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High purity germanium detector radioactivity monitoring for defected fuel detection in Indian Pressurized Heavy Water Nuclear Reactors

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ABSTRACT

Operation of Nuclear Reactor with defected fuel can result in excessive radioactive contamination which makes maintenance work around the heat transport equipments, piping and tubing very difficult. Besides, increased release of fission products, in turn, increases the radioactivity levels in various areas of Reactor Building and also the radioactivity discharged to the environment which can affect people and disrupt safety. Presently in the Indian Pressurized Heavy Water Reactors (PHWRs), the presence of failed fuel in the core is detected by offline measurements of I-131 activity in the heat transport system and Delayed Neutron Monitoring System. These systems have limitations of being sample based systems which continuously cannot monitor the increase in radioactivity due to fuel failure. High purity germanium detector monitoring is proposed by me as an introduction of continuous monitoring of fission product activity which will increase the efficacy of the Nuclear Reactors in detection of defected fuel thereby increasing the safety of the plant.

Keywords: *High purity germanium detector, radioactivity, contamination, delayed neutrons and Nuclear Reactors*

1. INTRODUCTION

Safe operation of Nuclear Reactors for generation of electricity is the top most priority as any compromise in the safety can result in release of radioactivity beyond acceptable limits resulting in harm to public, working personal and environment. As can be inferred from several nuclear disasters that have taken place across the globe, the "safety culture" supersedes the commercial production. Failure of nuclear fuel (which is a source of nuclear energy) is one such event which can impede safety and hence needs to be timely detected. [2]

In Indian Standard Nuclear reactors, fuel failure detection and monitoring is currently employed through sample based I-131 detection in the coolant and off-line and manual Delayed Neutron Monitoring System. These systems though help in detection of increase in radioactivity due to fuel failure have their limitations. High purity germanium detector is proposed to correct these limitations providing continuous monitoring of fission product activity resulting from fuel defect and hence is a breakthrough system in improving the overall safety of the plant.

1.1 I-131 Monitoring in failed fuel detection and its limitations

The presence of the failed fuel is indicated by steady increases of the volatile fission product and noble gases in the PHT coolant. The defective fuel pin initially releases the long lived noble gases (especially Xe-133 & Kr-88) and after some deterioration the volatile fission products (like I-131) get released. Once the breach of the fuel cladding occurs, the gaseous fission products &

volatile fission products in the fuel clad gap are reloaded like puff and mixed with the PHT coolant & circulated. Because the fuel is already irradiated, lots of fission gases (long lived and short lived) will remain in the clad and as soon as fuel failure takes place, the gases will come out like “puff” and after that the release will reach a steady state. I-131 is also continuously removed through the purification system. So as the fuel fails, I-131 activity in the PHT coolant reaches to peak and then decreases to a steady state. Presently, I-131 activity analysis is done off-line at the radiochemistry laboratory once per shift (8 hours) by collecting the sample of PHT from the sample collection station. Hence as I-131 & noble gases activities from the failed fuel decay due to delay between collection and detection and with the off-line monitoring, it is not possible to detect the iodine spike. I-131 level exceeding 2-3 micro ci/litre is the probable indication of the presence of failed fuel.

1.2 Delayed Neutron Monitoring System and its limitations

Delayed Neutron System starts when I-131 level exceeds 2-3 micro ci/litre because it might be probable indication of the presence of failed fuel. [3] This system is based on detection of fuel failure by delayed neutron detection with the help of BF3 Counters. The counts of delayed neutrons emitted from the group of fission products (Br-87 and I-137) increase during the fuel failure which is detected by the counters. [3]

- $_{35}Br^{87} \xrightarrow[-1\beta 0]{T_{1/2}=56\ s} {}_{36}Kr^{87} \longrightarrow {}_{36}Kr^{86} + {}_{0}n^{1}$
  (Excited state) (stable) (Delayed Neutron)
- $_{53}I^{137} \xrightarrow[-1\beta 0]{T_{1/2}=22\ s} {}_{54}Xe^{137} \longrightarrow {}_{54}Xe^{136} + {}_{0}n^{1}$
  (Excited state) (stable) (Delayed Neutron)

Where, $T_{1/2}$ denotes half-life. Note that delayed neutrons are not emitted at the moment of fission. Their emission is delayed by the half-life equal to the half-life of their precursors.

