ON-LINE LOW CONCENTRATION STACK ACTIVITY RELEASE MONITORING SYSTEM FOR NUCLEAR REACTORS

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INTRODUCTION

Monitoring of radioactive effluents at Nuclear Installations is extensively reported, detailing aims & designs of Health-Safety Program[1].The references[2,3] describe techniques of Nuclear Data Processing with computer[4] based On-Line monitors.Using these as guidelines and with state-of-the-art technology,a monitoring system is successfully implemented which provides greater functionality,reliability,operator-acceptance and meets the stringent requirements of Health-Physicist & Regulatory Board.Although sophisticated techniques of Nuclear Data Processing & Analysis are used in laboratory instruments,porting these to field instruments calls for special expertise.

SYSTEM CONFIGURATION AND HARDWARE FEATURES

The system consists of main channel and hot standby channel.Each channel comprises of one Air Particulate Beta monitor,one Iodine-131 monitor and one Gross Gamma (mainly Ar^{41}) activity monitor as shown in fig 1. Activity released is measured through detector assemblies consisting of photomultiplier tube and scintillator (plastic for Beta Particulate monitor, NaI(Tl) for Iodine-131 & Gross Gamma monitor) and are shielded by lead rings. Beta and Iodine-131 activity is accumulated on easy to remove and replace filter paper[a] and charcoal cartridge[b] respectively,whereas two litres of chamber surrounding the detector assembly is used for Gross Gamma activity monitor.The direction of flow and position of filter is carefully selected to improve detection sensitivity. The hardware is identical in three monitors. Iodine-131 monitor functions as 128 channnel,16 bit wide Multichannel Analyser performing energy-spectrum processing, while only gross counting is performed in other two monitors.The design of microcomputer is based on popular,8 bit microprocessor with standard VME back plane (single height,six layer,five slots) and plug in EURO boards facilitating ease of testing, and maintenance.A hand held terminal provides user friendly man-machine interface for setting up the important system parameters. Liquid Crystal Display essentially displays the integral release,release rate of the activity in Engineering units.Pulse height spectrum is continuously displayed on CRO, in XY mode,enabling easy calibration and precise marking of Iodine-131 window. Comprehensive report of activity released is made available through printer and the system also annunciates alarms in case the integral release,release rate exceed the set alarm limits. Logarithmic analogue output is provided for remote logging.

SYSTEM SOFTWARE DESIGN FEATURES

System software is designed and developed adopting modular approach for ease of testing and modification. It offers adequate degree of freedom for incorporating advanced statistical & analytical techniques to improve the performance of the system. Integral release and Release rates are computed on the basis of gross counts obtained within a set period of time in Beta Particulate and Gross Gamma monitors, while in Iodine-131 monitor,net peak area under the Iodine-131 peak is used. Intrinsic interference due to the background is minimised in Iodine-131 monitor by incorporating spectrum analysis technique,wherein Trapezoidal Compton background area is determined employing End Point Averaging Technique (EPAT) .Software critically balances the contradictory requirements of fast response time and acceptably good statistical stability along with accurate determination of lower detectable limit of 10^{-11} µCi / ml by automatic selection of optimum acquisition time interval.Additional feature of the software common to all the three monitors is the sliding averaging technique used for providing stable display information of activity release with acceptable time constant and update time. System software also supports interfacing of the monitors to IBM compatible PC,where energy spectrum can be analysed by powerful spectrum analysis techniqes for radioactive isotopes other than Iodine-131.

NET PEAK AREA COMPUTATION

From figure 2, Total peak area and its standard deviation using simple Total Peak Area (TPA) method[5] are computed as

$$\text{Total Peak Area (TPA)} = \sum_{i=K1}^{i=K2} C_i - \{ [(K2 - K1 + 1) / 2] * [C_{K1} + C_{K2}] \} \qquad (1)$$

$$\sigma TPA = \left\{ \sum_{i=K1}^{i=K2} C_i + [(K2 - K1 + 1) / 2]^2 * [C_{K1} + C_{K2}] \right\}^{1/2} \quad (2)$$

