NUCLEAR METEOROLOGY AT IFIN-HH

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The present study summarizes the development of meteorological survey system at IFIN-HH, the largest research institute in Romania dedicated to physics and nuclear engineering. The IFIN-HH site is located in a peri-urban area with non-homogenous terrain (land use, obstacles). The vertical wind and temperature profiles in complex terrain differ comparing with the flat homogenous terrain. Consequently, the assessment of the stability classes is difficult to achieve and special procedures were developed. The monitoring of the external gamma dose in real time is correlated with on-line measurements of precipitation and ^{222}Rn concentration in air. The data analysis in the last years demonstrates that the short-term increasing of external gamma dose due to natural causes can be easy detected and the attention limit for anthropic radioactive pollution can be decreased.

Key words: Nuclear meteorology, non-homogenous terrain, atmospheric stability classification, external gamma dose.

1. INTRODUCTION

Nuclear meteorology investigates the distribution of radioactive aerosols and gases in the atmosphere and has a long history: "With the widespread use of atomic energy, large quantities of radioactive gases and aerosols of artificial origin have been deposited in the atmosphere during the last fifteen years; contamination of the atmosphere has occurred, presenting a biological hazard " [1].

Nuclear reactors as well as other major nuclear units require extensive meteorological monitoring during the entire life-cycle (*i.e.*, design, engineering, construction, cold and hot functional testing, operation, and decommissioning). The meteorological information is used for routine radiological and chemical release consequence analysis, real-time consequence assessments of accidental releases of radiological and chemical species, and potential environmental impacts resulting from design basis accidents of new nuclear facilities or those related to

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the modifications of the existing facilities. In addition, the meteorological monitoring program supports environmental compliance, development of *National Environmental Policy Act* (NEPA) impact analyses, *Safety Analysis Report* (SAR) accident assessments, and the protection of the workforce during operations from natural phenomena hazards. The broad scope of the meteorological monitoring program includes all parameters necessary to characterize the atmospheric environment within a 20 km radius of these nuclear facilities and beyond.

The dispersion of pollutant in the atmosphere is driven by turbulence and key issues were explained recently [2].

The amount of turbulence depends primarily on the temperature lapse rate (which represents the temperature vertical gradient) and the surface velocity gradient, but there are also other factors that may enter. Conditions at the surface exhibit a regular diurnal change, caused by solar heating, which is modified by clouds and wind. During the night, the lapse rate is small, and is often a temperature inversion, with warmer air above a radiationally cooled ground. The winds are low and the air is stable and laminar. When the sun rises, the heated earth becomes much hotter than the air, so the lapse rate becomes larger, encouraging instability and turbulence, which usually establishes a dry adiabatic lapse rate close to 9.86 °C/km. As the earth becomes even hotter, large bubbles of hot air leave the surface at intervals, and convection cells are established. Turbulence is, therefore, encouraged by a super-adiabatic lapse rate and rapid increase of wind velocity with height. In the morning, the velocity gradient increases to a critical point, when the turbulence grows. The turbulence rapidly establishes at least an adiabatic lapse rate, and so it will continue to grow.

Following the national nuclear law and the requirements in EURATOM TREATY (available at http://www.euratom.org/) also, IFIN-HH must demonstrate the capacity to assess the impact of the atmospheric release of radioactive pollutants. Modern atmospheric transport models need direct meteorological data (wind speed and direction, temperature, humidity, solar or net radiation), but also input data that must be achieved by processing of the direct data. The atmospheric stability class or turbulence information, the effective emission height of released pollutant, and height of mixing layer are needed. The roughness length, the Monin-Obukhov length and surface energy budget are required for some models, also. A minimal input data base needs at least the stability class of the atmosphere and the height of the mixing layer (the zone near the surface where the dispersion occurs). The development of the IFIN-HH meteorological survey system was done in accordance with the Romanian law [3–8], but also using international practices and guidance [9-15].

