Discriminating Tritium Monitor
For
The Tritium Removal Facility
At
Darlington Nuclear Generating Station

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Abstract

In CANDU reactors, deuterium (heavy water) is used as a moderator and also as the primary heat transport from the nuclear fuel. In time, tritium is formed by neutron capture by the deuterium, producing a mixture of tritiated deuterium. If left to accumulate, the tritium oxide would become a hazard to operating staff, and to the public via emissions through the ventilation stacks, should any leak occurs from the heat transport system, or from the moderator system. The subsequent fluid evaporation from any spill or leak would give rise to airborne hazards due to the presence of tritium oxide in vapor form.

The purpose of the Tritium Removal Facility (TRF), located at the Darlington Nuclear Generating Station Fig.1, is to reduce the tritium concentration in the heavy water moderator. A low concentration of tritium is desirable, as it would significantly reduce the tritium occupational exposures and any environmental emissions during the life of the station.

In the TRF building, there are large inventories of elemental tritium gas as well as in the tritium oxide form. Since the latter is the greater hazard from a health physics point of view, it is used for reporting purposes, hence higher levels are usually, but unnecessarily, reported if all tritium emissions were reported as Tritium Oxide.

A Discriminating Tritium Monitor, described in this paper, was designed to discriminate between the two tritium species and would allow for a more accurate means of reporting exposures and doses.

Fig. 1 Darlington Nuclear Generating Station with Tritium Removal Facility (View from South)

Fig. 2 The Tritium Removal Facility

Introduction

The heavy water in the operating nuclear reactors is sampled on a regular basis, and quantities are drawn and transported to the Tritium Removal Facility (TRF) Fig. 2, for upgrading, i.e. for removing the Tritium component, then recycling the heavy water back into the reactors.

As part of the removal process, Fig.3, the tritium becomes present in both the oxide and elemental form, and substantial inventories are generated. These become a radiological hazard whenever a pathway for release occurs, e.g. from leaks, component failures, and from possible spills. Due to the above, the following are required:

1. To remove the Tritium, in whatever form from the heavy water - hence the TRF was built.
2. The monitoring of Tritium is mandatory.
3. The reporting of Tritium emissions is mandatory.

To prevent the over-reporting of Tritium emissions, a Discriminating Tritium Monitor was designed and placed in service.

Characteristics of Tritium

Tritium is the third isotope of Hydrogen with a single electron orbiting the nucleus of one proton and 2 neutrons.

Tritium is weakly radioactive and has the following characteristics:

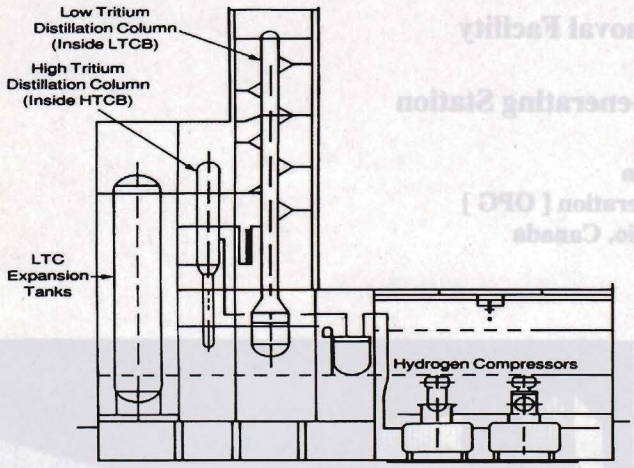

Fig. 3 The Heavy Water Management section of the Tritium Removal Facility

- Half Life 12.33 years
- Biological Half Life ~ 2 weeks within the human body
- Energy Level 18.6 keV, 5.6 keV mean energy
- Activity 355.94×10^{12} Bq.gm^{-1} [9620 Ci.gm^{-1}]
  802.70×10^{12} Bq.ml^{-1} [21695 Ci.ml^{-1}]

- It decays by ejecting its electron to form ^{3}He which is a stable element
- Chemically, it is indistinguishable from Hydrogen, or from Deuterium
- It is produced in CANDU heavy water reactors as an unwanted by-product
- It is also produced in trace amounts in the upper atmosphere by cosmic reactions
- And also found in water at very low concentrations

