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The Impact of Tritium Contamination of Air Humidity and Ground Water on the Tritium Concentration of Tissue Water in Plants Studied under Real Conditions

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Abstract

This is a summary of results obtained in a measuring program aimed at studying the influence exerted by the tritium offer in the ground water and in the water vapor of air on the tritium contained in plant tissue water. The studies were performed at the western borderline of the Karlsruhe Nuclear Research Center in a narrow area which, on account of its location, is of special interest with respect to the various tritium emitters. The determinations covered the tritium concentrations in samples of air humidity, ground water and precipitations as well as in the tissue water of needles and leaves, respectively, of different trees. The methods applied in sample preparation and the measuring technique are described in detail. After the tritium emissions strongly varying with time and the relevant meteorological parameters had been duly taken into account, unambiguous relations were found between the tritium concentration of the humidity of the air and the tritium contamination of plants.

Der Einfluß von Tritiumkontaminationen der Luftfeuchte und des Grundwassers auf die Tritiumkonzentration des Gewebewassers von Pflanzen unter realistischen Bedingungen

Zusammenfassung

Der vorliegende Bericht faßt die Ergebnisse eines Meßprogrammes zusammen, dessen Ziel es war, die Einflüsse des Tritiumangebots aus dem Grundwasser und aus dem Wasserdampf der Luft auf den Tritiumgehalt des Gewebewassers von Pflanzen zu untersuchen. Die Untersuchungen wurden am Westrand des Kernforschungszentrums Karlsruhe in einem eng begrenzten Gebiet ausgeführt, das aufgrund seiner Lage in bezug auf die verschiedenen Tritiumemittenten von besonderem Interesse ist. Bestimmt wurden die Tritiumkonzentrationen in Luftfeuchte-, Grundwasser- und Niederschlagsproben sowie im Gewebewasser von Nadeln bzw. Blättern verschiedener Bäume. Probenvorbereitungsverfahren und Meßtechnik werden ausführlich beschrieben. Nach Berücksichtigung der zeitlich stark variierenden Tritiumemissionen und relevanter meteorologischer Parameter ergaben sich eindeutige Beziehungen zwischen der Tritiumkonzentration der Luftfeuchte und der Tritiumkontamination der Pflanzen.

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1. INTRODUCTION

This report presents the part of a program carried out in the Health Physics Division at the Karlsruhe Nuclear Research Center during a period of study authorised by the International Atomic Energy Agency. It is at the same time a realisation of part of the environmental tritium monitoring program under Research Contract No. 1302/CF sponsored by IAEA and carried out in the Health Physics Division.

In the period preceding the present program the Health Physics Division carried out investigations of the tritium concentration in plants at several sampling points in the immediate vicinity of the Karlsruhe Nuclear Research Center [1, 2].

As a preliminary to the realisation of the program, results from previously obtained measurements were analysed. For the purpose of acquiring a significant collection of information including the relationship between the emission of tritium and the contamination in the environment, it was decided to limit the investigation to one location to enable observations to be made of all the conditions arising from the varying concentration levels of tritium in gaseous and liquid effluents in a particular period. At the same time, it was also decided to use such a sampling location to determine the variation in the tritium concentration in air humidity from different emission sources through the angular deviations from the main wind direction. Also included in the program was the investigation of different types of biological material (trees), the tests being made at frequent intervals.

As far as the biological material is concerned, the program allowed for the investigation of the tritium concentration in the tissue water of plant samples, pine and spruce needles, oak and hornbeam leaves. In addition, investigations were carried out of the tritium concentration in air humidity, precipitations and ground water. The results were compared with tritium releases from different sources by gaseous and liquid effluents and with meteorological parameters such as wind direction, diffusion category, absolute air humidity etc.

The advantage of this program is that the relationships between tritium concentrations in plants and their environmental media can be carried out under real conditions, because the sampling location is situated on the premises of working nuclear facilities. But precisely because of this, the measurements have to be carried out at low level ranges of tritium concentration in contrast to the use of tritium as a tracer of high concentration under experimental conditions. However, a disadvantage of real experimental conditions is that the tritium contamination values at the sampling location depend on many parameters such as, for example, the tritium emission rates of different sources and their emission heights, the wind directions and the diffusion categories, etc.

2. TRITIUM EMISSIONS FROM THE KARLSRUHE NUCLEAR RESEARCH CENTER

Tritium is emitted into the environment by liquid effluents from sewage treatment plants as well as gaseous effluents from several exhaust stacks and is introduced into the air as tritiated water vapour.

Table 1 shows the levels of tritium emitted during 1975 and 1976 observed from various emitters of the Karlsruhe Nuclear Research Center; the table also shows the heights of the sources above ground level. The authorized annual value of tritium emitted by the WAK reprocessing plant is given in the table. Lack of information about the daily emission rates from WAK made it impossible to include an evaluation of the influence of these releases in the results of the program.