2. SITE CHARACTERISTICS AND DEVELOPMENT OF METEOROLOGICAL SURVEY SYSTEM

IFIN-HH is about 3 km away from Bucharest border and is situated in the middle of a forest and surrounded by agricultural land and peri-urban areas (Figure 1). Exhausted radioactive products are emitted from stacks of 40 m height and the effective source height is between 44 and 55 m. The met tower was built with the highest measurement level at 60 m and the intermediate level at 30 m. Due to the restrictions in national regulations the meteorological tower was built at IFIN-HH site, nearby a forest and surrounded by buildings. The tower was built in 1994–1996 with contribution from the Romanian Government and International Atomic Energy Agency (IAEA) (providing the meteorological sensors). The minimum distance to the forest border is 360 m (West direction) and the maximum is 1240 (East direction). The obstacles around the met tower have a height of 12–15 m. This is a situation of non-uniform roughness and the wind profile is strongly disturbed. The classical methods regarding the assessment of atmospheric stability [7, 16] do not allow a robust assessment of the atmospheric stability in such conditions. The meteorological tower was operated with 2–3 levels of measurements in 1998–2000, with 7200 hours of good performance only, due to problems with electric power or thermal conditions. The meteorological sensors used in that period were provided by IAEA and were of moderate quality. The data acquired in 1998–2000 give an overview on the statistics of the wind direction and wind velocity and a poor assessment of the atmospheric stability. Comparing those data with the historical data in the Romanian plain, changes in the average wind velocity and wind rose are observed. The improved instrumentation used in the present explains the lower frequency of calm situations than those observed with the sensors in 1960's. The major achievement in 2000 was the real-time acquisition of the meteorological data and the automatic transmission for the European project Real-time On-line DecisiOn Support system for nuclear emergencies (RODOS) [17], Romania being the second country after Germany which was able to provide real-time data.

After a period of financial constraints (2000–2006), a full refurbishment started in 2007 regarding the metallic structure of the tower, electrical engineering, meteorological sensors, associated building, etc. The tower instrumentation started delivering information in April 2008 and the tests emphasised the needs for upgrading the temperature sensors. High precision temperature sensors, ventilated, were acquired and tested to measure the temperature gradients with accuracy of less than 0.1 °C/100 m. The sensors for wind velocity and direction, temperature, relative humidity, precipitation, and the data logger (DL2e, Delta-T-Device, UK) were achieved. Based on a Norwegian Grant (RADO – Romanian Atmospheric 3D Observatory, STVES. 2008 115266) many instruments were acquired: a) a ceilometer (Nimbus Jenoptik, Germany) for detecting the cloud cover and cloud height, as well as the aerosol properties; b) a net radiometer (Nr Lite2, Kipp & Zonnen, The Netherlands) for measuring the net radiation; c) a 3D sonic anemometer (USA1 Scientific, Metek, Germany) and a fast gas analyser (LI-COR7500A, USA) for measuring the 3D wind velocity and direction, sonic temperature and fluxes of momentum, sensible and latent heat, as well as CO_2 fluxes; d) a gamma tracer for measuring the external gamma dose (GammaTracer XL2, Saphymo, Germany); e) a monitor for measuring the Radon (^{222}Rn) in air (AlphaGuard PQ2000 PRO, Saphymo, Germany). All the old and new instrumentations were included in a line of measurements and data processing (Figure 2) providing automatic updates at each 10 minutes as average values of all the measured data recorded at 10 seconds. The software processing all the data was done in-house with minimal help from suppliers. In parallel, efforts were done to overpass the difficulties regarding the assessment of the stability category. In 2011 the system operated 97.1 % of time and in 2012 96.8 %, a performance satisfying the requirements for the nuclear meteorology [10, 12].

Fig. 1 – Satellite map of IFIN-HH site.

A careful analysis of the row and processed data emphasises that the quality of the data must be improved. The wind sensors are too close to the tower metallic structure and the measurements are affected by the tower induced turbulence. The wind sensors have poor performance at low wind speed and during the winter time or freezing rain they do not work properly. The precipitation gauge during the winter time gives erroneous reading. The data logger has low robustness. Consequently, the financing was requested and provided by the Romanian Authority for Scientific Research and new equipment was achieved. The new line of measurement satisfies the performance for nuclear meteorology [10] and is now in final tests.

