is its low depletion rate, which is a factor of 7 times less than that of rhodium. Platinum detectors are very sensitive to gamma flux, but only mildly sensitive to neutron flux. Because the depletion rate of platinum is very small, it can be neglected. Generally, both gamma and neutron signals are proportional to the assembly power.

The characteristics of a new detector are the long life time due to the low depletion of emitter materials and the capability of reactor protection as well as reactor monitoring. The new detector uses vanadium and platinum as the emitter materials to meet the long life time and reactor protection capability. Vanadium detector is used for reactor monitoring and platinum detector is used for reactor protection. To determine the number of emitter strings, a comparative study of the power peaking factor monitoring accuracy for various self-powered fixed in-core detector geometries was made, and the configuration of the optimal detector design was also established and verified.[1] The design of a new detector consists of five-string vanadium detector elements, and three-string platinum detector elements. The detector assembly also contains a background wire for compensation of noise signal and a thermocouple for use in the post-accident monitoring system. This new hybrid detector can be used for both reactor <u>M</u>onitoring <u>A</u>nd reactor <u>P</u>rotection (MAP).

II. Detector Diameter and Configuration

The mechanical configuration of the MAP detector assembly was developed and verified. To achieve the required signal-to-noise ratio, an evaluation for the minimum necessary signal levels of each platinum and vanadium detector elements was performed. Because the resolution of the in-core detector signal processing devices in OPR1000 is about 1nA the minimum signal should be greater than 200nA to achieve 0.5% measurement accuracy. The detector diameters are also determined based on that fact. Moreover, the emitter of Pt-clad detector consists of a core of inconel surrounded by a thin(~0.05mm) layer of platinum. It is expected that the sensitivities of the Pt-clad detector will vary less with irradiation than those of the solid emitter type. An important additional advantage is the much smaller amount of Pt required, which has the potential for a significant saving in cost. The sensitivity of vanadium and platinum detectors can be written as follows.[2]

$$S_{vanadium} = 2.05\times10^{-24} D^{1.23} A\cdot m^{-1} /(n\cdot m^{-2}\cdot s^{-1}) \quad (1)$$

$$S_{Pt-clad} = 2.70\times10^{-25} D^{1.47} A\cdot m^{-1} /(n\cdot m^{-2}\cdot s^{-1}) \quad (2)$$

where, D is the diameter of emitter and the gamma ray sensitivity is defined here in terms of the neutron flux. Also, the current of detector is,

$$I = S \cdot \Phi_{th} \cdot L \quad (3)$$

where, L is the length of detector.

From the evaluation of the measurements obtained during the platinum detector demonstration program of YGN 4,[3] the prompt response of platinum detectors produces relatively small electric current. So it is necessary to maximize the current of platinum detectors. In order to get maximum current signals from both emitters, the MAP design will maximize the diameters of the platinum and vanadium detector elements. The platinum detector element will have diameter of 2.64mm and the vanadium's will have 1.33mm. Using the above equations and the diameters of the emitter materials, the currents of the detectors are shown in table 1.

Table 1. Sensitivity and Current of the emitters

Emitter	Sensitivity (A/nv-cm)	Current (㎂)	Remarks
V	0.29	0.91	
Pt	0.11	0.59	Pt-clad
Rh	0.97	1.59	YGN4 data

The configuration of the electrical connectors used in the MAP detector design includes separate connectors for the platinum and vanadium signals. The vanadium detector and thermocouple signals are output through a connector identical to the connector currently used on the rhodium detector assemblies installed at the OPR1000. The platinum detector signals are output through a separate three pin connector.

The axial and radial configuration of the MAP detector assembly design is shown on Figure 1. The final radial configuration maintains the diameter of the outer thimble sheath of the detector assembly at the diameter(11.43mm) of the rhodium detector assembly currently used in OPR1000. There are eight detector elements and one thermocouple sub-assemblies contained within. The sheath and insulator thickness of the detector element outer sheaths are identical to those of rhodium element design currently used in OPR1000.

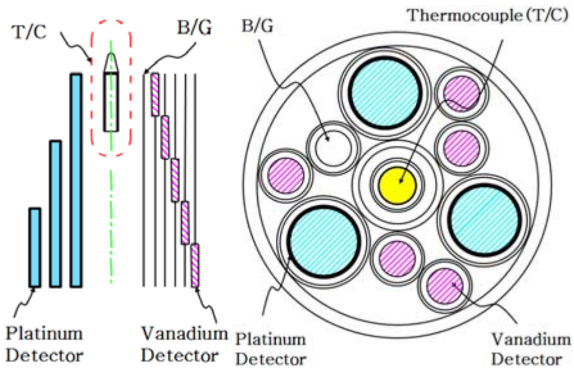

Figure 1. Axial and Radial Configuration

III. Implementation Options

There are two options associated with the method of implementation that have a direct bearing on the design of the signal processing system associated with the MAP detector design.

The first option is to use the MAP design variant that can be installed initially to provide only signals from the vanadium detector elements. The vanadium element signals and the thermocouple signal can be measured and output from containment using the existing signal processing hardware. The platinum detector signals are output through a separate electrical connector from the detector assembly. The cables, containment penetrations, and signal processing electronics needed to support the use of the platinum detector signals in the CPC can be added when time and funding permit.

The second implementation option is to implement the CPC changes needed to support the MAP detectors simultaneously with the installation of the MAP detector assemblies and to utilize two electrical connectors. The primary connector is identical to the connector used on the rhodium detector assemblies currently used at OPR1000. The signals from the five vanadium detector elements and the thermocouple are output through the primary connector. This configuration allows the MAP detector's power distribution monitoring capabilities to be back fit into operating plant without requiring changes to the signal processing cables or electronics. There will be minor changes to CECOR/COLSS needed to support the use of the vanadium detector element configuration for power distribution measurement purposes. The secondary connector of this variant is used to output only the signals from the platinum detectors. The signals from this connector only need to be used when the CPC methodology and associated systems are updated to use the input from the platinum elements to replace the inputs provided by the ex-core detectors.

IV. Conclusion

A preliminary evaluation has been performed to determine the geometry of MAP detector. The MAP detector design with five strings of vanadium for the power distribution monitoring and three strings of platinum for the core protection is the optimum design. In the near future, more comprehensive evaluation for the MAP detectors will be performed with a real reactor simulation model. And the implementation options of MAP detector for the OPR1000 are suggested. It can be used as the monitoring system only with some algorithm changes of CECOR/COLSS, and also can be used as the protection system with more changes of CPC devices.

References

[1] Kyoon Ho Cha, et al., “Geometry Determination for New Fixed in-core Detector of KSNP plant,” KNS Spring Meeting, May 2004
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[3] C.J. Allen, "Response Characteristics of Self Powered Flux Detectors in CANDU Reactors," AECL, May 1978