A Study of Criticality Alarm Systems in Fuel Reprocessing Plant

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Abstract: Nuclear power plants are essential for the generation electricity to meet the electrical energy demand of the fast developing country like India. Indian nuclear power programme planned with three stage nuclear power programme, based on closed fuel cycle. Reprocessing plants are designed for critically safe operation in handing fissile material by Mass, Volume and Concentration. Criticality Alarm system are important for the prompt detection and alarm for the sake of radiation safety of the plant personnel. Criticality Alarm System (CAS) are mandate for plant's continuous monitoring and their performances are evaluated periodically.

Key Words: Nuclear power programme, reprocessing plants, fissile material, Criticality Alarm system, prompt detection and alarm

1. INTRODUCTION

Indian Nuclear power programs have been started to meet the energy deficiency against the requirements of the county. Indian nuclear programme planned with three stages of nuclear power programme, based on closed fuel cycle.

First Stage of Indian Nuclear program: It has the plan to operate thermal reactors using natural Uranium for producing electricity and Plutonium. Some of the reactors are in use and few more are in construction stage.

Second Stage of Indian Nuclear program: It has the plan to use the Plutonium from first stage of Indian nuclear program in Fast Breeder Reactor (FBRs) to breed more Plutonium from 238U and 233U from Thorium. A Fast Breeder Test Reactor (FBTR) is in operation for gaining experiences and study purposes of FBR technology.
Third Stage of Indian Nuclear program: It has the plan to use of 233U to sustain breeder reactors by converting Thorium to 233U.

2. CLOSED FUEL CYCLE

The fuel cycle is set to be closed if the un-burnt fuel along with plutonium which is produced in the reactor due to nuclear reaction is recovered and reused in the reactor as fuel. Reprocessing of the spent nuclear fuel is essential for the recovery of un-burnt fuel (uranium) and plutonium (which is bred from the fertile 238U nuclide in the reactor) from the fission products and also from minor actinides. These fission products have to be removed to meet the fuel specification and to reduce the shielding requirement for the downstream processing of recovered uranium and plutonium. Reprocessing process depends on the chemical form of the spent fuel (whether metal or oxide or carbide), the burn up and cooling period given to the spent fuel after discharge prior to their processing. This cooling reduces the radioactivity associated with the fuel since the fission products undergo radioactive decay.

3. REPROCESSING SEQUENCE

Purification and separation of uranium and plutonium from the spent fuel has been carried out both by aqueous processes. The step involves chopping and dissolution of the fuel in nitric acid, feed clarification and conditioning of the resulting solution suitable for the subsequent solvent extraction. Pu and U should be in the IV and VI valency states respectively, under these conditions both U and Pu are highly extractable as compared to the fission products. Reconversion is a step in which, the solution containing either uranyl nitrate or plutonium nitrate is precipitated and converted into their respective oxides. Plutonium is precipitated as oxalate using oxalic acid. On calcinations, this precipitate is converted to oxide. U from the uranyl nitrate solution is either directly denitrated or precipitated as ammonium diuranate with ammonium hydroxide which is then calcined, to produce uranium oxide. These oxides are sent for refabrication and conversion to fuels for reuse in the reactor.

4. CRITICALITY SAFETY

The plutonium concentration in thermal reactor spent fuel is 0.3 to 1.5 % of the total heavy metal (uranium and plutonium) while in fast reactor spent fuel it is around 25 to 30%. Due to this higher concentration of plutonium in fast reactor spent fuel, Reprocessing plant for fast reactors need to be designed with criticality safety.