Tritium (Oxides) Levels at OPG Nuclear Plants

The extraction process in the TRF reduces the Tritium levels in the heavy water brought in for upgrading and can produce a heavy water purity of > 99.9% which is then introduced into the reactor moderator and heat transport systems. Neutron capture is on-going during reactor operation and on average, the tritium accumulation can be:

- Within the Moderator ~3.7×10^{11} Bq.kg^{-1} [~ 10 Ci.kg^{-1}]

The Licensing Limit for the Moderator is
7.4×10^{11} Bq.kg^{-1} [20 Ci.kg^{-1}]

- Within Heat Transport System for Darlington Station
~5.5×10^{10} Bq.kg^{-1} [~ 1.5 Ci.kg^{-1}]

The Tritium Oxide levels for the Heat Transport System are site specific and there is no licensing limit.

Dose Impact of Elemental Tritium versus Tritium Oxide

The significance of the radiological hazard of tritium is dependent on its chemical form. At the Darlington Nuclear Generating Station, the Maximum Permissible Concentrations in air (MPCa's) for a 40 h week are:

- Tritium Oxide 3.7×10^{5} Bq.m^{-3} [10 µCi.m^{-3}]
- Elemental Tritium 74000×10^{5} Bq.m^{-3} [200,000 µCi.m^{-3}]

i.e. a ratio of 20,000:1; the greater impact comes from the oxide form.

The above MPCa's for Darlington come from ICRP Publication 72, 1996 [Ref. 2] where the Inhalation Dose Coefficient is:

- Tritiated water 100 % deposit
- Elemental Hydrogen 0.01 % deposit

Where the ratio is 10,000:1

The Derived Emission Limits [DEL's] for Darlington are set at:

Tritium Oxide [HTO] 8.73×10^{14} Bq.wk^{-1} [2.36×10^{4} Ci.wk^{-1}]
Tritium (HT) 8.88×10^{15} Bq.wk^{-1} [2.40×10^{5} Ci.wk^{-1}]

Where more HT than HTO is produced by a factor of ~10.

Therefore, reporting all Tritium as oxides is grossly inflating the probable dosages. The Discriminating Tritium Monitor was designed to alleviate the problem of over-reporting.

The Discriminating Tritium Monitor [DTM]

The DTM was designed to be an on-line instrument to detect the releases of Elemental Tritium gas and Tritium Oxide, separately and in real time. It is able to distinguish between the two species and hence enable the correct reporting of emitted releases, and therefore public dosages, to the environment. The DTM, Fig.4, comprises a Sampling System, The Detectors, Data Handling, and the Display.