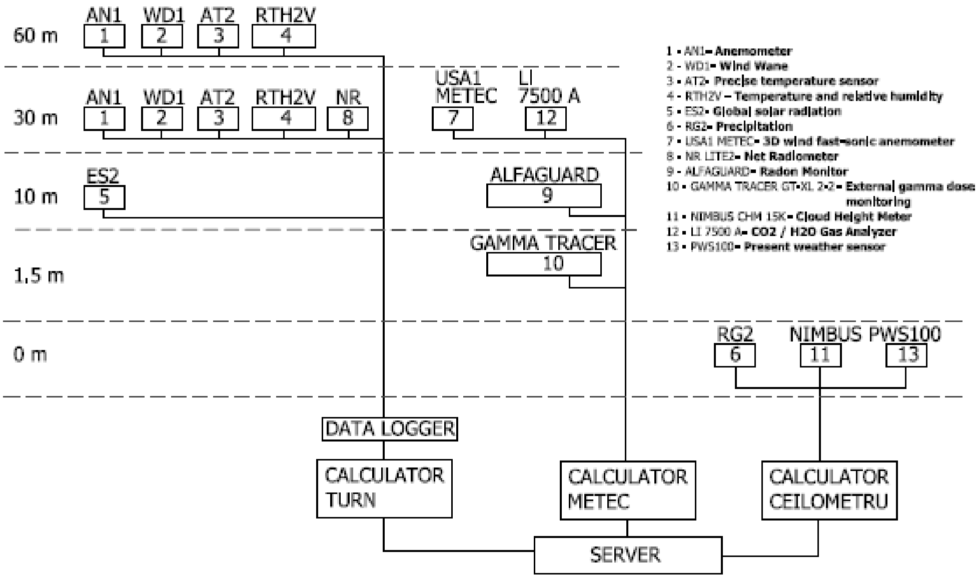

Fig. 2 – Flowchart of the measurement system.

3. ASSESSEMENT OF THE ATMOSPHERIC STABILITY CLASS IN NON-HOMOGENOUS TERRAIN

The Romanian guidance, as well as many others, uses the Pasquill-Gifford classification where the balance between mechanical turbulence (friction) and thermal turbulence (sensible heat) is used to assess six stability classes: from A – very unstable to F – very stable, with class D – neutral stability. For assessing the stability class, insulation, cloud cover and wind velocity at 10 m height are needed (Table 1). Other methods for assessing the stability class considers solar or net radiation, temperature gradient, standard deviation of wind direction, but also the wind velocity at 10 m [18-21]. All the previous methods were empirically developed for the case of flat terrain with homogenous distribution of obstacles, an ideal case. Any major nuclear unit is not built on flat terrain and consequently, all those classical requirements for flat terrain are not accomplished and this was demonstrated in many cases [22].

Analysing the measured values of temperature gradient, net radiation and standard deviation of wind direction for the IFIN-HH case, correlations are observed (Figure 3) as for the flat terrain. A direct classification of the atmospheric stability is not possible because the wind profile is changed by the non-homogeneity of the terrain.

Table 1

Pasquill-Gifford stability classification

Surface wind	Insolation			Night	
Speed (at 10 m) (m s^{-1})	High	Moderate	Slight	≥ 4/8 low cloud cover[*]	≤ 3/8 cloud cover
< 2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

[*] Thinly overcast

Note: Neutral class D should be assumed for overcast conditions during day or night

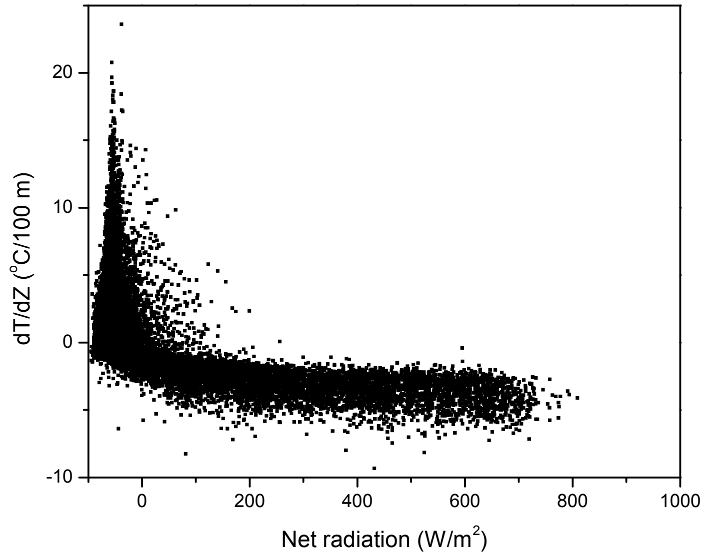

Fig. 3 – Correlation between Net radiation and temperature gradient.

