動力爐用 補償型 電離函의 제작 및 실험

논 문
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Manufacture and Experiment of Compensated Ionization Chamber for the Nuclear Power Reactor

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[ABSTRACT]

A neutron detector, in general, can not be utilized as the thermal neutron detecting chamber in the nuclear power reactor, especially P.W.R. due to the characteristics of high temperature, high pressure and high neutron flux in a reactor vessel.

We have performed an experiment to detect the thermal neutrons at 400°C and high flux of thermal neutron in a power reactor.

Coating boron-10 on the aluminium plates by means of surface diffusion method at 600°C for 5 hours in an electric furace, also we made a typical chamber which was compensated ionization chamber filled with free air as an ionization gas.

It was checked the chamber characteristics in the TRIGA MARK-II Reactor at the power level from zero to 250KW.

The chamber current showed a perfect linear increase to power increase. However, many variation of the measured current were observed within the power of 50KW.

I. Introduction

A number of neutron detectors has been developed for the measurement of thermal neutron in a neutron source and an experimental reactor.(1—6) In addition various detection equipment has been designed to measure neutron flux under a high temperature in a power reactor in due consideration of varied characteristics inside of the reactor, especially mechanical characteristics of detector itself affected by a high temperature, high pressure and neutron damage by neutron flux in the reactor (7—13)

In the present experiments, the detector was so designed that it could be used to a power reactor and made it possible to measure thermal neutron under the neutron flux of -10^{13} -10^{14} on'/cm² sec. at 400°C. It was also compensated with an intensive gamma ray in the core of power reator. Since the ratio of gamma ray thermal neutron flux in the ordinary reactor is more than 1,000 : 1, a gamma compensated ionization chamber was designed for the present experiments in order to measure only the neutron being eliminated by gamma background. the characteristics of this chamber were carefully investigated to find out the possibility of domestic production of a neutron detector for the most inporant out-core of the power reactor which will be introduced to Korea in the near future. The source of gamma ray is produced by prompt fission, fission decay, neutron capture, inelastic neutron scattering, de-excitation of residual nuclei and bremsstrahlung.

The nuclear fission and gamma ray produced by the decay of generating materials of nuclear fission are generally the source of gamma ray in addition to a gamma radioactivity abandoned by the material of the neutron detection chamber. This chamber was fabricated with local materials and technical know-how. In order to employ the reaction principle of B^{10} (n,α) Li^7, boron was coated over aluminum plate

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by the surface diffusion method. These aluminum plates were isolated and fixed with an insulator in the aluminum chamber, then power source was added to between the plates so as to read the electric current produced by the thermal neutron flux with a micro-micro ammeter.

2. Experimental

2—1. Principle of the Compensated Ionization Chamber

It is difficult, in general, to measure only the neutron flux i in a mixed radiation of neutron and r-ray with an ionization chamber. Therefore, the detector was designed in the form of a compensated ionization chamber.(14) The principle of this form is to isolate it in 2 regions, one of which is so made as to be a sensitive volume, to neutron and the other to only r-ray.

As Fig. 1 shows the neutron detector used for the present experiments is composed 2 chambers of neutron sensitive volume and r-ray compensated volume, one of which consists plates 1 and 2 and the other consists of plates 2 and 3. plates 1 and 3 are the accelerating plate of plus-minus ions which grounded plate 2, while 2 polarities connect each different voltage of V1 and V2.

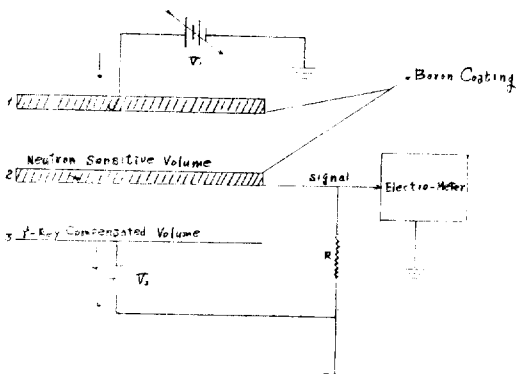

Fig. 1 Principle of the compensated ionization chamber

Plate 2 becomes a collecting electrode for signalling affected by neutron, positioned at the center between plates 1 and 3 so as to equalize the current flowing by r-ray in the two chambers. The two volumes become equalized, eccordingly, and gamma ray produced therein is balanced and then eliminated, so that the signal of neutron alone may run in plate 2 which is the intermediate electrode. When the chamber is irradiated by r-ray, the current to the two volumes may be abjusted as follows; i.e. when the current by r-ray running between plates 1 and 2(neutron senstive volume) is expressed as I+r and the current by r-ray between plates 2 and 3(r-ray conpensated volume) as I—r, the absolute value of these tow currents |I+r| =|I—r|. Since the current direction is opposite, it may be expressed as I+r—I —r=O. And also when the detector is irradiated by the mixed radiation of neutron and r-ray, only neutron may be measured with the current yielded by the difference of current to each volume. In other words, if the whole current in the neutron sensitive volume is Ion'+I+r, the current at the same time in the r-ray compensated volume is only I-r. Therefore, we may obtain (Ion' +I∓r)—I—r=Ion', where the 'Ion' is the signal current of the detector by only the neutron flux which makes it possible to possible to perform the measurement.

