Nuclear reactor power measurement based on ^{17}O (n,p) ^{17}N as a new channel

Somayye Seyfi[1], Morteza Gharib[2]

1. Nuclear Science and Technology Research Institute (NSTRI), P.O. Box 143995-1113, Tehran, Iran
2. Department of Energy and Physics, Amirkabir University of Technology, P.O. Box 15875-4413, Tehran, Iran

Introduction

Tehran research reactor (TRR) is a representative of pool type research reactors using light water, as coolant and moderator. In a typical pool or tank type reactor, neutron-measuring channels are usually comprised of any combination of fission chamber (FC), compensated ionization chamber (CIC), and uncompensated ionization chamber (UIC). These neutron detectors are immersed in water and placed at a close distance around the core, inside the reactor pool or tank. Moreover, in most reactors including TRR, information gathered on reactor power is also checked against calorimetric thermal power. Nevertheless, there are still other methods such as measurement systems using Cherenkov radiation and ^{16}N gamma detection. This reactor is chosen as a prototype to demonstrate and prove the feasibility of ^{17}N detection as a new redundant channel for reactor power measurement.

One of the stable isotopes of oxygen is ^{17}O with abundance of 0.039% in natural oxygen [Bethe, 1974]. ^{17}N radioisotope is produced by ^{17}O (n,p) ^{17}N reaction. This radioisotope decays with a half-life of 4.17s followed by emitting a neutron with most probable energy of about 0.9 MeV. Thus, emitted neutron is considered as a delayed neutron. The real process is as follows:

$n + {}^{17}O \longrightarrow {}^{17}N + p$ (1) $\qquad {}^{17}N \longrightarrow {}^{17}O^{*} + \beta$ (2)

${}^{17}O^{*} \longrightarrow {}^{16}O + n$ (3)

^{17}N production is directly proportional to fast neutron flux. Therefore, reactor power could be derived by measuring delayed neutron population intensity at any fixed point on exit water pipeline. It should be noted that ^{17}O (n,p) ^{17}N reaction has a neutron threshold energy of 8.2 MeV with an average effective cross section of about 2.16E-5 b indicating that only very fast neutrons are capable of inducing such reaction, though very poor. Against all odds, one could still expect to have enough delayed neutron intensity that fulfills measuring purposes. A rough estimation of ^{17}N concentration and its relevant delayed neutron source is to be conducted for the sake of comparison. This requires knowledge of core neutron flux and its fraction above 8.2 MeV energies. Neutron flux within the core is calculated by MCNP code below and above this threshold. Thus, concentration of ^{17}N and its specific activity as well as its subsequent disintegration to neutrons could be estimated. Rough calculation shows that strength of the order of 100 delayed neutrons per second per cm^3 of exit water is to be expected. Considering a value of about 1325 cm^3 for detector effective volume, total number of delayed neutrons reaching BF3 is estimated to be $3*10^5$ neutrons per second. It should be noted that this is a conservative estimate and should be taken as a minimum value. Such preliminary estimations ensure us of having sufficient count rate for the full range of reactor power prior to any experiments.

Methods and Materials

In the present work, a BF3 detector is selected because of its availability as neutron detector and positioned next to 10"outlet water pipeline, which is accessible to operators for all kinds of services known as pit valve (Fig.1). As a preliminary measurement a set of BF3 detector, its associated electronics, and multichannel analyzer system (MCA) are employed. Data given in the next section are taken in this fashion. For BF3 detector the threshold plateau curve, working voltage and dead time were measured. For the measurements, the 20Ci ^{241}Am-Be and 10 mCi^{60}Co sources were employed and a common working voltage of 2200 volts and lower level discriminator of 0.5 volts were used for the detector. All these are arranged so that to exclude gammas from measurements and to ensure just neutrons are counted. As a result, a typical spectrum of BF3 output is gained as shown in Fig.2 in which total area under the curve is a measure of neutrons.

