A NEW METHOD FOR D_2O TO H_2O LEAK DETECTION AND IDENTIFICATION OF LEAKY HEAT EXCHANGER IN THE PHWR BY CHERENKOV PHOTON COUNTING TECHNIQUE

by

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Scientific paper
http://doi.org/10.2298/NTRP180606012D

In pressurized heavy water reactors, leaks from D_2O primary coolant and moderator to H_2O secondary coolant and other light-water systems in heat exchangers cannot be completely ruled out. High cost of D_2O demands that its loss should be prevented to maximum extent possible. Traditionally D_2O leak detection and identification of leaky heat exchanger is carried out by measurement of tritium activity in H_2O. Since tritium emits low energy beta radiation, its concentration in H_2O is measured by mixing it with liquid scintillation solution in a definite proportion in counting vial and counted in a Liquid Scintillation Analyzer. It is very sensitive method for leak detection, but identification of leaky heat exchanger is time consuming and may require low power operation or reactor shut down. In the new method, high energy beta emitting fission products, which emit Cherenkov photons in H_2O, were used as the tracer. H_2O was poured in 20 mL plastic vials without scintillator and counted on Liquid Scintillation Analyzer. D_2O leak was identified by comparing the Cherenkov photon count rate with that of the blank. A discrimination ratio significantly higher than average Cherenkov photon count rate for all heat exchangers was used to identify the leaky one. The technique has advantageous over existing method of D_2O leak detection, such as, (1) scintillation chemicals are not required (2) low power operation or reactor shut down is not required for identifying the leaky heat exchanger (3) no generation of radioactive chemical waste (4) on-power leak identification reduces generation of radioactive liquid waste. .

Key words: pressurized heavy water reactor, D_2O to H_2O leak, Cherenkov photon counting

INTRODUCTION

In pressurized heavy water reactor (PHWR) natural uranium is fuel and D_2O is used as primary coolant and moderator. D_2O flows inside the pressure tubes (PT) containing fuel bundles. Primary heat transport (PHT) system transports heat generated in reactor core to steam generators (SG), where light water boils-off in secondary side to generate steam for the turbine. D_2O after releasing heat in SG returns back to other half of reactor channels through centrifugal pumps. A simplified flow diagram of PHWR is given in fig. 1 [1]. To ensure adequate safety of PHWR, ultimate heat sink (UHS) and associated residual heat removal systems are in place to transport residual heat loads from reactor core, safety-related structures, sys-

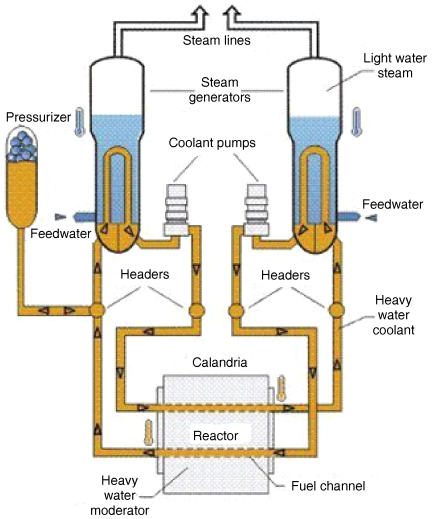

Figure 1. PHWR simplified flow diagram

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tems and components and spent fuel storage bay. Heat transport systems associated with UHS consist of heat exchangers (HX) which provide cooling to PHT shutdown cooling system pumps, moderator pumps, PHT bleed coolers, PHT main pump gland and motors, PHT shutdown coolers, moderator coolers *etc*. These HX are of shell and tube design, in which D_2O flow inside the tube and H_2O flow in shell side. The H_2O flowing in secondary side of HX is called active process water (APW). The process water cooling system (PWCS) remove heat from APW through process water heat exchangers and dissipate the heat to UHS *i. e*. to atmosphere or large water body [2]. Cooled APW is collected in a common storage tank and circulated in closed loop.

In fresh D_2O, tritium activity is negligible. Because of very high neutron flux in nuclear reactor, deuterium in D_2O is converted to tritium by neutron capture. Therefore, with passage of time, tritium activity concentration in D_2O increases. In addition volatile fission products (FP) such as isotopes of iodine and noble gases released from failed fuel are also observed in primary coolant. Since primary coolant being at high temperature and pressure, instances of D_2O to H_2O leak in HX cannot be completely ruled out. Besides having economic implications, D_2O leak also pose health hazard due to presence of tritium, other activation products and FP present in it. All possible measures are to be adopted to ensure normal and healthy functioning of the plant to comply with regulatory release limits [3].