Fig. 2 illustratrates the compensated ionization chamber designed for the present experiments, and the principle upon which it is based is as shown in Fig. 1. However, the aluminum plate was increased to 5 plates in order to enlarge the sensitive volume.

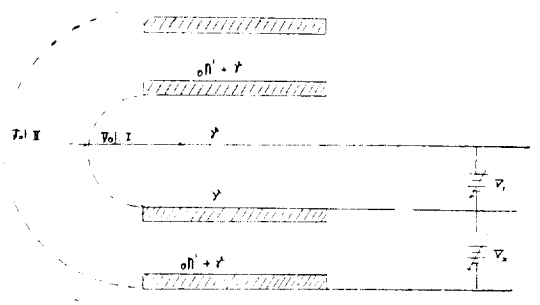

Fig. 2. Scheme of compensated ionization chamber in large volume with associated circuit

The two volumes (Vol. I) in the center of Fig. 2 above maintain the equilibrium of the electric charge with the measurement of only gamma and the outer

two volumes (Vol. II) are made to be sensitive to neutron and gamma so that gamma ray may be compensated by the adjustment of the voltage V1. and V2. The current by gamma results in elimination and the current signal of only neutron appears on the micro-micro ammeter.

2—2. Design of Chamber

a. Boron Coating

As described previously above the chamber for the present experiments was so designed as to measure neutron flux only at the time of a high temperature (~400°C), high neutron flux and gamma ray. The local alumium plate of 1mm thick and 87.5mm diameter in size, which has a smaller absorption cross section affected by neutron was made in due consideration of neutron damage and boron was coated over the plate. Since the boron powder could not be applied for painting with organic binding agent, it was fused by electricfurnace at the temperature of 600°C and the powder of B_2O_3[B—10(18.1%), B—11(18%)] was coated over the aluminum plate after having heated continuously for 5 hours by the surface diffusion method. At this time the free energy by the substitution reaction of the two materials, Al and B_2O_3 is as shown in Fig. 3 below. The chemical equation of the surface diffusion occurring between Al and B_2O_3 is as shown in Fig.3 below. The chemical equation of the surface diffusion occurring between Al and B_2O_3 is x $2Al+B_2O_3 \rightarrow Al_2O_3+2B$. The isolated boron atom is packed with the Al atom on the surface, where the free energy of (Al_2O_3-2B) is stabilized by far in comparison with that of $(2Al+B_2O_3)$ as seen from Fig. 3.

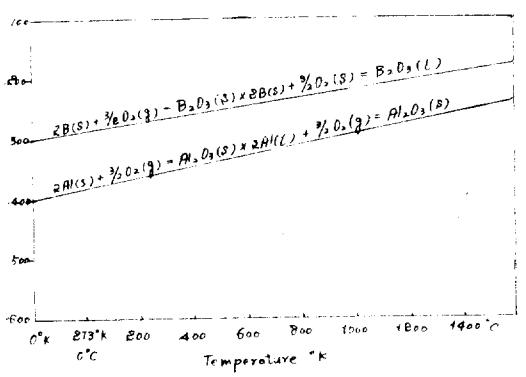

Fig. 3. Free energy diagram

This proves that Boron can be diffused upon penetrating into the surface atom of Al. Therefore, the B-Al compound can be used when a high temperature of 400°C is maintained in the reactor.

b. Coating thickness

The range of neutron (0.025ev) in B^{10} is expressed as $(g/cm^2 = \frac{W}{0.6026})$, where W is the atomic weight of Al and 6 is cross section of neutron absorption of B^{10} expressed in barns. Since the range $\lambda = 4.2 mg/cm^2$ is obtained, the coating thickness of B^{10} should be less than $4.2 mg/cm^2$ and the maximum energy Q of α-particle generated by the reaction of $B^{10}(n, \alpha)Li^7$ is 2.3 Mev. The reaction formula is as follows:

$$_5B^{10} + _0N^1 \rightarrow _3Li^7 + 2H_2^4 + Q$$

$$Q = 2.3 \text{ Mev}$$

where, the kinetic energy of Li is ELi≒1 Mev and that of-α particle is Eα 1.47 Mev. Therefore, the experimental formula expressing the range of α-particle in the general material is $Ra(mg/cm^2) = 0.5R(cm) A^{1/3}$, where Ra is the range at the time of atomic weight A of material a and R is the range of α-particle in air. According to this formula, the range of α-particle in B^{-10} is $Ra = 0.85 mg/cm^2$. Therefore, the thickness of Boron coating should be less than $0.85 mg/cm^2$, so that α-particle can be easily emitted. In the present experiments, however, Al-plate was coated in about $1 mg/cm^2$ thickness in due consideration of the loss of Boron atom during diffusion and the coating amount of B^{10}.