5. RADIOLOGICAL SAFETY

Reprocessing of fast reactor fuel is being carried out inside the Stainless Steel box, which is within lead Containment

Box (CB). Alpha, Beta radiation doses are confined within the CB. The gamma radiation also limited in CB to the extent of 10^5R/hr. CB is maintained in the most negative pressure compared to the operating area, to prevent any contamination. The associated works in processing are carried out in fume hoods and Glow boxes. Radiation works are allowed to work in operation area with Thermo Luminescent Dosimeter (TLD).For the special work in operating areas and for maintenance Radiation Work Permission (RWP) procedure are followed with Electronic Pocket Dosimeters (EPD) which gives alarm when dose exceeds the set limit. Continuous Air Monitor(CAM)s are provided in operating area, Analytical labs, waste fault, etc based on the alpha and beta particle in air concentration for continuous monitoring and for alarm while it exceeds the set limit

6. FIRE SAFETY

Reprocessing plant is designed to operate in fire safe manner. External purging of organ gas provided during the de-cladding operation to prevent fire.

7. SIGNIFICANCE OF CAS IN REPROCESSING

Spent fuel reprocessing plant is proposed to handle spent fuels from Fast Breeder Test Reactor (FBTR) and Prototype Fast Breeder Reactor (PFBR). As the fissile materials are being handled in different forms from decladding stage to waste storage, criticality control at each stage has importance. Criticality safety evaluation for each stage in the process was carried out taking into account of normal and off normal conditions of the various operations in the plant [Ref 1]. However in the operational stage of the plant, it is necessary to install criticality alarm system at specific locations to alert the personnel for rapid evaluation in order to avoid further exposure from criticality event. A detailed calculation which includes gamma dose estimation due to hypothetical criticality event assumed in specific locations inside the process cells were carried out using point kernel code, IGSHIELD to find out the locations where CASs have to be placed in the plant. Prompt gamma energy released during criticality event and it is consider that the total number of fissions as 1.0E+18 fissions for minimum incident of concern for detection [Ref 2].

8. Salient features of CAS

Gamma radiation based CAS, Indigenously designed and developed. It consists of three detector electronics channels and an alarm electronics module [Fig 1]. Each detector is connected its respective electronics channel independently.

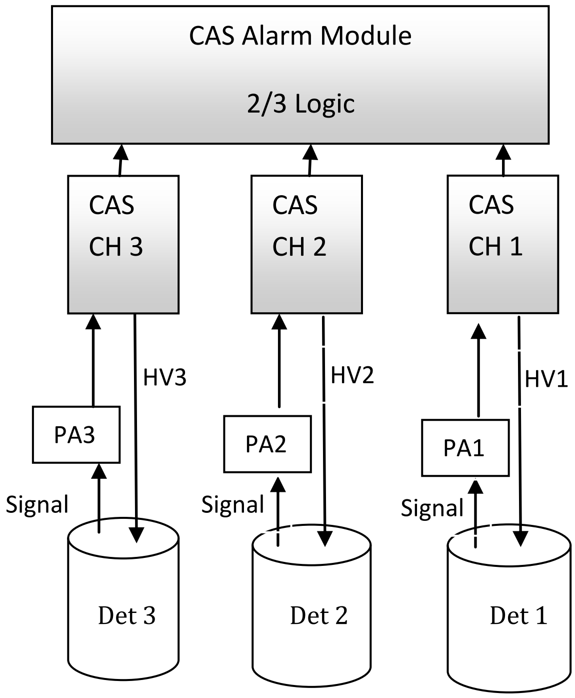

Fig 1: CAS schematic diagram

8.1 CAS Detector: Detector is a cylindrical ion chamber made up of Stainless steel cylinder having the sensitive volume of 300 CC. Argon and Nitrogen gases are filled at the pressure of 12.5 Kg/ cm^2. Operating voltage of the detector is 300 to 1000V DC. Sensitivity of the detector is $3x10^{-10}$ A/R/hr over the range of 0.03 to 14 Mev .Detector electrodes (Anode and Cathode) are being biased by High Voltage (HV). Depending upon the energy deposited by the radiation, respective ions are collected between electrodes contributing a current in the order of nA. Characteristic of detector is shown in fig 2.