Detection of chronic low level D_2O to H_2O leaks in HX is carried out by measurement of tritium activity level in H_2O by real-time tritium-in-water monitor and periodical manual sampling and analysis by liquid scintillation counting technique. In the former, the H_2O sample from HX outlet is passed through plastic scintillator film packed flow cell. Two photomultiplier tubes (PMT) are optically coupled on either face of flow cell and tritium measurement is done in coincidence mode. Operating experience shows that as sample is passed through flow cell, impurities and particulate substance in sample get trapped in plastic sponge detector. This results in reduced transparency of detector with time during online monitoring, thus affecting sensitivity. This demands frequent replacement of detector and therefore maintenance of the system is difficult. Later method is very sensitive for the leak detection. As D_2O ingress progresses tritium activity builds up in H_2O, which is flowing in closed loop system. This increased background activity makes it difficult to identify leaky HX by measurement of tritium activity level in individual HX outlet during reactor operation. Identification of leaky HX may require isolating one of them at a time, sampling outlets of the individual HX and measurement of tritium activity. Identification of defective HX by this method would require low power operation or reactor shutdown.

A simple and fast method of D_2O to H_2O leak detection and identification of leaky HX during steady state operation of reactor by Cherenkov photon counting the H_2O in liquid scintillation analyzer (LSA) is investigated. It makes use of the short lived FP in H_2O, which emit high energy beta radiations, in place of tritium as the tracer for leak detection. High energy beta emitters in water produce light scintillations called Cherenkov radiation. Cherenkov radiation is induced when charged particle move through dielectric medium faster than velocity of light. The minimum electron energy, called the Cherenkov threshold energy, necessary for production of Cherenkov radiation is related to particle relative phase velocity (β) and refractive index (n) of the transparent medium, as delineated in eq. (1)

$$\beta \quad \frac{1}{n} \tag{1}$$

For the relativistic equations, β is related to the kinetic energy (E) of the electron, by eq. (2)

$$E\,[\mathrm{keV}] \quad mc^2 \; \frac{1}{\sqrt{(1 \quad \beta^2)}} \quad 1\,; \quad mc^2 \quad 511\,\mathrm{keV} \tag{2}$$

Equation (2) indicates a threshold energy required for the production of Cherenkov radiation by electrons. In water with a refractive index of 1.332 is used as Cherenkov radiator, β is 0.7508 according to eq. (1), and thus it is possible to measure Cherenkov radiation over 264 keV according to eq. (2) [4]. From beta particle energy 264 keV Cherenkov photon output increases rapidly with energy up to about 2 MeV, but further increases in energy results in smaller proportionate increases in light output [5]. ^{90}Y is prolific producer of Cherenkov light, due to its higher mean beta energy. Majority of ^{90}Sr will not produce Cherenkov light since their energy will be below the ~250 keV thresholds [6]. For a perfect geometry of two-photomultiplier measuring chamber and mean quantum efficiency of 20 %, theoretical counting efficiency is calculated as 72 % for ^{89}Sr and 85 % for ^{90}Y [7]. Mean beta energies of these isotopes are 587 keV and 933.6 keV respectively [8].

Short lived isotopes of iodine (^{132}I, ^{133}I, ^{134}I, ^{135}I) are observed in significant quantities in primary coolant during steady state operation of reactor. Mean beta energy of these isotopes is 470, 405, 620, and 335 keV respectively [8]. Among them ^{134}I is a prolific producer of Cherenkov radiation in water due to its high mean beta energy emission. Hence Cherenkov photon counting technique of the H_2O can be made use of for D_2O to H_2O leak detection in HX. Since the ^{134}I ($T_{½}$= 52.5 min) concentration reach equilibrium very early in closed loop APW system in comparison with tritium ($T_{½}$=12.3 years) activity, the results would facilitate to identify leaky HX. The details of the D_2O to H_2O leak detection and identification of leaky HX by

Cerenkov photon counting technique is explained in this paper.

METHODS AND PROCEDURES

This study involved (1) evaluation of the feasibility of using LSA for Cherenkov photon counting, (2) measurements of Tritium activity concentration in H_2O samples from process water HX outlets to detect D_2O leak (3) estimation of FP activity concentration in D_2O sample collected from primary coolant during reactor operation using high purity germanium detector based gamma spectrometer to investigate source of these radio isotopes and (4) Cherenkov photon counting of the H_2O samples from HX outlets to detect D_2O leak and identify the leaky HX. The present study was carried out at 220 MWe PHWR, Kaiga Generating Station, Unit-3&4, India. The details of the instruments used and methodology adopted for the measurement are presented in the following:

Instrumentation

A Perkin Elmer Tri-carb 2900TR LSA was used to estimate tritium activity and Cherenkov photon count rate of samples. This system consists of two diametrically opposed bi-alkali PMT housed in a 2" thick lead shield to reduce background. The signals after initial processing are subjected to a coincidence circuit having a resolving time of 20 ns and passed into analogue to digital converter (ADC). ADC has a conversion gain of 4K channel which is pre-calibrated to 0.5 keV per channel.