c. Construction of chamber

The plane and cross section of the ionization chamber are as shown in Fig. 4. Table 1 shows the chemical composition of Al-chamber and Al-plate, together with geometrical dimension. The wall thickness of the chamber is 5.5mm and Al-plate is 1mm thick. The range of thermal neutron in Boron is thinner than $4.2 mg/cm^2$ calculated in item 2b above.

Table 1. Chemical composition of Al-Chamber & Al-Plates

Material	Si%	Mg %	Zn %	Mn %	Cu %	Fe %	Al %	Remarks
Al-Chamber	0.60	0.88	0.04	0.20	3.21	0.41	94.66	Domestic
Al-Plates	0.17	0.09	0.03	—	0.005	0.06	99,645	U.S.A.

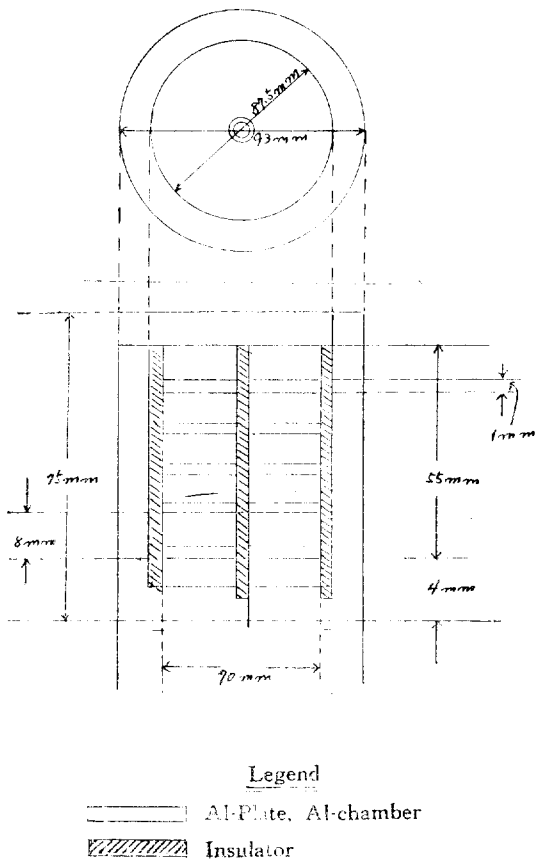

Fig. 4. Geometrical dimension of ionization chamber

Porcelain rod(mulite-structure) was used for the insulation of the supporting bar and static electricity of each plate, so that the leakage current may be maintained to a minimum extent. But the leakage current of the porcelain rod was maintained within the scope of -10^{-12} Amp.

3. Results

3—a. Zero adjust

In order to measure net current or signal output of the chamber due to neutron flux, the temperature of the chamber to Co^{60}(1.17 Mev. 1.33 Mev) 30 curies of the r-ray source was maintained uniformly at 450°C. The saturation current of the 2 volumes of the chamber was measured, result of which is as shown in Fig. 5 below.

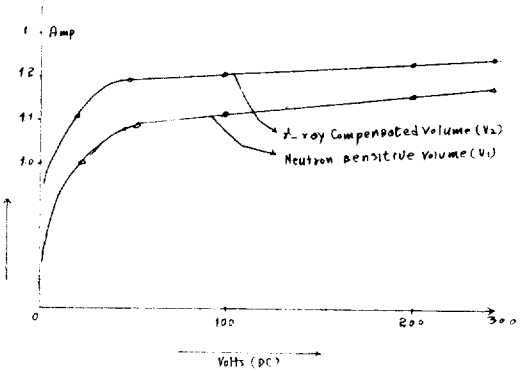

Fig. 5. Voltage vs. current characteristics of each volume

The signal current due to the r-ray compensated volume and the neutron sensitive volume was 1.2×10^{-9} Amp and 1.1×10^{-9}Amp, respectively, at V1=V2=50volts. The two currents reached saturation at 300 volts. The curve of the saturation current due to the two volumes of the chamber was almost coincided with each other in its curvature as Fig. 5 shows. The difference of the saturation current of the two volumes was probably caused by the failure of complete coincidence with each other at the time of manufacturing and assembling the chamber as indicated in item 2(c) above. Therefore, the range of the operating voltage of V1 and V2 of each volume was determined as show in Table 2 below. The operating voltage of the two volumes is also indicated in this table. Within this voltage range the value of V1 and V2 can be obtained at will, and the error of the two curves is 1×10^{-10} Amp at the maximum which can be disregarded in a reactor, an intensive gamma ray, especially in a power reactor.