The first step in order to assess the atmospheric stability class was to understand the effects of roughness change on the wind profile. The height, area and distribution of the obstacles characterise the roughness of the land surface and influence of the wind profile. A sudden change of the terrain roughness induces an internal boundary layer and changes the wind profile. A map of the terrain roughness for a 5 km radius around IFIN-HH was generated and two models for air flow over complex terrain were used: FLOWSTAR [23] and LINCOM [24]. Depending on wind direction and atmospheric stability, the ratio between wind at 30 and 60 m height at IFIN-HH site relative to those in flat homogenous terrain was obtained. In order to use these relationships in practice, it must establish first if the atmosphere is unstable, neutral or stable and this is done considering the solar radiation (measured) and sensible heat at surface (estimated) [21]. When solar radiation and surface heat are positive, the unstable case is assessed, while if the solar radiation is positive but surface heat is negative, a neutral case is preferred. When solar radiation is negative, neutral or stable situations are assessed. For the night stable case, the 60 m measurement level is above the internal layer and the mezoscale roughness length of 0.3 m is used to convert the measured wind speed with the equivalent one in flat homogenous terrain. For the unstable case, the internal boundary layer is low and the close area affects the wind profile. For the assessment of the standard deviation of wind direction, the well-established procedures are used [25, 26] using the direct information from the wind vanes at 0.1 Hz (limited by the quality of sensors used in 2010–2013). Due to the occurrence of the meandering (slow change of the predominant wind direction) there are situations when the stability class is assessed with errors if the time interval for data analysis is one hour. The IFIN-HH meteorological survey system is developed for general use including the emergency situations, consequently the standard time interval for data averaging and processing is 10 minutes. For this time interval, the meandering situations are easily solved by comparing the subsequent average of wind direction and standard deviation.

After two years of data acquisition and processing, all procedures used for the assessment of the atmospheric stability class were analysed regarding their robustness for the non-homogenous terrain as it is IFIN-HH case. In this respect, the cloud cover given by the ceilometer together with the general constraints recommended by the *Nuclear Regulatory Commission* (NRC) [27] was used. The data analysis for the IFIN-HH case eliminates some procedures in literature [7, 10, 16]. The best results were obtained using the net radiation and standard wind speed at 10 m [19]. The net radiometer used in IFIN-HH gives erroneous results for intense rain. In case of intense rain during the day time, the solar radiation and standard wind speed are used and during the night time, the wind and the sign of the temperature gradient are used [14].

The meteorological survey system previously described and given in Figure 2 operates continuously from 01.07.2010 and for the last three years, the hourly data cover 96.7 % of time, a performance in accordance with the nuclear standards. The quality of wind vane was lower comparing with the requirements [10] and a wind threshold of 0.9 ms^{-1} was imposed for accurate measurement of speed and direction. For a wind velocity lower than 0.9 ms^{-1}, the wind direction has larger errors than 5 degrees and the assessment of sector from which the wind blows is less accurate (16 sectors were used). Winds lower than 0.9 ms^{-1} have a frequency of 10 % and the post-processing of the data given by 3D sonic anemometer show that only in 2 % of the cases the wind sector was incorrectly assessed.

For the application of the meteorological data in radiation protection the statistics of the wind direction (16 sectors) and stability classes are needed (Figure 4). In sector 1 the wind blows from North and in sector 9 wind blows from South.

During the summer time (1 April to 30 September) the statistics do not differ too much. Precipitations occur most frequently when the wind blows from NE, but also from SW (Figure 5). In 74 % of the cases, the rain intensity is lower than 1 mmh^{-1} and strong rains (higher than 10 mmh^{-1}) occur in 1.5 % of the cases. Detailed information regarding the data processing can be obtained (in Romanian) upon request.