Other forms of tritium emission were found to be insignificant and therefore were not subject to continuous detection. Daily emission rates from the MZFR and FR 2 heavy water reactors vary from 0.1 to 25 Ci/d. Tritium emission from FERAB, compared with MZFR and FR 2, has a value of about a hundred times less. Fig. 1 shows a site plan indicating the main tritium emitters.

Emitter	Height of emission in m	Tritium release in Ci	
		1975	1976
FR 2 (44 MW_{th}, D_2O-moderated)	99	285	170
MZFR (200 MW_{th}, D_2O-moderated)	99.5	765	703
WAK (Reprocessing plant, 40 t/a throughput, $3x10^4$ MWd/t)	60	1000*	1000*
FERAB (incineration facility for solid radioactive wastes)	70	467	213
Decontamination plant for liquid wastes	19	53	73
Sewage treatment plant			
a) evaporation	∿2	∿2**	∿3**
b) liquid effluents	-	2821	4024
Several minor emitters	∿10	5	20

Table 1 Tritium releases by the Karlsruhe Nuclear Research Center in 1975 and 1976 [2]

*authorized value

**estimate based on an average evaporation rate of 1 mm/d for 800 m^2 of uncovered surface

Tritium in the liquid effluents from all sources in the Karlsruhe Nuclear Research Center is discharged via sewage treatment plants into a former branch of the Rhine river about 2 km away and mixed with surface water before flowing 23.6 km to the main part of the Rhine river [3].

The four final buffer basins of the sewage treatment plants (see Fig. 3) constitute a further source of tritium emissions through evaporation to the air. Therefore, in the immediate environment the tritium concentration in the air may reach significant values.

At the end of August 1975 a conspicuous depression in the soil led to the detection of a leak in the piping system of the sewage treatment plant on the site of the Karlsruhe Nuclear Research Center (see Fig. 3, point L). At the point where a plastic pipe penetrated a concrete control pit, a leakage was found about 3 meters deep in the ground through which low level effluent water from laboratories, after having passed a decontamination facility, escaped into the soil and had possibly done so over a period of several weeks. The leakage point lay between the storage basins of the sewage treatment plant and the so-called 'cyclator' (see Fig. 3) in which precipitations take place.

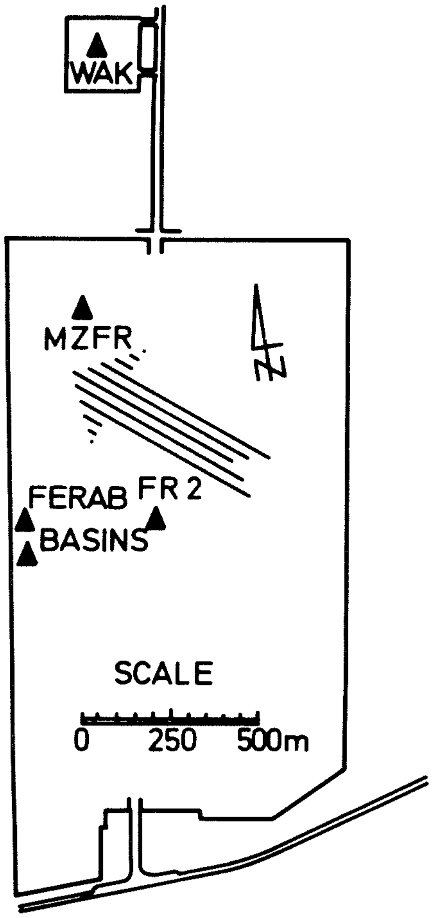


Fig. 1 Site plan indicating the main tritium emitters ▲ of the Karlsruhe Nuclear Research Center ←— Direction of ground water flow

On discovery, the leakage was immediately repaired. As a result of this incident there was a considerable increase in the tritium concentration in the ground water.

Several ground water drillings were made on the premises of the sewage treatment plants so that the extent and diffusion of tritium contamination of the ground water could be controlled. The ground water in the area of the Karlsruhe Nuclear Research Center flows from south-east to north-west. The ground water level lies about 4.7 m deep. For the flow direction see Figs. 1 and 3. The variation in time of the tritium concentration of the ground water has been observed regularly [3].

3. SAMPLING PROGRAM

3.1 LOCATIONS AND FREQUENCIES OF SAMPLING

As already mentioned in the introduction, the investigation of the tritium concentration was carried out at one sampling location. Fig. 2 shows the main tritium emitters of the Karlsruhe Nuclear Research Center as well as the three sampling locations: 'West,' 'North-East' and 'Reference.' At these sampling locations, among others, investigations of the tritium concentration were carried out before the period of the present program [1, 2]. The sampling program comprises tritium investigations at location 'West.' This location makes it possible to observe the conditions stated above.