Table 2. Variable range of operating voltage

Voltage	Voltage Range(Volts)	Error(Amp)
V1	50-300	1×10^{-10}
V2	30-300	1×10^{-10}

3-b. Measurement of thermal neutron

In order to minimize the noise of output signal, this water-tight chamber connected with coaxial cable was placed just above the core of the experimental

reactor of TRIGA MARK-II(thermal power 250KW). The operating voltage of the chamber was fixed at V1=264 volts and V2=60 volts, respectively. The result showed that the signal current of the chamber was zero when the output of the reactor was zero power. The signal curren of the chamber to the thermal neutron was measured after having increased gradually the power up to the full power of 250KW. The thermal neutron flux at the full power was -2.5×10^{-12} on'/cm^2 sec. and the chamber current was 3.4×10^{-6} Amp. Fig. 6 shows the result of this experiment.

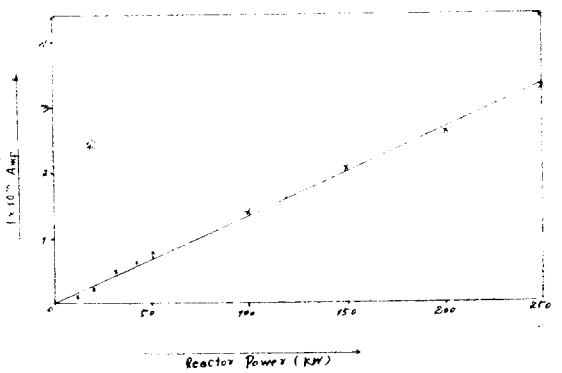

Fig. 6. Reactor power vs. chamber current

The chamber current showed a perfect linear increase to power increase, and therefore it may be seen that the measurement characteristic was satisfactory. However, many variations of the measured current were observed within the power of 50KW.

4. Conclusion

This detector specially designed in order to detect only thermal neutron at a high temperature(—400°C) with compensated gamma ray in a thermal reactor will be able to obtain satisfactory result when it is used as an in-core-monitor above the core. In the present experiments it may be used as an out-core monitor if further improvement is made, especially this detector can be used for high temperature, pressure and neutron flux of the pressurized water reactor(PWR) to be introduced to this country in the near future. The problems to be considered for further improvement of the detector may be described as follows:

4—a. Since aluminum is used for the construction of the chamber, it can not be used if the in-core temperature of PWR is over 500°C. Therefore, a miniature fission chamber (4, 6, 11) of stainless or nimonic tube and a self-powered detector(14) using Rh-103, V-51, Cd, Co-59 as a micro-emitter developed recently are the most suitable detectors for alarming neutron of the in-core.

4—b. In the present experiments the neutron detection efficiency of the detector at the full power of 250KW is as follows:

$$=\frac{Q\cdot I}{W\cdot q}$$

where, $Q=3.2\times10^{-11}$ watt-sec/fission

W=Power, 250KW

$q=2.62\times10^{-15}$ Amp-sec.

I=Chamber current, Amp.

Therefore, $=1,764\times10^{-7}$ valve of which is lower than the efficiency of thermal neutron detection of the normal chamber. The sensitivity $_s$(S) of the present chamber may be expressed in $S=\frac{I}{1.13\times10^{-14}\phi}$ Since $I=3.4\times10^{-6}$ Amp, and $\phi=2.5\times10^{12}$ on'/cm^2—sec., it becomes to be $S=3\times10^{-14}$ Amp/on'/cm^2-sec.

As the resultant value of the above, the reason why the detection efficiency and the sensitivity(S) of the chamber are lower than those of the normal chamber are that; 1) the boric acid powder (B^{10}—18. 1%, B^{11}—81%) which contains a small amount of Boron^{-10} coating material, was used, and therefore the boron used effectively was 18.1% because of the difficulty in obtaining the material of Boron^{-10}; 2) the free air (0_2—20%, N_2—80% etc.) used in the chmber brought about a decrease in the ionization effect. Althouh the measurement efficiency may be enhanced by enclosing a certain amount of gas such as Ar or He which accelerates the ionization effect, it could not be carried out due to technical difficulty; and 3) about 10^{-12} Amp of leakage current runs in the insulation property of the supporting rod used, and therefore the insulator should be good enough to be 10^{-14} Amp or equal. It was also difficult to make available material of the least neutron damage and organic radicactivity.

If these problems are solved it may be considered possible to improve to a great extent the detection efficiency and sensitivity of the chamber. Therefore, the chamber specially designed for the present expe-

riments may be used successfully as a thermal neutron detector under a high temperature and pressure of power reactor, especially it is expected that the chamber will be used as a thermal neutron detector of the out-core.

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