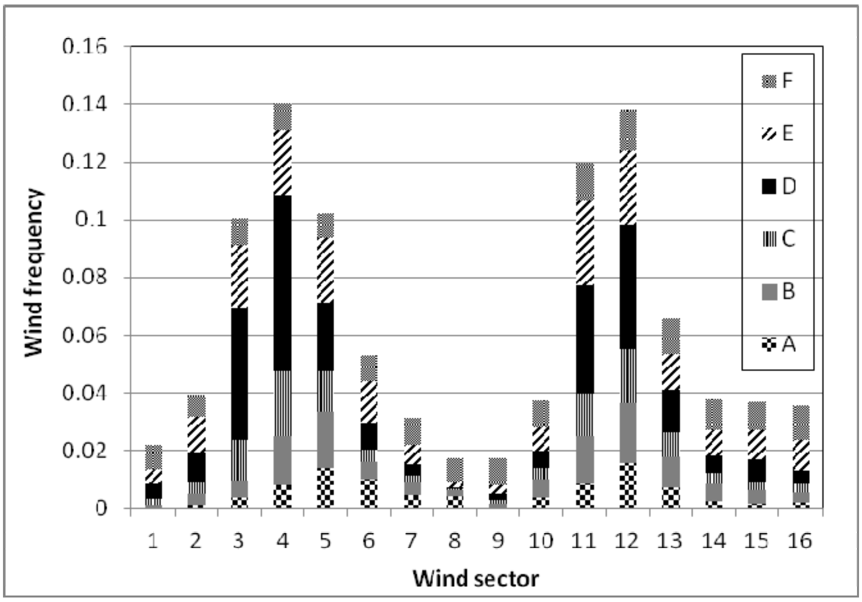

Fig. 4 – Statistics of wind sectors and stability classes.

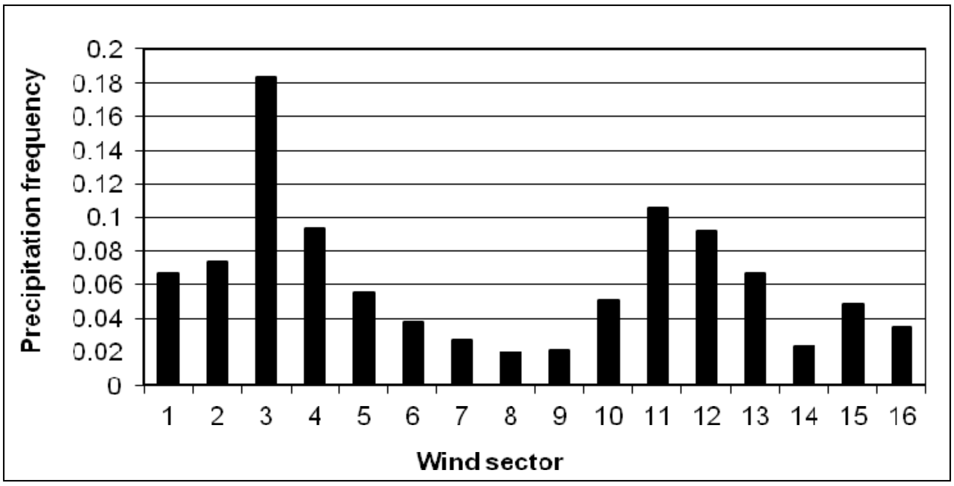

Fig. 5 – Precipitation frequency in each wind sector.

4. EXTERNAL GAMMA DOSE

The monitoring of the external gamma dose is mandatory for IFIN-HH site and is measured currently at various locations using thermo-luminescent detectors and reported as monthly averages. Few gamma dose meters for real time measurements are also used. The cosmic radiation and natural radioactivity in soil are the main contributors to the external gamma dose and the Chernobyl accident has a small contribution also. These are considered the natural background for the external gamma dose. A very small contribution comes from radon and radon progeny in air. The ^{222}Rn decay products in the atmosphere are transported to the ground by the scavenging effects of the rainfall [28] and the environmental gamma-ray intensity at the ground surface is significantly increased up to several tens of percent of intensity compared to the dry conditions. ^{214}Pb (half-time of 26.8 minutes) and ^{214}Bi (half-time of 19.9 minutes) are the main progeny contributors to gamma dose. The variations in environmental gamma ray dose rates can seriously interfere with the monitoring of the unexpected releases of radioactivity from nuclear facilities. Radon is monitored at 10 m height and gamma dose rate at 1.5 m height. The measurements of each monitor recorded as averages for 10 minutes are registered in the data base and can be correlated with precipitation (Figures 6, 7). The dose increases in correlation with precipitation intensity up to 60 % and in about 2 hours from the last precipitation, it decreases at normal values. An example for the external dose rate, the precipitation rate and the radon concentration is given in Figure 8. In Figure 8, the radon concentration at 10 m is relatively low, but the precipitation transports the radon progeny from the atmosphere on to the soil, increasing the external dose up to 80 % above the background. There are also few