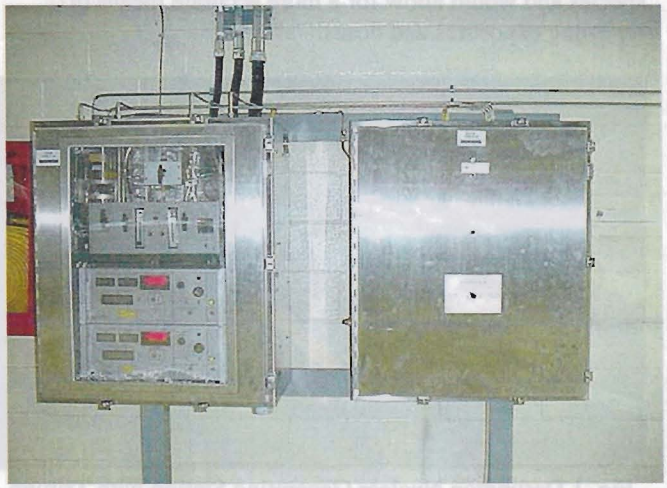

Fig. 4 The Discriminating Tritium Monitor with Dryer

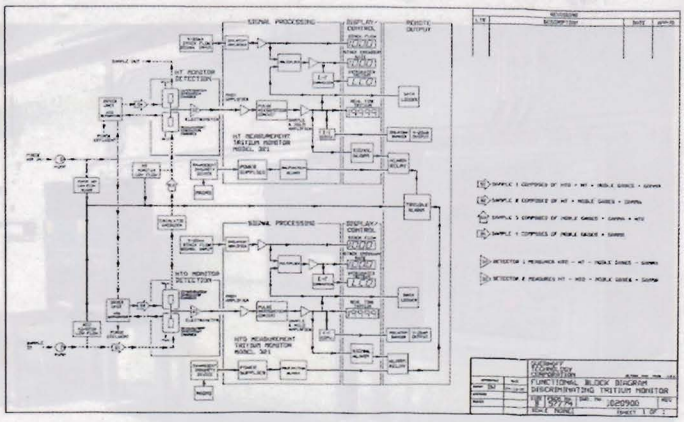

Fig. 5 Schematic of Discriminating Tritium Monitor

The Sampling System draws the sampled gas from the ventilation stack, passes it through a filter and splits into 2 streams. One stream passes the gas through as is, and is for both the Tritium Oxide and for Elemental Tritium. The second stream passes through a desiccant to remove the HTO vapor/moisture, leaving only the Elemental Tritium gas in the air. The flow rate is adjustable between 0-10 $L.min^{-1}$, Fig.5. There is adequate desiccant and filter capacity for a weekly sampling period. The air-in leakage is <<1% and there is the facility for periodic purging with dry instrument air to reduce any Tritium memory.

The Detectors are ion chambers having the required range and compensate for both Noble Gas and for background gamma compensation. The ion chambers are of special propriety (of the manufacturers) design and use a wire grid phantom wall construction to reduce plate-out by about 3 orders of magnitude. The ion chambers are of a differential type having a dryer in-between to remove the HTO. Subtraction between the 2 ion chambers gives the net Elemental Tritium. Each ion chamber assembly is a dual chamber type to compensate for background. Fig.6. Ion chamber volume is about 1200 cm^3.

The Data Handling can sample data for at least a week with a meter display panel meter that shows 4.5 digits. The panel meter can display locally on the instrument or remotely in the Control Room. Fig.7. A layout of the Dryer assembly is shown in Fig.8.

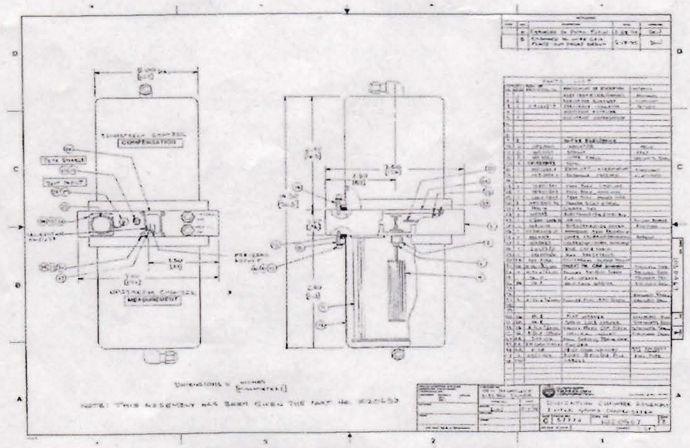

Fig. 6 Ion Chamber Assembly

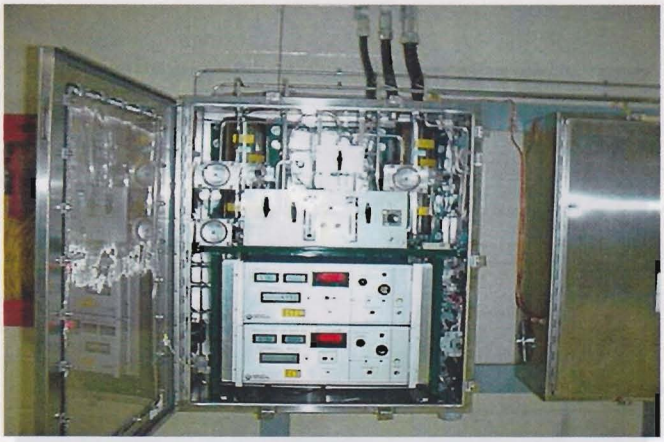

Fig. 7 View of Ion Chambers and Data Display

Performance

The performance of the DTM can be summarized in the following tabulation:

Range:	0- 739.96 $MBq.m^{-3}$	(0-19999 $\mu Ci.m^{-3}$)
Resolution:	3.7 x 10^4 $Bq.m^{-3}$	(1 $\mu Ci.m^{-3}$)
Accuracy:	1.85 x 10^4 $Bq.m^{-3}$ 1 sigma, with alpha suppression	(± 0.5 $\mu Ci.m^{-3}$)
Noise:	1.85 x 10^4 $Bq.m^{-3}$ 1 sigma, with alpha suppression	(± 0.5 $\mu Ci.m^{-3}$)
Stability/drift:	3.7 x 10^4 $Bq.m^{-3}$	(1 $\mu Ci.m^{-3}$)
Response:	15 s for	0 – 2960 $Bq.m^{-3}$ (0 - 80 $nCi.m^{-3}$)
	2 s for signals	> 2960 $Bq.m^{-3}$ (> 80 $nCi.m^{-3}$)
Alarms:	- High Level (latching or non latching) - Malfunction	

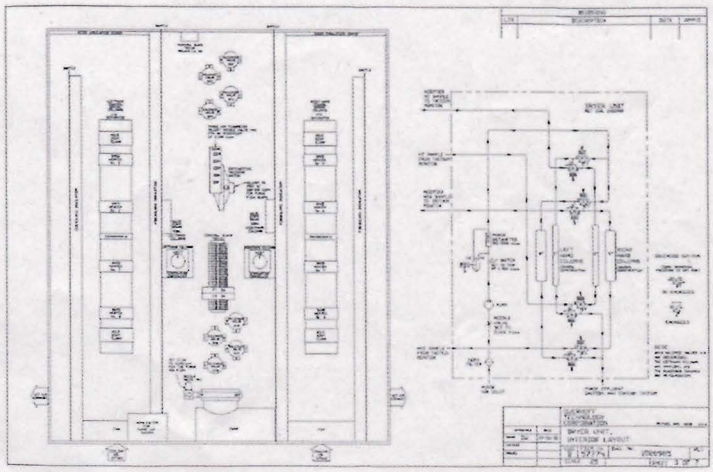

Fig. 8 Schematic of Dryer Assembly

Fig. 9 The Stack Monitoring System at the Tritium Removal Facility

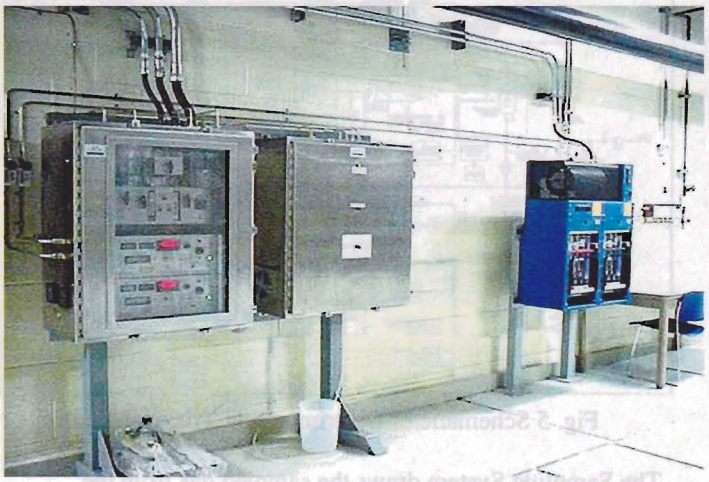

Fig. 10 The Discriminating Tritium Monitor with C-14 Sampler

Summary

The Discriminating Tritium Monitor [DTM] forms part of the environmental emissions monitoring program at the Darlington Nuclear Generating Station. It is located at the Tritium Removal Facility, and supplements the Stack Monitoring System, Fig. 9, and the Carbon-14 Sampling system, Fig.10. The DTM was brought into successful service in late 2000.

References

1. Tritium Detection and Measurement at Darlington's Tritium Removal Facility, by N. Sion, Conference on Tritium Technology in Fission, Fusion and Isotopic Applications, Toronto, May 1-6, 1988.
2. Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 5, Compilation of Ingestion and inhalation Dose Coefficients. Annals of the ICRP, Publication 72; Vol.26 No.1, 1996. Table A-3, Page 84.