Development of a microcontroller based monitor for measurement of tritium in heavy water

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Abstract
A microcontroller based instrument for measurement of tritium in heavy water at concentration equal to or more than hundred milli-curie per litre is described. The tritium monitor has been designed using plastic scintillation film in a perspex cell and two photomultiplier tubes (PMTs) working in coincidence mode. The scintillation cell with coincidence electronics has a discrimination capability and enables to detect tritium in the presence of external gamma radiation. The monitor characteristics measured with tritiated water are presented. Sensitivity of the system is ~460 CPS/Ci/litre under normal background level of 10-20 µR/hr.

Introduction:
All Indian operating Nuclear Power Plants (except TAPS 1&2) are based on natural uranium as fuel and heavy water (deuterium) as moderator and coolant. The most important radiological concern in these Pressurized Heavy Water Reactors (PHWR) is tritium. During reactor operation deuterium is activated by fission neutron to form tritium. Tritium decays into helium, emitting a soft $\beta$-radiation ($E_{\text{max}} \approx 18$ keV) with a radiological half life of 12.3 years. The tritium concentration in heavy water increases continuously (due to long half-life) and does not attain equilibrium even after longed reactor operation. Instances of spillage/leakage of the heavy water from primary or secondary loops are quite possible during reactor maintenance operation. These leakages may lead to high derived air concentration (DAC) levels in work areas which may lead to cordonning the area for quite some until DAC levels fall below acceptable limits. The dose from tritium is mainly due to inhalation and skin absorption. For continued operation of the reactors, tritium has to be extracted from heavy water or tritiated heavy water should be replaced by virgin heavy water. The tritium monitor described here can be used in heavy water upgradation plants to continuously monitor tritium concentration in feed and product heavy water within reasonable period of time.

Detector unit:
Thin plastic scintillator film ($\approx 70 \, \mu$m) of $\sim 1$ cm$^2$ area is embedded on one side of a perspex disc which was enclosed inside a water tight stainless steel body with inlet and outlet nozzle for flow of the sample liquid. On either side of the cell is optically coupled with high gain photomultiplier tubes (PMT) as shown in Fig.1. The cell can hold approximately 15cc of liquid. The complete detector assembly i.e two PMTs, flow cell, preamplifier are housed in light tight chamber. Care is taken to withstand minor vibrations by proper anchoring of all sub assemblies. Both PMTs are coupled to perspex windows of the cell with optical grease for proper light transmission.

Electronic Assembly:
In case of soft beta emitters like tritium betas, the light emitted from the scintillator will be very low. To detect these low intensity light flashes, two inch diameter bi-alkali low dark current PMTs were selected. These PMTs are in coincidence mode operation to enhance signal to noise ratio and to minimize the background pulses. The electronic modules used for amplification, pulse shaping and discrimination of the detector signal are shown in fig. 2.

The electronic system provides coincidence outputs in two channels. The lower channel (CH1) covers the
counts due to pulses from a maximum of 18 keV beta energy absorption i.e. includes all pulses due to tritium beta. The upper channel (CH2) covers pulses from beta energies greater than 18 keV and also due to gamma background. However higher beta energy also partly contributes in lower channel (CH1). This technique not only yields very low background levels, but also provides good gamma rejection. The counting system consists of a HV unit, amplifier & coincidence logic board and a microcontroller board (89LV55 based) with user friendly counting software features. The instrument can be set in count rate mode or normal counting mode. All counting parameters and the calendar can be set by the hex keypad. After every measurement cycle the software applies the calibration factor to the background corrected average count rate in the tritium channel and displays the activity in millicurie/litre. The instrument has the following features:

1. 2 line x 16 character LCD display on the front panel
2. Tactile HEX keypad
3. Facility to enter counting parameters and data through a menu driven software
4. Non volatile memory-EEPROM for data storage
5. Real Time Clock with battery backup
6. Audio and visual alarm provision
7. RS232 serial interface
8. 4-20 mA current loop for remote display.

**Instrument calibration:**

An in-house designed calibration setup consisting of leak tight sample container, flow rate meter, stop cock and collecting vessel was arranged to get a sample flow rate of 40 cc/min to 100 cc/min flowing under gravity through the detector assembly. A continuous sample flow of 70 cc/min was adjusted and measurements were recorded at 2, 5, 10 and 15 minute sampling intervals. Background measurement is done by circulating distilled water through the detector flow cell. Lead shielding can be used around the detector to reduce the ambient background radiation level. The detector was operated without shielding in our laboratory under normal gamma radiation level and the recorded background count rate is ~0.5 CPS. The sensitivity for measuring tritium is a function of the efficiency, the background and the counting time. The sensitivity of the instrument was determined by diluting tritiated heavy water of 4Ci/l concentration for different tritium concentrations i.e. 100 mCi/l to 3.8 Ci/l and by comparing the monitor output with the concentrations determined by liquid scintillation counting (LSS) techniques of our laboratory. After each measurement, the flow cell was flushed with distilled water to wash out any tritium residue. The time required to flush the scintillator cell was also recorded. The sample line was sampled for 15 minutes so that the effect of residual activity from the previous line is minimized. After passing the detector cell with high activity tritiated water solution, the observed increase in the background count rate due to memory effect is within acceptable limit corresponding to the range of measurement. The system stability and reproducibility were checked by repeated recirculation of tritiated water solution through the detector system. The results of the testing of instrument are presented in Table 1. In Fig. 3 as shown in graph the measured count rate in tritium channel is within ±5 % in 100 mCi/L – 4 Ci/L range and the linearity of the instrument is found to be within ±10% full scale.

**Table 1: Instrument response to estimated activity**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Tritium Conc. in heavy water (mCi/l)</th>
<th>Monitor Display (mCi/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>109</td>
<td>109.2 ± 2</td>
</tr>
<tr>
<td>2.</td>
<td>545</td>
<td>529 ± 7</td>
</tr>
<tr>
<td>3.</td>
<td>1088</td>
<td>1087 ± 22</td>
</tr>
<tr>
<td>4.</td>
<td>2520</td>
<td>2548 ± 62</td>
</tr>
<tr>
<td>5.</td>
<td>3800</td>
<td>3886 ± 96</td>
</tr>
</tbody>
</table>

![Fig. 2: Block Diagram of Tritium-In-Heavy Water Monitor](image-url)
Conclusions:
The measured and calculated sensitivity of the instrument is in agreement with each other within the statistical limits under ambient background of 10-20 µR/hr for sample flow rate in the range 40 to 100 cc/min. The instrument was calibrated and can be used for monitoring the tritium concentration in heavy water in the range 100mCi/l to 4 Ci/l. Plastic scintillation detector is suited for monitoring tritium in heavy water. Different measurement ranges of the system can be obtained using a scintillation cell with appropriate detector thickness and surface area. At present, the study of the possibility of interference due to presence of other radionuclides in heavy water with the scintillation monitor described is in progress.

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References