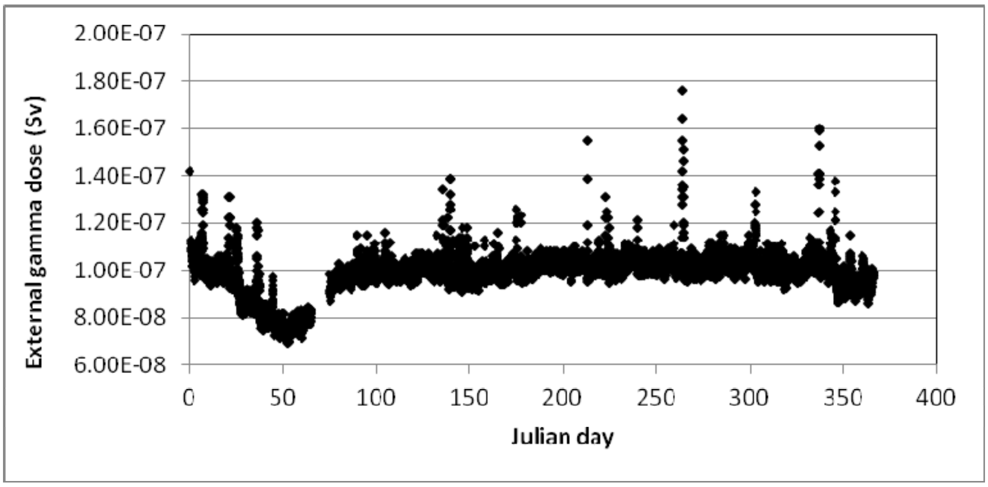

Fig. 6 – External gamma dose for 2012.

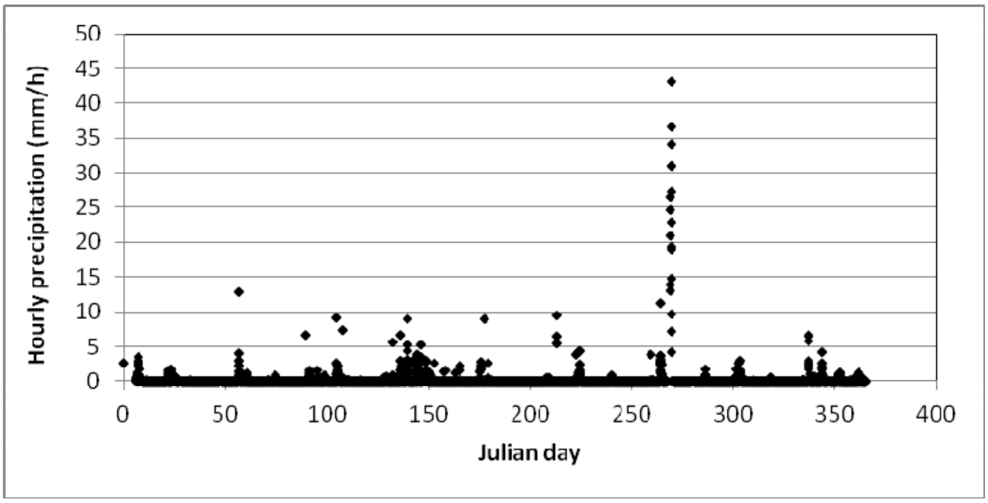

Fig. 7 – Precipitation for 2012.