A high purity germanium detector of coaxial type (Canberra Eurysis, EGPC 15-1.80) coupled to a PC-aided 16K MCA and InterWinner 4.1 software (Canberra Eurysis, IW.1) is used for gamma spectrometric analysis of primary coolant samples. Efficiency calibration of detector was performed by using ^{137}Ba, ^{137}Cs, and ^{60}Co liquid standard radioactive source (Board of Radiation and Isotope Technology, BRIT, Mumbai) of activity 9.2, 14.9, and 5.6 Bq respectively.

Performance evaluation of Tri-carb 2900TR LSA for Cherenkov photon counting

Performance of the LSA for Cerenkov photon counting was carried out by estimating Figure of Merit (FOM) of the system. FOM is a measure of effectiveness of counting system in presence of background, and is a parameter to be evaluated for optimization of the sample counting conditions. Blank samples were prepared by dispensing de-mineralized water in fresh plastic counting vials. Pulse height originating from Cerenkov radiation in water does not exceed the equivalent of ~ 50keV for pulse height spectra calibrated on energy scale. Hence energy region 0-50 keV was selected to include all pulse heights originating from Cerenkov effect [9]. The counting time was 1hour. Counting efficiency for high energy beta emitters was determined using ^{90}Sr-^{90}Y calibrated liquid standard with specific activity 1.85 $BqmL^{-1}$ supplied by BRIT, Mumbai. Counting efficiency (η) of Cerenkov photon counting for ^{90}Sr-^{90}Y liquid source in water was determined for sample volumes from 5-20 mL using following eq. (3)

$$\eta \quad \frac{N_t \quad B}{AV_{\mathrm{ml}}} \tag{3}$$

and the FOM, is determined using eq. (4)

$$FOM \quad \frac{\eta^2}{B} \tag{4}$$

where N_t is the total counting rate, B – the background counting rate, A – the specific activity in $BqmL^{-1}$, and V_{mL} – the volume of ^{90}Sr -^{90}Y standard solution in the counting vial.

Isotopic analysis of primary coolant D_2O

The D_2O sample was collected from the primary coolant sampling station while the reactor was under the steady state operating condition. The isotopic analysis of the primary coolant sample was done by counting 5 mL of the sample in a plastic vial on the HPGe detector, mentioned in the previous section, which is calibrated for the same geometry. The decay correction for the delay in the sample collection and the analysis are incorporated by the option available in the Inter Winner software.

Measurement of Cherenkov photon count rate in primary coolant D_2O

The 5 ml of D_2O sample was dispensed in a plastic counting vial and counted in the LSA without adding the scintillation solution and the count rate was noted. The counting time was 1 min. The measurement of the Cherenkov photon count rate was repeated with the time delay and the results were noted. The primary coolant water sample was diluted 10^2, 10^3, 10^5, and 10^6 times and 5-20 ml of the aliquot of easc diluted sample was subjecrted to the Cherenkov counting.

Tritium activity concentration measurement in H_2O samples from HX outlets

The H_2O samples from various HX outlets were collected in the fresh polythene bottles. The 1 mL

aliquot of the sample was dispensed with 5 mL of liquid scintillator solution in the counting vial and the Tritium activity was measured in LSA in a direct DPM mode [10].

Measurement of Cherenkov photon count rate in H_2O from HX outlets

The H_2O samples from various HX outlets were collected in the polythene bottles and poured into the 20 mL plastic counting vials and counted in the LSA for one minute. The Cherenkov photon count rate was noted during the suspected D_2O leak in HX.

RESULTS AND DISCUSSION

Cherenkov photon counting performance of tri-carb 2900TR LSA

The pPerformance of Tri-carb 2900TR LSA for Cherenkov photon counting was evaluated using standard source of ^{90}Sr-^{90}Y (in liquid form), which is a high energy beta emitter. Background count rate for blank samples, counting efficiency and FOM of LSA for ^{90}Sr-^{90}Y liquid standard with 5, 10, 15, and 20 mL sample in plastic counting vial is given in tab. 1. The results show that background count rate is in the range of 13.3-13.6 counts per min. (cpm) for blank sample volume of 5, 10, 15, and 20 mL. Cherenkov photon counting efficiency is maximum for 10 mL standard (35.4 %) and it reduces for higher or lower volume of standard in the counting vial. Gunther *et al*. [11], reported Cherenkov photon counting efficiencies of ^{90}Sr, ^{89}Sr, and ^{90}Y as <2 %, (24 1) %, and (39 2) % respectively for aqueous solutions poured in 20mL glass vials without scintillator and counted on liquid scintillation counters of the type Perkin Elmer 3170 TR/SL for 600 min. [11].