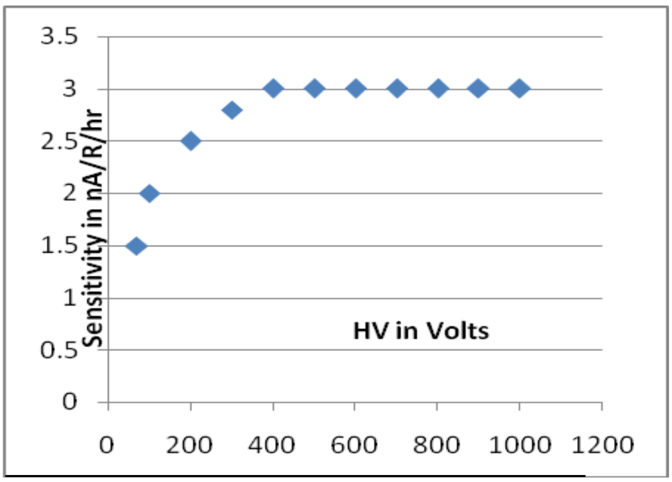

Fig 2 : HV Characteristics of Detector

8.2 Pre Amplifier (PA)

Very high input impedance Field Effect Transistor (FET) amplifier is used as preamplifier to improve the signal to noise ratio. Current from detector passing through a RC circuits where R = 1 GΩ and C = 2.2nF. The output voltage of the amplifier is calculated by the equation (A).

$V(t) = Vo*(1-e^{-(t/\tau)})*G$ ---- (A)

Where t = time in seconds, τ = time constant (RC), R= Resistor in ohms, C = Capacitance in farads and G is gain of the amplifier. Voltage output as per the sensitivity of the detector

Vo = I x R = 3x10^-10 x1x10^9 = 0.3V/R/hr --- (B)

The voltage belong to the alarm set 4R/hr is 1.2V
Dose rate equivalent voltage corresponding to transient alarm 3mR/0.5 sec is 21.6 R/hr. Substituting these vales in (A) gives the Vo as 1.23V which is greater than the alarm set limit (1.2V) ensures the Dose Rate Alarm (DRA)[Ref 2].

Calculating the value of τ from A, by substituting the values gives 446mSec which is less than the 500mSec in transient response ensures the Dose Alarm (DA).

Preamplifier is connected to the CAS channel by a 5 core shielded cable using a Allied connector. The preamplifier circuit is installed in an air tight container to protect the precision circuit and components.

8.3 CAS Channel

There are three channels in a CAS unit. Each channel consists of electronic circuit with the following features of power indicator, HV indicator, and channel alarm indicator, channel normal status indicator, test and reset push buttons. Channel has a analog panel meter with full scale range of 10 R/hr with 200 mR/hr resolution. AC power is being received from CAS bin, rectified, filtered and regulated in the channel to cater the channel battery(Class I) and IC 723 regulator is used to generate 9 V supply for electronic circuits. High voltage is being generated in the channel to bias the detector around 600 VDC. CAS channel generates alarm for dose both dose and dose rate. CAS channel is designed for failsafe operation which gives channel alarm in case of power failure or component failure. Individual electronic channel is provided with class I supply [Ref 3], which shall operate the system around 48 hrs without any other power supply. The power supply is backed up with Class II power supply, Class III power supply and Mains supply (Class IV).

8.4 CAS Alarm Module

The alarms from all the three channels are connected to alarm module by wiring.