Net peak area and its standard deviation using EPAT[3] are computed as

$$\text{Net Peak Area (NPA)} = \sum_{i=K1}^{i=K2} C_i - \left\{ [(K2 - K1 + 1) / 2] * [(B1 / N1) + (B2 / N2)] \right\} \quad (3)$$

$$\sigma NPA = \left\{ \sum_{i=K1}^{i=K2} C_i + [(K2 - K1 + 1) / 2]^2 * [(B1 / N1^2) + (B2 / N2^2)] \right\}^{1/2} \quad (4)$$

Where C_i is the counts of i^{th} channel

K1, K2 are cursor locations at left and right valley point of Iodine-131 peak, respectively

$\sum_{i=K1}^{i=K2} C_i$ is the Gross Area (GA) under the Iodine-131 peak

$[(K2 - K1 + 1) / 2] * [C_{K1} + C_{K2}]$ is the Trapezoidal Compton background Area (TA)

$[(K2 - K1 + 1) / 2] * [(B1 / N1) + (B2 / N2)]$ is TA using EPAT

B1 is the sum of counts over N1 channels including K1 and B2 is the sum of counts over N2 channels including K2. As seen from equations (2) and (4) EPAT gives considerable improvement in standard deviation than simple TPA method. An improvement of 22 % in standrad deviation was observed in the actual system by keeping N1 = 2 and N2 = 4 while the maximum difference in the value of net peak area, computed by two methods, was 6% only, which is acceptable. As EPAT and TPA methods assume linear background under the Iodine-131 peak, it may introduce error due to non linearity of compton background caused by presence of high energy isotopes. This error may be reduced by using Step Pedestal[4] or Quadratic Baseline interploation method for estimating the compton background under such conditions.

AUTOMATIC SELECTION OF OPTIMUM ACQUISITION TIME INTERVAL

Criteria[6] used for selecting new acquistion time interval aims at maintaining the Fractional Standard Deviation (FSD) constant throughout the monitoring range of the system. New acqusition time interval is estimated as : Let PA1 be the current peak area obtained after subtracting Trapezoidal Compton background Area (TA1) from Gross Area (GA1) under the Iodine-131 peak with acquisition time interval of T1. Let T2 be the optimum acquisition time interval for achieving the desired FSD_d, then peak area PA2 and its Variance will be as follows :

$PA2 = GA2 - TA2$ and $\sigma^2 PA2 = GA2 + [(K2 - K1 + 1) / 2]^2 * [(B1' / N1^2) + (B2' / N2^2)]$

But $GA2 = (T2 / T1) * GA1$, $B1' = (T2 / T1) * B1$, $B2' = (T2 / T1) * B2$ & $PA2 = (T2 / T1) * (GA1 - TA1)$

$\therefore \sigma^2 PA2 = \{ T2 / T1 \} * \{ GA1 + [(K2 - K1 + 1) / 2]^2 * [(B1 / N1^2) + (B2 / N2^2)] \}$

And $\sigma^2 PA2 / PA2^2 = (FSD_d)^2 = (T1 / T2) * (FSD_o)^2$ Where $(FSD_o)^2 = \sigma^2 PA1 / PA1^2$

i.e $(FSD_o)^2 = \{ GA1 + [(K2 - K1 + 1) / 2]^2 * [(B1 / N1^2) + (B2 / N2^2)] \} / \{ GA1 - TA1 \}^2$

$$\text{OR} \quad T2 = (FSD_o / FSD_d)^2 * T1 \quad (5)$$

Equation (5) gives the optimum acquisition time interval for the FSD desired. Figure 3 shows the estimated absolute fluctuations in computed activity release through stack as a function of activity accumulated on charcoal filter, for fixed FSD of 1 % and variable acquisition time interval as predicted by equation (5). The graph indicates that though response time improves with increase in accumulated activity , the absolute statistical fluctuations in estimated integral release also increase, thereby worsening the minimum detectable limit. Thus in the adopted fixed filter scheme, either for loaded or fresh filter paper / charcoal cartridge, sufficiently large counting times are required. Based on these findings, system was tested with various large counting time intervals, results of which are plotted in figure 3. The results clearly point out that counting time of 60 minutes as the optimum fixed counting time resulting in acceptable statistical performance for measuring low concentration release rates (50μCi / day or 10^{-11} μCi / ml). Large counting time is also necessary for applying decay correction.