FOM is minimum for 5 mL sample volume (86.5) and maximum for 10 mL (94.2) sample. Minimum detectable activity (MDA) was estimated in units of $BqmL^{-1}$ using equation adopted by ANSI (1996)

$$MDA \quad \frac{3 \quad 4.65\sqrt{\frac{R_B}{t_B}}}{\eta V} \qquad (5)$$

where R_B is the background count rate, t_B – the background counting time, η – the counting efficiency in the percentage and V – the sample volume in mL [9] and the results are given in tab. 1. The MDA are 0.12 Bq mL^{-1} and 0.03 $BqmL^{-1}$ for 5 and 20 mL sample, respectively. Hence, the sample volume was set as 5 mL for counting the D_2O samples as they contain high specific activity radioactive materials. On the other hand sample volume was set as 20 mL for counting low active and diluted primary coolant D_2O samples and H_2O samples from various HX outlets.

Cherenkov photon counting of primary coolant D_2O samples

A typical pulse height spectrum due to Cerenkov photons from primary coolant D_2O sample obtained from Packard Tri-carb-2900TR LSA is given in fig. 2. The pulse height varies from 0 to 50 keV. Cerenkov photon count rate obtained for 5 mL of primary coolant samples is given in tab. 2, column 13. Result of Cerenkov CPM observed for diluted primary coolant sample (diluted by 10^2, 10^3, 10^5, and 10^6 times) is shown in fig. 3. The count rate approached background level for sample which is diluted to more than 10^5 times. For 10^5 dilutions, the observed counts are 3, 5 and 10 times the background CPM for sample volume of 5, 10, and 20 mL respectively. H_2O flow rates through various HX employed in reactor are 2-600 m^3h^{-1}. Estimated D_2O leak rate to reach this level of dilution in secondary side with above flow rate is 0.02-6 kgh^{-1}. Hence it is implicit that the results of Cerenkov photon counting of H_2O samples from HX outlet would indicate D_2O to H_2O leak since similar level of dilution is expected in chronic low level D_2O leaks in HX.

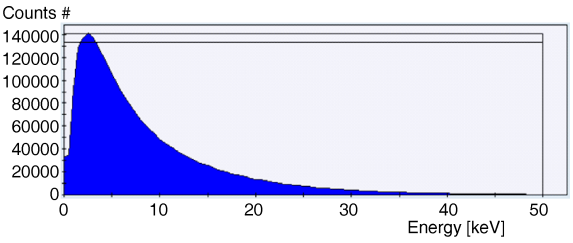

Figure 2. Pulse height spectrum produced by the Cherenkov photons from a sample of the primary coolant D_2O seen on the computer monitor of the Packard Tri- carb-2900TR LSA

Table 1. The Cherenkov photon counting performance of the Tri-carb 2900TR LSA

Sample volume [mL]	Background (cpm)	Efficiency (η %)	FOM = $(\eta\ \%)^2/B$	MDA [$BqmL^{-1}$]
5	13.6 0.5	34.3 0.24	86.5	0.12
10	13.3 0.6	35.4 0.20	94.2	0.06
15	13.3 0.5	35.0 0.30	92.1	0.04
20	13.3 0.6	34.1 0.24	87.4	0.03

Table 2. Iodine and the noble gas concentration in the primary coolant and the Cherenkov photon count rate during the steady-state operation of Kaiga reactor