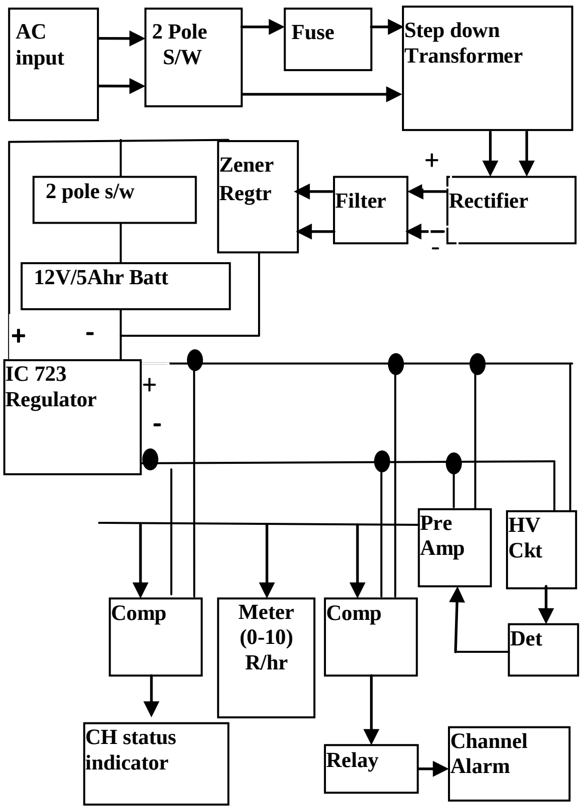

Fig 3: CAS channel block diagram

Fig 4: CAS unit consist of 3 Channels Alarm Module

The alarm module has independent power supply with battery backup, thematically shielded relays are connected to achieve 2/3 voting logic, used for the purpose.

The alarm module generates criticality alarm based on 2/3 voting logic to avoid spurious alarms. Alarm module of CAS is design to operate in failsafe.

8.5 Data acquisition of CAS

Dose Rate of all the three channels and CAS alarm are recorded continuously using a dedicated Radiation Data Acquisition System (RDAS). CAS- RDAS block diagram is shown in Fig 5.This is RS 485 based communication system in which all the CAS units are connected in a network loop. The voltage output from each of the CAS channel is connected to the Analog input of the Intelligent Sensor Module (ISM). CAS alarm of the CAS unit has been connected to the Digital input of the ISM. Criticality Alarm statuses of CAS units are indicated in Control room Annunciations by audio & Visual alarms [Ref 4].

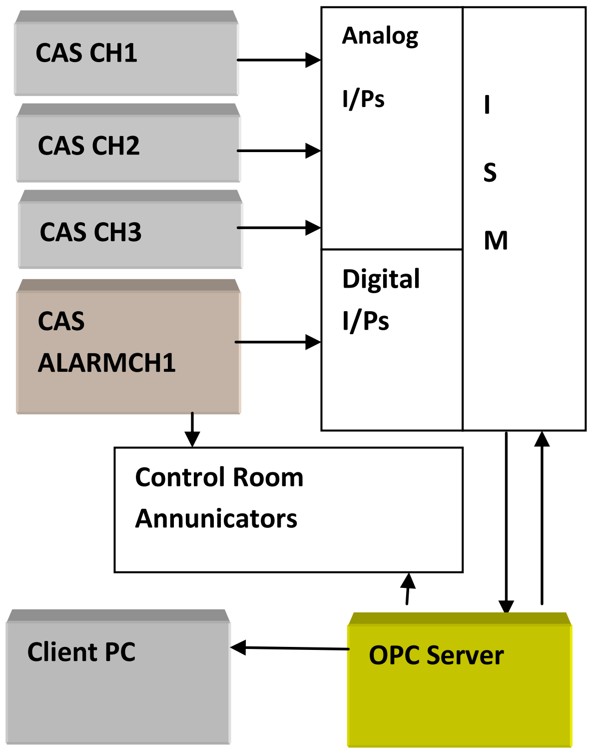

Fig 5 : CAS- RDAS block diagram

9. SUGGESTED IMPROVEMENTS IN THE CAS USED IN REPROCESSING PLANTS.

- Finite Impulse Test facility in individual CAS channels of CAS.
- Single channel alarm annunciation in control room enunciators for individual CAS channels.
- Distinction between Failsafe alarm and CAS Alarm.
- CAS units diverse channel locations and power supply
- Qualification of CAS for site specific Seismic requirements.

10. CONCLUSIONS

The detailed study of CAS has been carried out. The CAS units are meeting the functional requirements. There are scope for improvements which by implementation shall improve the reliability and redundancy.

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BIOGRAPHIES

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