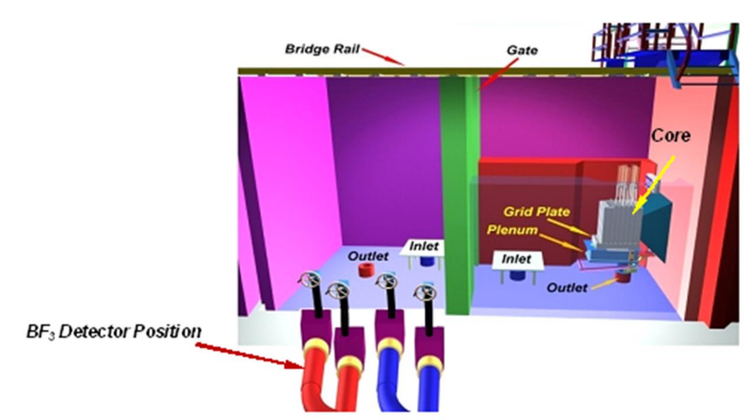

Figure 1. Schematic diagram showing detector position alongside exit water pipeline

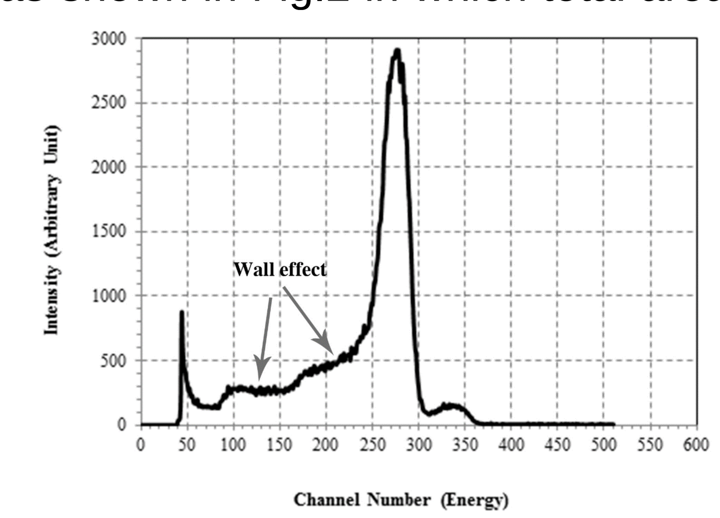

Figure 2. Spectrum of BF_3 counter in TRR at 3600 kW

Results

As for experiment, a set of measurements of neutron intensity are carried out. These measurements are to be compared with reactor power to check if they are linearly correlated. A BF3 counter on exit water pipeline measures neutron intensity in order to be compared with CIC channel, as a measure of true reactor power. For this purpose, a series of tests are conducted during reactor startup in which power is raised systematically. The first step of experiment began at power of 100W and in the next step power increased gradually. On each power level, 200 seconds spent for counting neutrons before proceeding to the next level.

Fig.3 shows variation of ^{17}N activity (i.e. delayed neutron counts) against true reactor power given by CIC channel. As it is observed, a good linearity exists between these two items revealing that, in principle, delayed neutron counting can be used as an independent power channel. A good measuring device, however, should fulfill two extra criteria namely sensitivity and fidelity. Sensitivity is checked to see if delayed neutron count follows the same pattern as true power changes. Fig.4 shows how BF3 detector response follows almost the same proportion as change of power indicated by CIC channel.

Finally, fidelity is also checked to see if systematic increase and decrease in power does not result in an appreciable shift in ^{17}N reading. For this purpose, reactor power is raised from as low as 100 watt to full power and back again and relevant ^{17}N counts are recorded simultaneously. Fig.5 shows that there is a perfect fidelity as far as ^{17}N channel is concerned as a new power-measuring tool.

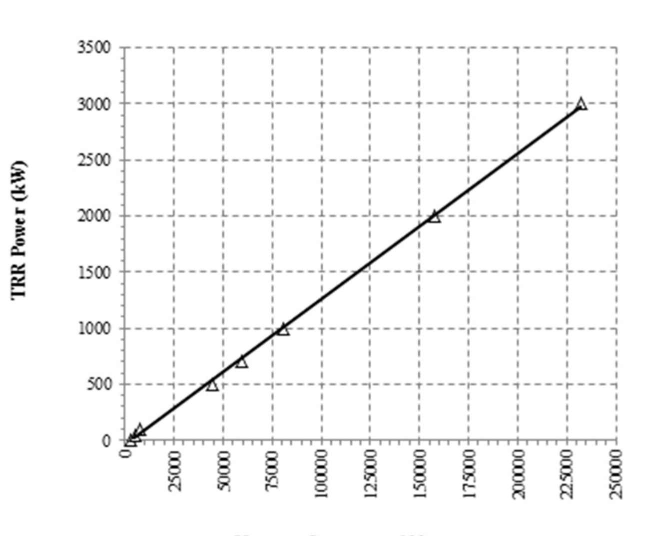

Figure 3.Comparison of BF3 readings versus reactor power (CIC channel).