Sample number	Fission product activity [MBqL^{-1}]											Cherenkov cpm
	^{85M}Kr	^{87}Kr	^{88}Kr	^{131}I	^{132}I	^{133}I	^{134}I	^{135}I	^{133}Xe	^{133m}Xe	^{135}Xe	
1	0.12	0.05	0.19	0.23	0.88	0.71	0.43	1.06	8.49	0.22	1.19	6.4 10^5
2	0.10	0.57	0.16	0.17	0.94	0.61	0.73	1.02	7.48	0.16	1.11	6.7 10^5
3	0.21	0.16	0.29	0.21	0.47	0.61	0.95	0.92	10.83	0.21	1.46	9.8 10^5
4	0.21	0.16	0.29	0.21	1.00	0.71	0.68	1.14	13.31	0.40	1.21	7.9 10^5
5	0.13	0.15	0.38	0.34	1.73	0.83	2.13	1.36	6.85	0.13	1.18	7.9 10^5
6	0.21	0.12	0.30	0.24	0.85	0.54	0.53	0.97	18.06	0.57	2.30	7.6 10^5
7	0.20	0.22	0.31	0.24	1.34	0.66	1.57	1.21	15.80	0.19	1.97	6.6 10^5
8	0.13	0.07	0.21	0.15	1.01	0.55	0.65	0.95	9.50	0.15	1.28	8.7 10^5
9	0.12	0.10	0.23	0.14	1.25	0.56	1.50	1.08	7.88	0.18	1.23	9.4 10^5
10	0.16	1.23	0.30	0.19	1.19	0.68	1.21	1.27	7.84	0.14	1.61	1.03 10^6
11	0.11	0.07	0.21	0.21	1.20	0.77	0.83	1.33	7.39	0.19	1.35	8.8 10^5
12	0.10	0.04	0.17	0.19	0.93	0.60	0.51	1.02	6.28	0.10	1.14	9.6 10^5

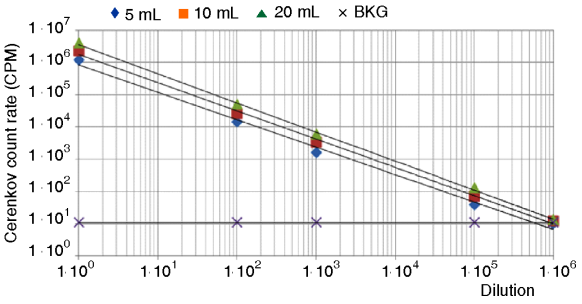

Figure 3. The Cherenkov photon count rate (cpm) with the primary coolant D_2O sample for different dilutions

Sources of FP in primary coolant D_2O

Iodine and noble gas concentration measured by gamma spectrometry of primary coolant samples during steady state operation of Kaiga Unit-3 is given in tab. 2, columns 2-12. The fission product data is given in tab. 3. Volatile FP (iodine and noble gases) can be released from uranium dioxide fuel into the free void space within the fuel element via solid–state lattice diffusion. FPs that is released into the gap will migrate towards the defect site of failed fuel elements, where they are released into reactor coolant. Uranium contamination resulting from a previous fuel loss from defected fuel elements, or from fuel manufacturing process itself, can lead to additional activity in PHT system when this contamination is deposited on in-core surfaces. FP due to uranium contamination will get released into coolant directly [12].

The mass balance for fission product inventory N_i (atom) released into primary coolant for isotope *i* and losses due to radioactive decay and coolant purification is given by the eq. 6

$$\frac{dN_i}{dt} \quad R_i \quad (\lambda \quad \beta_p)N_i \tag{6}$$

where β_p is the coolant purification rate constant (s^{-1}) and R_i is total release rate in to coolant from defective fuel and uranium contamination [12]. One can distinguish releases between defective fuel and uranium contamination by analysis of coolant activity during steady state operation of the reactor and generating a plot of the release to birth ratio (R/B) of measured iodine isotopes against their decay constants. This plot is generated by measuring coolant activity for each isotope and dividing this by its fission yield fraction to provide an effective R/B [13]. The plot generated with measured coolant iodine activity for Kaiga Unit-4 is

Table 3. Isotopic fission product data for the Iodine and the noble gases [8, 12]

Sample number	Radio nuclide	Decay constant λ [s^{-1}]	Fission product yield ^{235}U(10^{-2} atoms per fission)	Energy and intensity of beta radiations	
				Mean energy [keV]	Total intensity [%]
1	^{131}I	9.98E-07	2.88	181.9	100
2	^{132}I	8.37E-05	4.30	470	12.5
3	^{133}I	9.26E-06	6.70	405	100
4	^{134}I	2.20E-04	7.71	620	101
5	^{135}I	2.91E-05	6.30	335	100.3
6	^{85m}Kr	4.30E-05	1.30	280	78.3
7	^{87}Kr	1.52E-04	2.52	1330	100
8	^{88}Kr	6.78E-05	3.55	360	101
9	^{133m}Xe	3.66E-06	0.019	–	–
10	^{133}Xe	1.53E-06	6.70	100	99
11	^{135}Xe	2.12E-05	6.54	307	100