Delayed neutron system can work effectively when the delay time of every coolant channel sample is same i.e. 50 sec. If delay time is lesser than 50 sec, the background neutron counts due to tramp uranium, neutrons emitted by N-16 and N-17 (produced in the coolant) will hamper the reading. On the other hand if the delay time is larger than 50 sec then the actual delayed neutron signal becomes too weak for detection. Equalizing delay time of every sample as 50 sec is a huge task because it means that every sample shall have same tubing length up to the detector for the same flow. [1]

1.3 Proposed High purity germanium radioactivity detector On-line system

High purity germanium detector monitoring is the system which continuously monitors the radioactivity in the coolant and alerts the operator automatically when the value exceeds the set limits.
Whenever the fuel failure occurs there is a sudden burst of release of the fission product trapped in the pellets clad interface (gap) into the coolant. Soon the fission product activities release reaches steady state value. The new activity level in the PHT depends on the defect size. As the coolant is at high pressure, D_20 enters into the clad by small amount and as soon as water enters in the clad it vaporizes due to high temperature. In the clad pellets gap, D_20 steam and gaseous and volatile fission product exist. Only small fraction of the fission product will release into the coolant by diffusion process. At the initial period of the clad breach, release rate of the fission products will be high and then it will reach to the steady state value which depends on the size of the defect when the reactor is operating at the steady power level. Fission products from the fuel clad gap can be released forcefully by the power cycling due to water logging effect. Within few minutes of occurrence of the fuel failure, the iodine concentration will reach a slightly higher value than the previous equilibrium value and after that iodine concentration is suppressed by Ion Exchanger column. The gaseous fission product monitoring system monitors four selected isotopes (Xe-135, Xe-133, Kr-88 and I-131) continuously and produces the signal that forms the basis of early warning of the fuel failure.

For monitoring system sample shall be taken from the discharge of the primary circulating pump because at this position complete mixing of the Primary Heat Transport (PHT) coolant takes place. Sample line shall be taken one line from each loop. System shall be designed such that sample from either loop-1, loop-2 or both loops can be monitored at a time. This enables the operator to determine which loops containing defective fuel bundle.

For gamma ray spectrometry, high purity germanium (HPGe) detector shall be selected due to high resolution so that it can separately detect the closely spaced energy emitted by the different fission product. For these types of detectors, cooling is main problem because detector temperature is to be maintained at minus 190 deg. Celsius. Generally, the detector is cooled by liquid nitrogen. HPGe detector with liquid nitrogen refilling frequency once in 1.5 years is available in the market.

1.4 High purity germanium radioactivity detector electronics

Germanium detectors have P-I-N regions where Intrinsic (I) region responds to radioactive radiation, like gamma rays when operated in reverse bias, an electric field reaches the intrinsic or depleted region. Radioactive rays interaction with the depleted region results in production of holes and electrons which are swept by the electric field to the electrodes. The charge, thus produced proportional to the energy of the incoming radiation, is transformed into a voltage pulse by an integral charge-sensitive preamplifier. [4]

Band gap of germanium is low. This requires that there must be provision to cool the detector to limit the thermal generation of charge carriers. This in turn reduces the reverse leakage current which may otherwise result in introduction of large amount of noise affecting the detector's energy resolution. Therefore reactor shall be cooled at the temperature of 77 °K. Block Diagram of the typical detector is shown below in the Figure-1 & 2 where MCA is Multi Channel Analyzer which is used to detect and analyze the spectrum of incoming voltage pulses and HTS is Heat Transport System.

