RADIOLOGICAL SAFETY SYSTEM BASED ON REAL-TIME TRITIUM-IN-AIR MONITORING IN ROOM AND EFFLUENTS

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In this paper we describe an improved real-time tritium monitoring system designed for Heavy Water Detritiation Pilot Plant from National Institute for Cryogenics and Isotopes Separation, Rm. Valcea, Romania.

The system consists of three fixed tritium-in-air monitors which measure continuously tritium-in-air concentration (in both species: vapour and gas) in working areas and gaseous effluents. Portable tritium monitors with ionization chamber, and tritium-in-air collector combined with liquid scintillation counter method are also used to supplement fixed instrument measurements.

The main functions of tritium monitoring system are:

To measure tritium-in air concentration in working areas and gaseous effluents;

To alarm the personnel if tritium concentration thresholds are exceed;

To integrate tritium activity released to the environment during a week and to cut off normal ventilation when the activity threshold is exceeded and start the air cleaning system.

Now, several especially functions have been added. So that now, using appropriate conversion factors, the tritium monitoring system is able to estimate effective dose rate before starting an activity into the monitored area, during this activity, or soon as the activity was finished. Another new function has been added by coupling tritium-in-air monitoring system with control access system. This is very useful for quick estimating of tritium doses. For official dosimetry, we estimate internal dose for individuals by measuring tritium in urine.

With all these features our tritium monitoring system is really a safety system for personnel and for environment.

Keywords: Radiation protection, Tritium monitoring, Safety.

1. Introduction

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Handling of tritiated water of high tritium concentration asks for new considerations about health hazards. Thus, Radiation Protection Department of ICIT Ramnicu Valcea has the mission to find new solutions in order to protect personnel, environment and population, and to apply the ALARA principle in this type of practice.

Until now, when very low activity of tritium was involved, the tritium-in-air monitoring method was the simply collection of water vapour in air from working area, followed by recovering of collected water and measuring of tritium concentration by Liquid Scintillation Counting technique.

For the next phase (when heavy water with high tritium activity concentrations will be handling), in order to apply ALARA principle and fulfill the requirements of national regulators authority, we proceed to design a radiological safety system that is based on real-time tritium monitoring of working rooms and gaseous effluents.

2. System design considerations

In order to design an efficient radiological safety system for the Detritiation Pilot Plant, several issues was taking in account:

Which are the source terms?

What are the necessary functions that must be accomplished by the radiological safety system in order to provide a quite efficient protection for personnel, population and environment?

What are the proper techniques for tritium-in-air monitoring in order to make the system to be able to accomplish those functions?

Source terms

All the potential leaking sources of process fluid have been evaluated both for normal functioning of the plant and for several deficiency scenarios involving the opening of various systems containing tritiated fluid, but we did not proposed ourselves to detail this analysis.

We conclude that minimum three locations from the Detritiation Pilot Plant must be monitored continuous and in real time. These are:

1) The area of the catalytic isotopic exchange module, because here are located several equipments (isotopic exchange column, vessels, heat exchangers, pumps, etc.) which contain or circulate large amount of tritium in all three forms (liquid, vapour and gas). The sampling points are much closed to equipments mentioned above.

2) The enclosing cold-box of the cryogenic distillation module, because a high activity of tritium gas exists inside of this module. The sampling line is connected with exhaust duct of the vacuum pump.

3) The exhaust stack of the ventilation system. The air sampling from this stack will be done by an isokinetic sampling system.

Required functions

In order to provide a quite efficient protection for the personnel, population and environment, the following requirements have to be taking in account in the designing of radiological safety system:

- continuous monitoring of tritium in working areas and gaseous effluents;
- discriminating between the two forms of tritium (vapor and gas), especially for the area of isotopic exchange module;
- the system will be able to measure, analyze and display in real time the monitoring parameters;
- assessing the amount of tritium released to the environment through the exhaust stack of the ventilation system;
- alarming the personnel visually and auditable when pre-established thresholds for tritium concentration or total activity are exceeded;
- the system will be able to initiate the shut-down procedure and drain off the plant as well as to start the Air Cleaning System when the tritium-in-air concentration exceeds pre-established threshold;
- real time estimating and displaying of dose rate corresponding to the monitored locations;
- estimating of individual doses of operators, and recording/updating these values with the aim of a computer application;
- the monitoring system will be able to command lock/unlock the access to the radiological area for personnel when tritium concentration in radiological area is too high, or when individual dose (or other stipulations of radiation protection procedures) require this action.