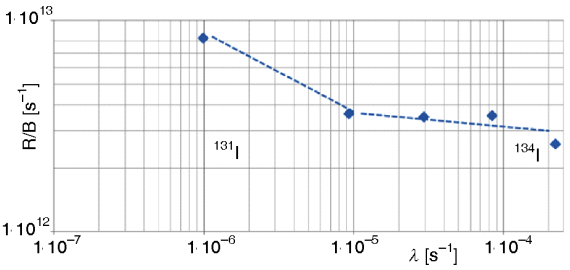

Figure 4. Curve of the R/B value for the radio iodines in the primary coolant D_2O *vs.* λ

shown in fig. 4. The isotopes, ^{131}I and ^{133}I show an exponential dependence on the decay constant (from defective fuel release) while a flat slope for the short lived isotopes (^{132}I, ^{134}I, and ^{135}I) indicates presence of uranium contamination. ^{131}I has long half-life and is therefore the predominant isotope with a large diffusional release. On the other hand, short-lived ^{134}I will decay before it is released from defective fuel element. Consequently these two isotopes can be used to distinguish defective fuel vs. uranium contamination contribution [12]. From fig. 4, normalized release rate (R/B) for ^{134}I is 1.2 10^{12}, and estimated amount of uranium contamination is 3.2 gm (in-core) yielded by equating R/B with normalized production rate N_f $_f\varphi$ [14], where is nuclear number density of ^{235}U; is fission cross-section for ^{235}U[15] and φ is neutron flux [16]. Uranium contamination within the core, particularly on pressure tube surfaces, act as a continuous long term source of dissolved fission products in primary coolant [17].

Iodine and noble gas activity concentration in primary coolant sample and results of the repeat counting of sample with time delay is plotted in fig. 5. Decay curves plotted for each isotope indicates that activity is reducing in accordance with their radioactive half lives – *e.* g., in the decay plot for ^{134}I, activity reduces from 1.93 $MBqL^{-1}$ to 0.1 $MBqL^{-1}$ within a time period of about 240 min, which is in agreement with the half life of this radioisotope, 52.5 min. In the figure, slope of the plot for Cherenkov photon count rate measured simultaneously closely follows decay curve of ^{134}I activity and it reduced to half of its initial value within 70 min. This indicates that among all the FP ^{134}I contributed significantly to Cherenkov photon counts for its higher concentration and Cherenkov photon yield in water, due to higher mean beta energy emission (intensity) 620 keV (101 %) [8]. Other short lived isotopes of iodine (^{132}I, ^{133}I, and ^{135}I), despite their significant concentration in primary coolant do not contribute significantly to Cherenkov counts because mean beta energy of these isotopes are low (tab. 3) and hence photon yield of these isotopes in water will be less. Among the FP noble gases, ^{133}Xe, despite its large concentration in primary coolant, contribute very less to Cherenkov photon counts since it emits low energy beta particles of mean energy (intensity) 100 keV (99 %), the energy which is far below the Cherenkov threshold.

The D_2O to H_2O leak detection and the identification of leaky HX by the Cherenkov photon counting

The D_2O to H_2O leak in HX would lead to gradual buildup of tritium activity in H_2O. Periodic sampling and analysis of H_2O for presence of tritium activity provides backup monitoring of any leakages in HX tubes during periods when the on-line monitors are inoperable / ineffective. Various HXs from samples are collected for leak detection includes shutdown cooling system pumps (SD/P 1-2), PHT bleed coolers (BCD) , PHT main pump gland and motors (PCPG/C 1-4), PHT

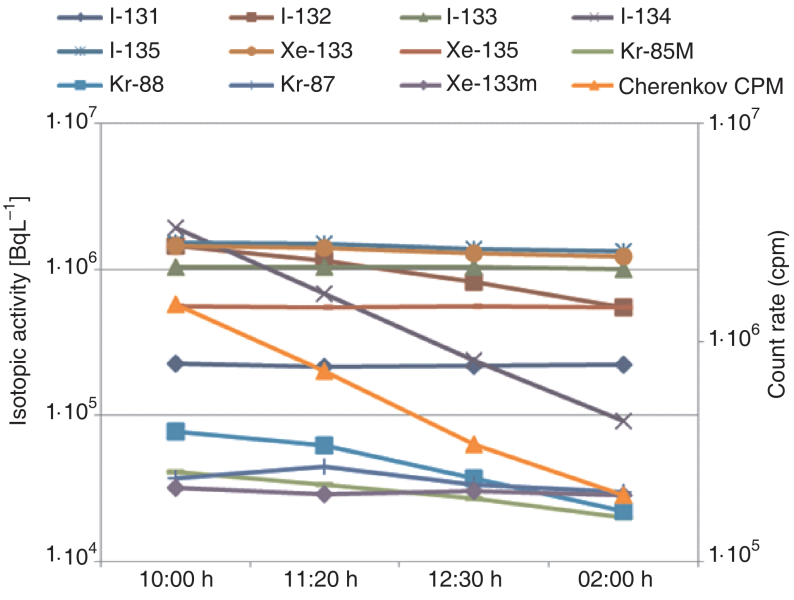

Figure 5. Isotopic activity and the Cherenkov photon count rate (cpm) for 5 mL primary coolant D_2O *vs.* time