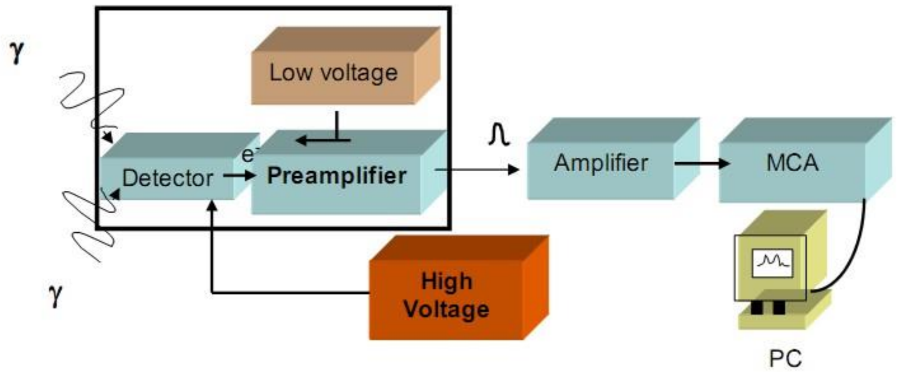

Figure-1 Block Diagram of High purity germanium detector electronics

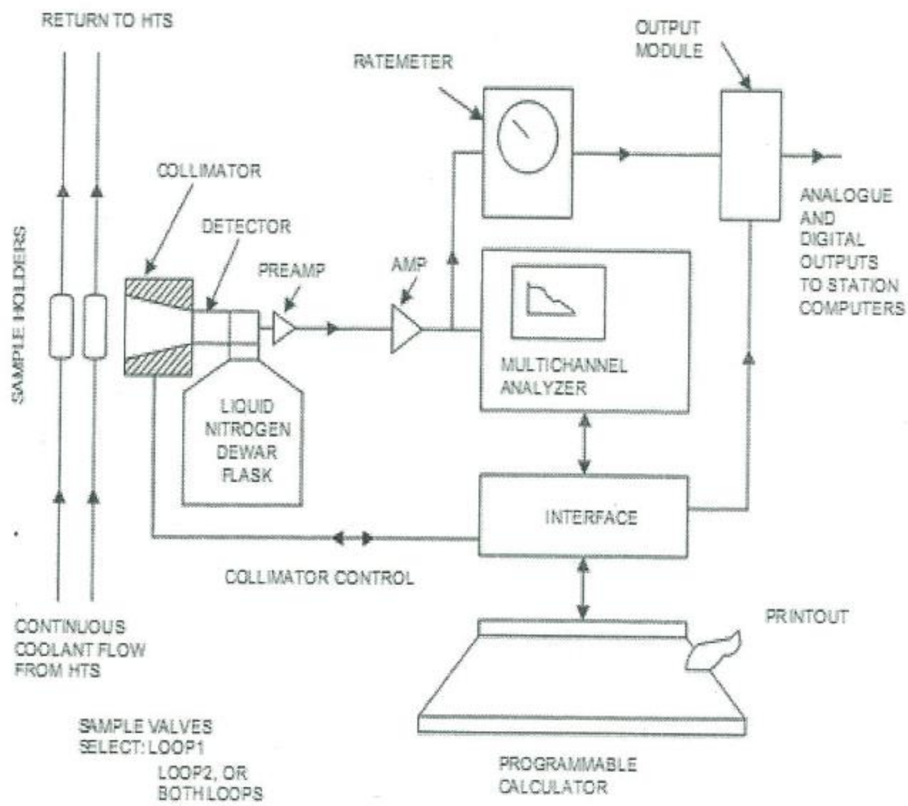

Figure-2 Schematic of the proposed scheme with respect to process connection

1.5 Advantages of High purity germanium radioactivity detector On-line system

1) If High purity germanium detector on-line system is provided, as soon as gaseous fission product activity increases in the coolant, it can be detected and Delayed Neutron Monitoring System scanning can be started to locate channel having failed fuel and failed fuel can be discharged as soon as possible and thus activity level in the primary heat transport system shall be less. The deterioration of fuel can be avoided. Thus fission product activities in the coolant can be maintained within prescribed limits.
2) Every shift (of 8 hours), plant personnel enters reactor building to collect the sample from sample collection station. Plant personnel are exposed to radiation when they enter the reactor building. After gaining sufficient experience of on-line monitoring, operator may not be required to monitor I-131 off-line and need not to enter reactor building in every shift to collect sample. Thus man-rem consumption shall be reduced.
3) If this monitoring system becomes reliable and operator can develop the confidence, then Delayed Neutron Monitoring system shall not be required to operate every day. Delayed Neutron Monitoring system can be operated weekly or biweekly in routine basis or after transient release of noble gases and iodine. Less operation of Delayed Neutron Monitoring system means less loss of heat from core.

2. CONCLUSION

High purity germanium detector on-line system installation in the standard nuclear Pressurized Heavy Water Reactors is very innovative measure and will be very advantageous as not only it will bolster the plant's safety by timely detection of fuel defects or fuel failure but also the reliability by increasing the detection capability with the provision of features like continuous and on-line monitoring.

3. REFERENCES

[1] AERB Safety Guide No. AERB/SG/D-7, Core reactivity control in Pressurized Heavy Water reactor.

[2] Radiological Safety Aspects of the Operation of Neutron Generators, International Atomic Energy Agency (IAEA) Safety Series no.-42

[3] Nuclear Power Cooperation of India Limited, Design Manual of Delayed Neutron Monitoring System for 700MWe reactors.

[4] Knoll, Glenn F., Radiation Detection and Measurement 4th Edition, Wiley, 8/2010. ISBN-13: 978-0470131480.