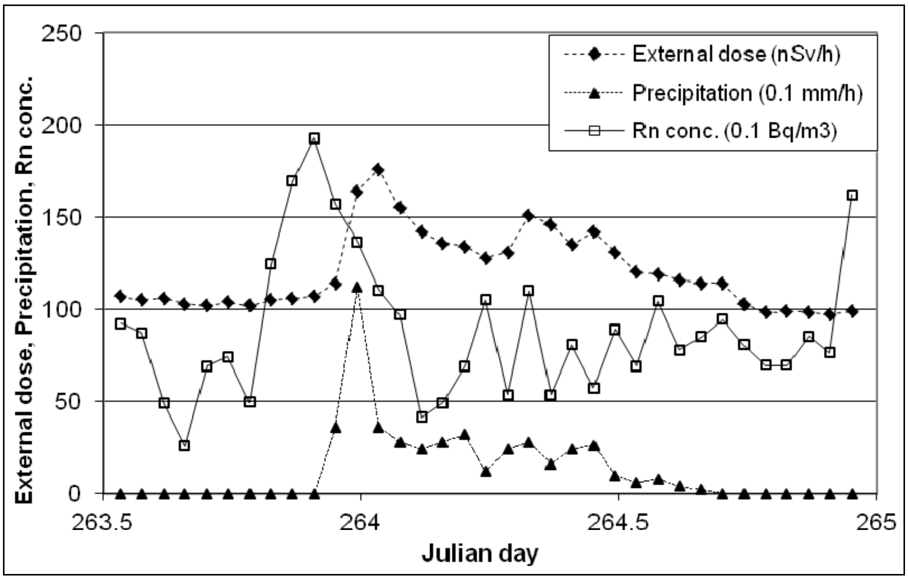

Fig. 8 – External gamma dose, precipitation and ^{222}Rn concentration for 21 September 2012.

cases when the dose increases with less than 20 % comparing to the background values due to high concentration of radon in surface air caused by the temperature inversions in the lower atmosphere (Figure 9). Operating the meteorological tower in real time with all sensors correlated, the on-line data analysis is possible and natural causes of the dose fluctuations can be detected. Finally, the attention limit for an accidental event is decreased at 20 % over the background.

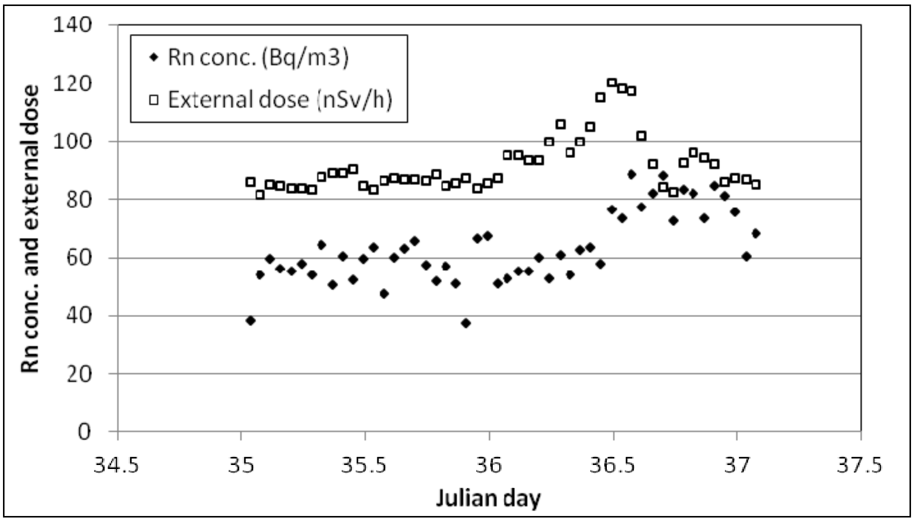

Fig. 9 – Increasing of external dose due to high temperature inversion at 30-60 m (from day 36.4 to day 36.66, the temperature gradient was lower than -1°C/100 m and the atmosphere was neutral).

5. FUTURE DEVELOPMENTS

The actual meteorological system must be further improved for the quality measurements used in nuclear meteorology based on the recent practices. Presently, new instrumentations are mounted and tested with the new longer and the sensors are mounted on new lateral arms longer than the previous ones, minimising the disturbances coming from the tower structure. Heated wind vane and cup anemometer of high quality are mounted at 30 and 60 m height, together with ventilated temperature and humidity sensors. For fast response, 2D sonic anemometers are used. All equipment was supplied by the Campbell Scientific (UK) together with a performing CR1000 data logger. A heated rain gauge is installed at 30 m height, far from the tower structure. A new special arm for 3D sonic anemometer is needed for assuring the verticality and mounting of the adjacent LICOR gas analyser. For full characterisation of precipitation, a Present Weather Sensor (PWS 100 Campbell Scientific) will be also used. After the tests in 2014 the new system will deliver accurate and fast information for all meteorological parameters including 3D turbulence as well as momentum, latent and sensible fluxes (eddy covariance).

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