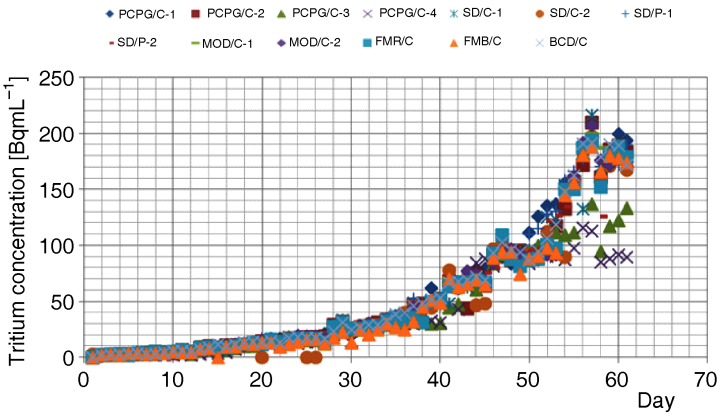

Figure 6. Tritium buildup in the H_2O sample from various HX outlets

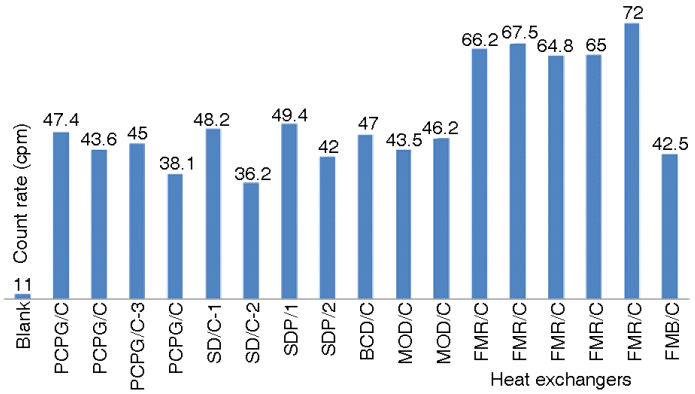

Figure 7. The Cherenkov photon count rate (cpm) of the H_2O samples from various HX outlets during the D_2O leak

shutdown coolers (SD/C 1-2), moderator coolers (MOD/C 1-2), fueling machine return cooler (FMR/C), fueling machine bypass cooler (FMB/C) *etc*. Tritium activity observed in the H_2O from various HX during a period of time in during reactor operation is shown in fig. 6. The figure shows that there is no increase in tritium concentration in H_2O during the initial days. Subsequently tritium concentration increases and reaches ~ 200 $BqmL^{-1}$ within a period of seven weeks. It clearly indicates D_2O to H_2O leak from HX. For arresting leak, it is required to identify the leaky one. But tritium activity is comparable in more than one HX samples and hence it is difficult to identify the HX, which has developed leak. This is due to the fact that as D_2O ingress progresses tritium activity builds up in H_2O, which is flowing in closed loop APW system and hence background activity increases till steady state condition is reached. For a particular leak rate, it will take about 130 days to reach the equilibrium concentration of tritium activity in the APW inventory of 500 m^3 with makeup rate for loses, 440 Lh^{-1}.

When tritium concentration in HX out let samples were ~200 $BqmL^{-1}$, results of Cherenkov photon counting of HX outlet H_2O samples are given in fig. 7. Cherenkov photon count rate for all HX outlet samples are more than three times the blank (11CPM), which clearly indicates D_2O leak from HX. Once D_2O leak started from a HX the "background" counts in H_2O increases and reaches equilibrium very early (<5 h) as the Cherenkov photon counts are contributed essentially by ^{134}I. Therefore H_2O from leaky HX is expected to exhibit count rate significantly higher than that of background level. Leaky HX is identified on the basis of ratio of their signal to background or Discrimination Ratio (DR) [18]. If DR corresponds to a particular HX sample is significantly higher (about 30 %) than the average Cherenkov photon count rate for all other HX, it is an indication of D_2O leak from the HX.

Let Cherenkov photon count rate for a single HX is S and average Cherenkov photon count rate for all HX is A. S is normalized to A and is expressed as

$$DR \quad \frac{S}{A} \tag{7}$$

From fig. 7, the range of Cherenkov photon count rate for various HX is 36.2-72.0 cpm. Count rate for FMR/C sample is showing higher value for repeat samples with an average of 61.7 cpm (S). Average count rate for all other HX is 50.6 (A). Substituting for S and A in eq. (6)

$$DR = 1.32$$

i. e. Cherenkov photon count rate of FMR/C sample is 30 % higher than average Cherenkov photon count rate for all other HX. It indicated that D_2O leak was from this particular HX. ^{134}I concentration in primary coolant was 4.5 $MBqL^{-1}$ during this period and heavy water leak rate was 2.2 kgh^{-1}. The same HX was iden-

tified as the leaky one by the traditional method of D_2O leak detection.