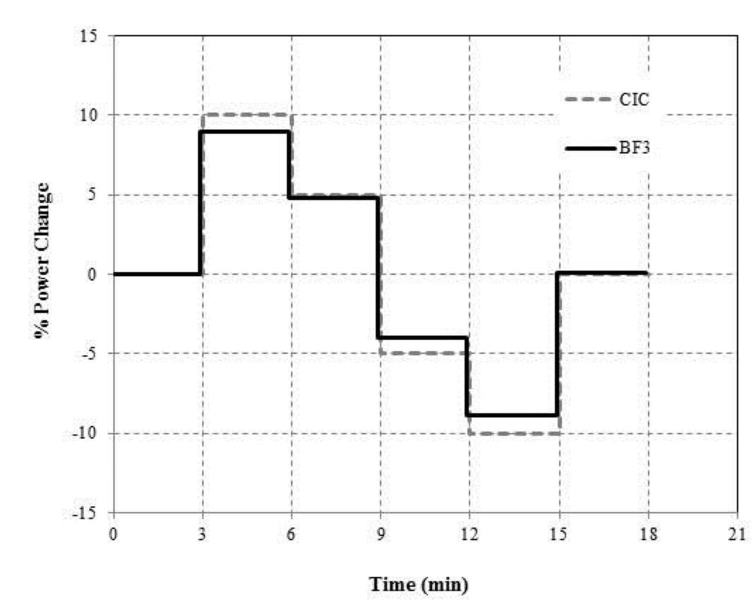

Figure 4. Sensitivity check to see if delayed neutron from ^{17}N measurements follow regular power

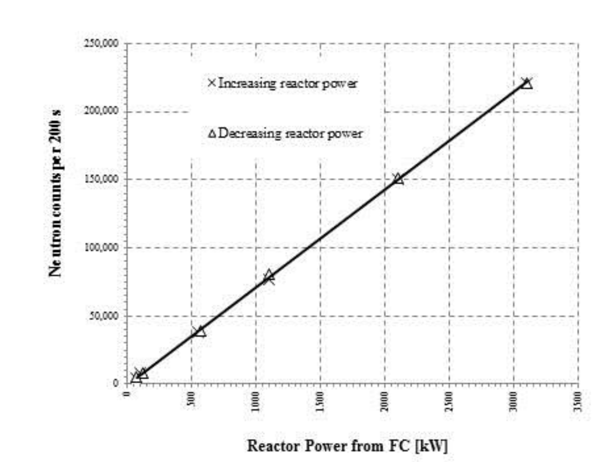

Figure 5. Fidelity experiment showing that delayed neutron measurements fulfill the test the same way as of other regular power indicators.

Discussion and conclusions

In this work, TRR is used to show that delayed neutron emission from ^{17}N disintegration could potentially be used as a basis for a new detection system measuring the reactor power. In practice, a BF3 counter is used as a proper neutron detector and its output handled through PC-assisted boards (AVR) to generate relevant signal proportional to reactor power. LCD display unit in control room (Fig.6) translated signals in terms of kW power as a complementary data to assist operators. As shown in figures, delayed neutron counting is a linear function of reactor power. Therefore, by proper calibration, one can present true reactor power in parallel with other channels.

However, no reliable value expected from low^{17}N rate at low powers. For the present set up, reliable power started from 10 kW power, though a large and more sensitive detector may help to improve this threshold. In brief, experiments showed that, this new detecting system installed on core exit water, could easily employed as an independent power measuring system by detecting and counting delayed neutrons resulting from^{17}N decay. The main advantage of this new channel is its independency, improved redundancy, and diversity. More importantly, the detecting system is out of water in a dry place and it is easily protected from harsh environment next to the core. Thus, it is easily maintained and handled if required. Short half-life (4.17 sec) of ^{17}N is another merit for this system, which allows recording fast transients in real time situations.

Finally, it is worth to note that the same principle discussed above could be applied to other reactor types (light water and heavy water; research or power reactors) as long as exit line of cooling system allows proper detector installation.

Fig6. LCD display unit to present delayed neutron counts in term of kW power of reactor.

Contact Information

Somayye seyfi

Email: s.seyfi7@gmail.com

Phone:+989127306529

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