SYSTEM CALIBRATION

Iodine-131 deposited on the charcoal layer closest to the detector, makes maximum contribution to the counts accumulated, while contribution due to subsequent layers of charcoal goes on reducing. Since effective depth of

charcoal for accumulating Iodine-131 is estimated to be 5 mm, a calibrated Iodine-131 source on filter paper was moved away from detector surface by 5 mm in steps of 1 mm and the average efficiency computed was found to be 10.32 %. Another important parameter is the effect of interference due to Gamma background.This was estimated by placing a Co^{60} source of 47 nCi (corresponding to $Argon^{41}$ release rate of 700 Ci / day) along with 3.75 nCi of Iodine-131 source and error due to interfering background was observed to be of the order of 20 %.System minimum detectable limit was determined using Iodine-131 source of 40 pCi under the clean background conditions with acquisition time interval of 60 minutes and it was found to be 60 µCi / day. Similar calibration of Air Particulate Beta monitor was performed using $Strontium^{90}$ & other Beta sources,deposited on filter paper,giving an average efiiciency of 20 %.The detector sensitivity of Gross Gamma monitor was determined by measuring the countrate from chamber filled with calibrated Ar^{41} sample and was found to be 1cps / pCi / ml.

CONCLUSION

Low concentration stack activity releases of 50 µCi / day were measured with the system installed at nuclear power plants in India.For composite Beta-Gamma detection using phoswich detector and simultaneous processing of multiple peaks,the eight bit microprocessor design can be easily upgraded to advanced 16 / 32 bit processor design.A networking configuration using network controller board on the same VME back plane can be provided.

FIGURES

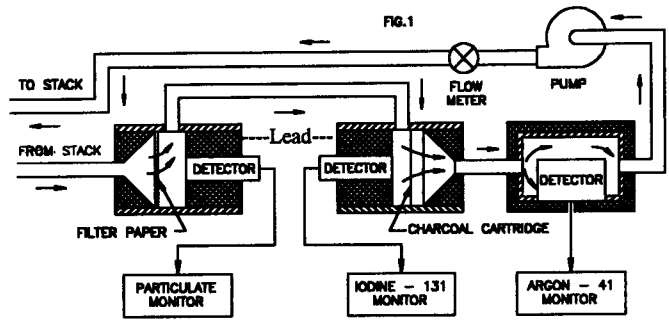

Figure 1

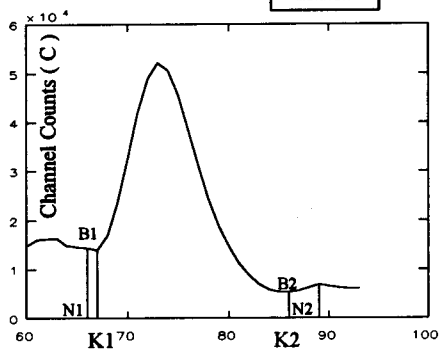

Figure 2 Channel Number (K)

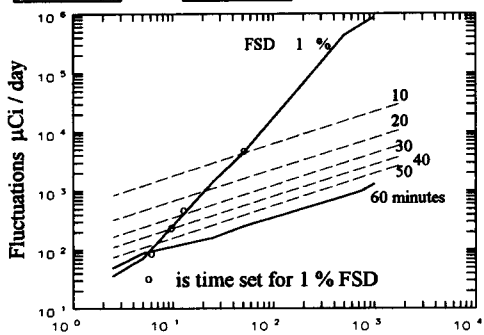

Figure 3 Filter Activity nCi

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3. Instruments Catalogue, Edition nine, Canberra Nuclear, Canberra Industries Inc. Meriden, CT 06450.
4. Terry C. Chapman, *IEEE Transactions on Nuclear Science* Vol 35, No 1, Feb 1988, pp 556 - 558
5. L. Kokta, *Nuclear Instruments and Methods*, 112 (1973), pp 245 - 251
6. Gary T. Alley , Martin L. Bauer *IEEE Transactions on Nuclear Science* Vol 35, No 1, Feb 1988, pp 559 - 561

a *A 50 mm diameter,1 micron pore size,Millipore cellulose fibre fixed filter*

b *12217 filter cartridge of Merlin Gerin ,57.7mm diameter, 26.8mm height consists of vegetable charcoal (coconut shell) impregnated with TEDA (Triethylene diamine) encapsulated in thermoplastic material*