CONCLUSION

A new methodology of Cerenkov photon counting technique of H_2O, the secondary coolant, could be successfully employed to detect the D_2O to H_2O leak in heat exchanger and identify leaky one during steady state operation of PHWR. Presence of fission products in H_2O was sensed by Cerenkov photon counting technique for the leak detection. A discrimination ratio significantly higher than the mean count rate for all heat exchangers was used to identify the leaky one. Non use chemicals and identification of leaky heat exchanger during full power operation of the plant makes the new method environmentally benign, saves economy and reduce generation of radioactive liquid waste in comparison with traditional method of identification of leak by measurement of tritium by liquid scintillation analysis.

ACKNOWLEDGEMENT

The authors would like to thank Dr. K. S. Pradeep Kumar, Associated Director, H S & E Group, BARC, for his guidance and keen interest in this work. Authors are thankful to Shri. Sanjay Kumar S., Site Director, Kaiga site, Shri J. R. Deshpande, Station Director, Shri D. D. Jain, Chief Superintendent and Shri Ashok Bhatia, Technical Services Superintendent, Kaiga Generating station 3&4 for their advice and support for this study. Authors are thankful to Dr. Ashok Kumar P., R. S. S. D., BARC for his valuable suggestions, discussions and encouragement. Authors are thankful to all officials of Health Physics Unit, KGS 3&4 and Environment Survey Laboratory, Kaiga site for their support and encouragement.

AUTHORS' CONTRIBUTIONS

D. Blangat conceived, performed gamma spectrometry, Cherenkov photon counting and wrote the paper. S. Managanvi carried out tritium measurements. R. P. Mana, K. Nerugundi and R. M. Tripathi made valuable contributions in various phases of this work. All authors extensively interacted, exchanging ideas, especially during the preparation of manuscript.

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Received on June 6, 2018
Accepted on October 15, 2018

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НОВА МЕТОДА ЗА ОДРЕЂИВАЊЕ ЦУРЕЊА ИЗ ТЕШКЕ У ОБИЧНУ ВОДУ И ИДЕНТИФИКАЦИЈУ ПРОПУСТЉИВОГ ИЗМЕЊИВАЧА ТОПЛОТЕ У PHWR РЕАКТОРУ ПРИМЕНОМ ТЕХНИКЕ БРОЈАЊА ЧЕРЕНКОВИХ ФОТОНА

Код реактора са тешком водом под притиском цурење из D_2O примарног система хлађења и модератора у H_2O секундарни систем хлађења и друге лаководне системе у измењивачима топлоте не може бити у потпуности искључено. Висока цена D_2O захтева да његов губитак буде сведен на минимлани могући ниво. Традиционално, детекција цурења D_2O и идентификација пропустљивости измењивача топлоте обавља се мерењима активности трицијума у H_2O. Пошто трицијум емитује нискоенергестко бета зрачење, његова концентрација у H_2O мери се мешањем са раствором течног сцинтилатора у коначном односу у епрувети и бројањем течним сцинтилационим бројачем. Ово је веома осетљива метода за детекцију цурења, али је идентификација пропустљивог измењивача топлоте временски захтеван посао и може условити и рад реактора на ниској снази или његово гашење. У новој методи, фисиони продукти који су извор високоенергетског бета зрачења и који емитују Черенкове фотоне у H_2O, искоришћени су као трагачи. H_2O је сипана у пластичне епрувете запремине 20 mL без раствора сцинтилатора и извршено је бројање течним сцинтилационим бројачем. Цурење D_2O идентификовано је поређењем одброја Черенкових фотона са бланко одбројем. Дискриминациони ниво, знатно виши него средњи одброј Черенкових фотона за све измењиваче топлоте, успостављен је и искоришћен за идентификацију пропустљивог измењивача топлоте. Предности ова методе над постојећим методама су: (1) сцинтилационе хемикалије нису потребне, (2) за идентификацију пропустљивог измењивача топлоте није потребан рад рекатора на ниској снази нити његово гашење, (3) нема стварања радиоактивног хемијског отпада и (4) идентификација цурења у току рада реактора смањује генерисање течног радиоактивног отпада.

Кључне речи: реактор са тешком водом под притиском, цурење D_2O *у* H_2O*, бројање Черенкових фотона*