A wide range of monitoring techniques is published in several sources together with interpretation of each method. [1], [2], [3], [4].

Choosing of the reliable tritium monitoring method require to consider a lot of factors, as: accuracy, detection limits, tritium concentration levels, response speed of the instrument versus fluctuations of tritium concentration, chemical forms of tritium (vapour or gas), etc. The radiological safety system that we designed is making allowances for all these criteria and all the above requirements.

Technical discussion and descriptions are given in the next section.

3. Conceptual design

Configuration

The radiological safety system of Detritiation Pilot Plant from Ramnicu Valcea is a real-time monitoring network that consists of the following main components:

M1 – Tritium-in-air monitor with 2 litres ionization chamber (type LB 6710-2H)

DL1 – Measuring electronics (type LB 5310T Data Logger)

M2 – Tritium-in-air monitor with 2 litres ionization chamber (type LB 6710-2H)

DL2 – Measuring electronics (type LB 5310T Data Logger)

M3 – Tritium monitor with 1.3 litres proportional counter tube (type LB 110)

DL3 – Measuring electronics (type LB 5310 Data Logger)

IS – Isokinetic sampling system (installed on the exhaust stack of the ventilation system)

F – Flow meter (to measure flow rate of air released to the external environment)

MSI – Monitoring system - Safety shut-down system Interface

MAI – Monitoring system - Access Control System Interface

CC – Central Computer

D – Display

A schematic of the system configuration is shown in the figure 1:

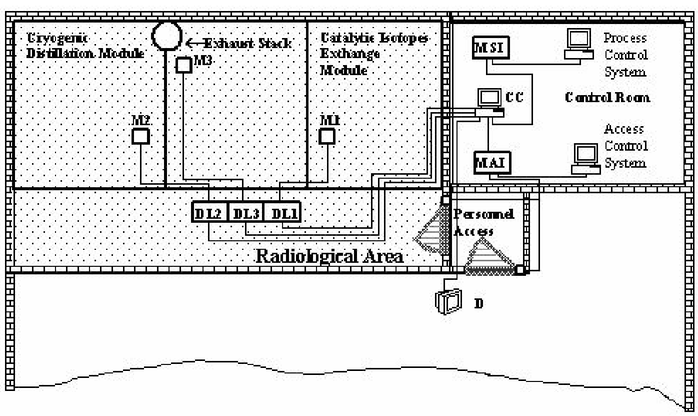

Fig 1. System configuration into the plant building

Technical characteristics of the tritium monitors [5], [6], [7]

- Tritium-in-air monitor LB 6710-2H:
- Detector: 2 litres flow-through ionization chamber;
- Detection limit: $3x10^4$ Bq/m^3 (1 fA electrometer current);

- Accuracy 3%;
- Calibration factor for tritium: 0.031 MBq/m^3/cps
- Measuring range (user changeable): 3x10^4 - 3x10^8 Bq/m^3 (sensitive) and 3x10^6 - 3x10^{10} Bq/m^3 (insensitive);
- Sampling flow rate (adjustable): 1–4 liters per minute, calibrated at 1.6 liters per minute;
- Gamma sensitivity: 0,36 MBq/m^3/(μSv/h) with Cs-137.

• Tritium monitor LB 110:
- Detector: 1.3 litres flow-through proportional counter tube (counting gas P10):
- Mixing ratio [measuring air] / [P10 gas]: 1/4;
- Calibration factor for tritium: 7.0 kBq/m^3/cps
- Detection limit (is varying with the measuring time):

Table 1

The detection limit function of the measuring time

Measuring time	Detection limit
30 s	5.4 kBq/m^3
1 min.	3.8 kBq/m^3
10 min.	1.2 kBq/m^3
1 h	0.5 kBq/m^3
24 h	0.1 kBq/m^3

• Measuring electronics, Data Logger LB 5310:
- User program on EPROM's; battery-buffered RAM; user-specific parameter setting option, permanent storage;
- Data acquisition via standardized counter inputs;
- Averaging of the measuring data with dynamic ratemeter;
- Standardized input or output current interfaces (0/4-20 mA)
- 3 status inputs and 4 alarm outputs (for relay connection) for external signal devices;
- Visual and audible signal for alarming;
- Bidirectional communication with central computer via local network (e.g. RS 485);
- Result output on printer.

Tritium monitors calibration

For purposes of initial and periodical calibration of tritium monitors in their locations, we built a simple mobile device for calibration purposes. This calibration device is based on continuous circulation of $(HTO)_{vapour}$ saturated air stream in a closed circuit. The saturated air stream is obtained by bubbling from vials containing different tritium standard solutions. [8]

System operation

The M1 monitor (LB 6710-2H) is devoted to continuously sample and measure the air from the area of the catalytic isotopes exchange module. The measurements, calculation, and data displaying are done by the DL1 (LB 5310 Data Logger).

The M2 monitor (LB 6710-2H) has the role to continuously sample and measure the air pumped out by the vacuum pump associated with the cold-box that encloses the cryogenic distillation module, in order to detect any tritium-gas leakage from the cryogenic distillation equipments. The measurements, calculation, and data displaying are done by the DL2 (LB 5310 Data Logger).

The M3 Monitor (LB 110) is devoted to continuously measure the total tritium concentration in air released to the external environment through the exhaust stack. The air to be measured is continuously sampling with the aim of Isokinetic Sampling System. The measurements, calculation, and data displaying are done by the DL3 (LB 5310 Data Logger).

The measured data processed by each Data Logger LB 5310 (DL1, DL2 and DL3) will be send via RS 485 link to the Central Computer for further processing by the software application to additionally provide the following:

a) *Estimation of Tritium Dose Rate*. This is calculated by the relation:

$$\dot{E}_{H-3}\,[\mu Sv/h] = DCF\left[\frac{\mu Sv \cdot m^3}{Bq \cdot h}\right] \times C_{H-3}(t)\left[\frac{Bq}{m^3}\right], \tag{1}$$

Where:

- *DCF* is dose-rate conversion factor;
- C_{H-3} is tritium-in-air concentration at the location of interest.

The dose-rate conversion factor was calculated for an adult taking into account the air intake rate, 8400 m^3/year, and the dose factor for tritium intake through inhalation mechanism, 1.8 x 10^{-11} Sv/Bq. In addition, in order to account for skin absorption mechanism, the dose factor for inhalation is multiplied by 1.5. [9], [10], [11], [12]

$$DCF = 2.6\times10^{-5}\left[\frac{\mu Sv \cdot m^3}{Bq \cdot h}\right] \tag{2}$$

b) *Estimation of Tritium Occupational Dose*. This is simple to calculate if we know the tritium instant dose rate and the time spent by an operator goes into the radiological area. The time spent by an operator goes into the radiological area is offered by the Access Control System, via MAI. The tritium doses estimated in this way are recorded into the data base called “Dose records”. To establish more precisely the tritium occupational doses for personnel, we are using the tritium in urine assay method.

c) *Estimation of total activity of air released to the environment over a period* (day, week or month) is done by the following relation:

$$\Lambda_{H-3}(\Delta T)=\int_{t}^{t+\Delta T}F(\tau)\cdot C_{H-3}(\tau)d\tau \qquad (3)$$

To establish more precisely the tritium occupational doses for personnel, we are using the tritium in urine assay method.Where:

- *F* is flow rate of air effluents through the exhaust stack;
- *C* is tritium concentration of air effluents.

The flow rate of air effluents through the exhaust stack of the ventilation system is measured by the flow meter F and transmitted to the LB 5310 Data Logger as a signal of 4 - 20 mA. The total activity released over a period is compared to DRL (Derived Release Limit, approved by Romanian licensing agency), and an emergency signal is generating, and Air Cleaning System is automatically started when the established threshold (50% from DRL) is overfulfilled.

The central computer can be set to command locking of all entries into the radiological area (technological rooms) in the following cases:

i) An alarm for high tritium concentration is generating. In this case the access is permit only with proper protective equipment and a *Safety Work Plan* (SWP);

ii) When an operator, are likely to be exposed to a dose higher than an allowable limit. In this case the access of that persons is denied;

4. Conclusions

The conceptual design of the radiological safety system based on real-time tritium-in-air monitoring in room and effluents is intended to provide the maximum achievable safety level, basing on the ALARA concept. The capabilities of this system are not only to inform any time personnel about tritium in air concentration level, but it will be able to:

- initiate the shut-down procedure and drain off the plant, as well as to start the Air Cleaning System when the tritium-in-air concentration exceed pre-established threshold;
- estimate tritium effective dose and instantly record and update individual effective doses, using a special computer application called "Dose Records";
- lock access into the radiological area for individuals in special hazardous conditions;
- calculate the total tritium activity released to the environment (per day, week, or month)

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