The position of the sampling location to the west of the Karlsruhe Nuclear Research Center is of special interest on account of the conditions for tritium contamination in the surrounding district by gaseous effluents from the main emitters, such as MZFR, FR 2 as well as FERAB, near the prevailing NE wind direction. Angular deviation of the main wind direction creates fluctuating conditions for the tritium concentration in air humidity in the area surrounding the sampling location.

The position close to the sewage treatment plants creates favourable conditions to study tritium contaminations in the environment by liquid effluents and by evaporation into the air from an uncovered surface, situated 2 m above ground level, formed by the four final buffer basins having a total area of 800 m^2. The effect of evaporation from the basin areas is the main reason for tritium contamination in air humidity. This contamination depends on the tritium concentration levels in liquids in the final buffer basins and on the temperature of the environment, on the wind velocity and on the diffusion category at the time. The tritium concentration in the final buffer basins reaches very high values and is subject to frequent time fluctuations.

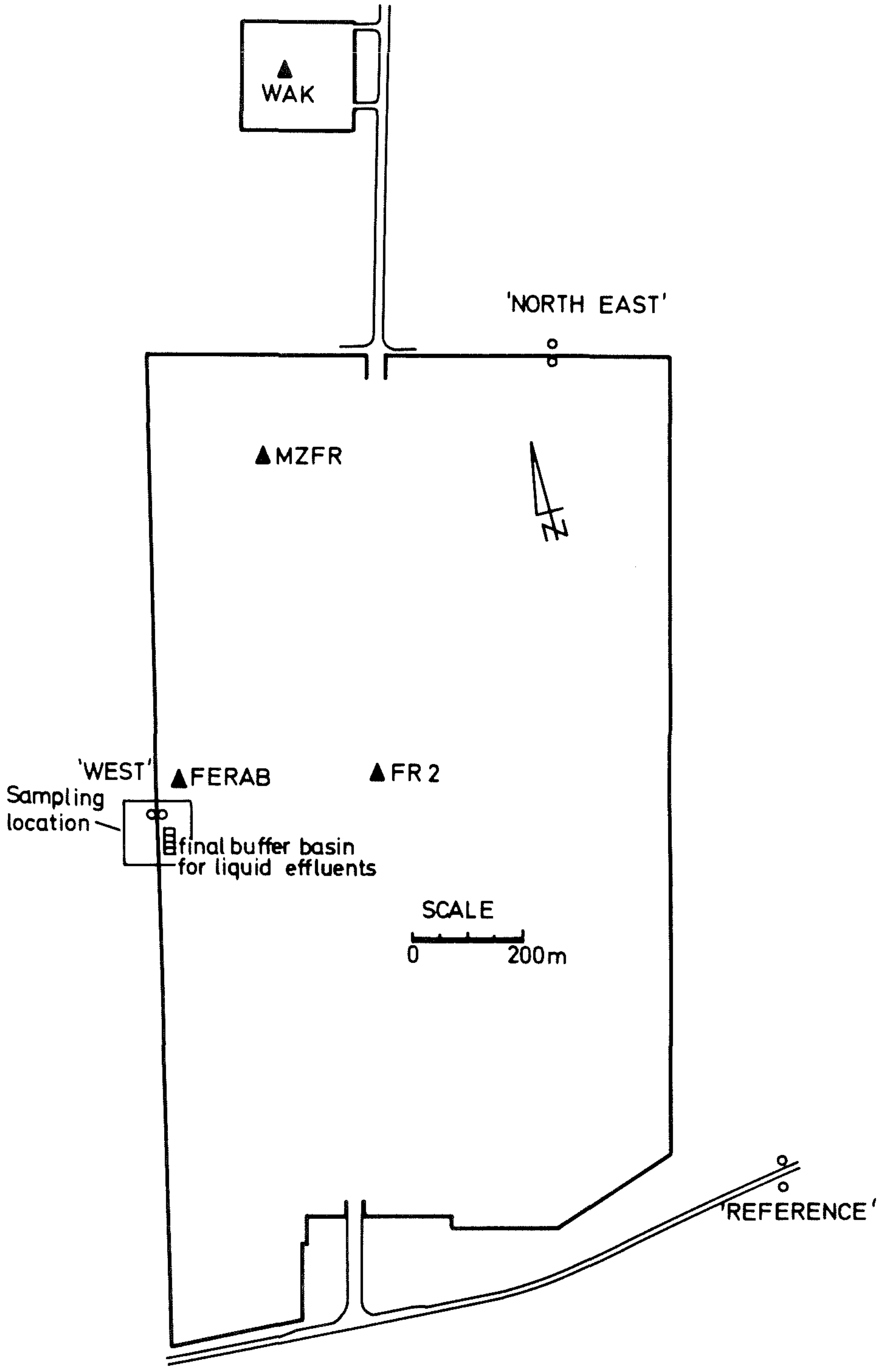


Fig. 2 Site plan indicating the 'West,' 'North-East,' 'Reference' sampling locations and the main tritium emitters.
□ Sampling location for present program (see Fig. 3).

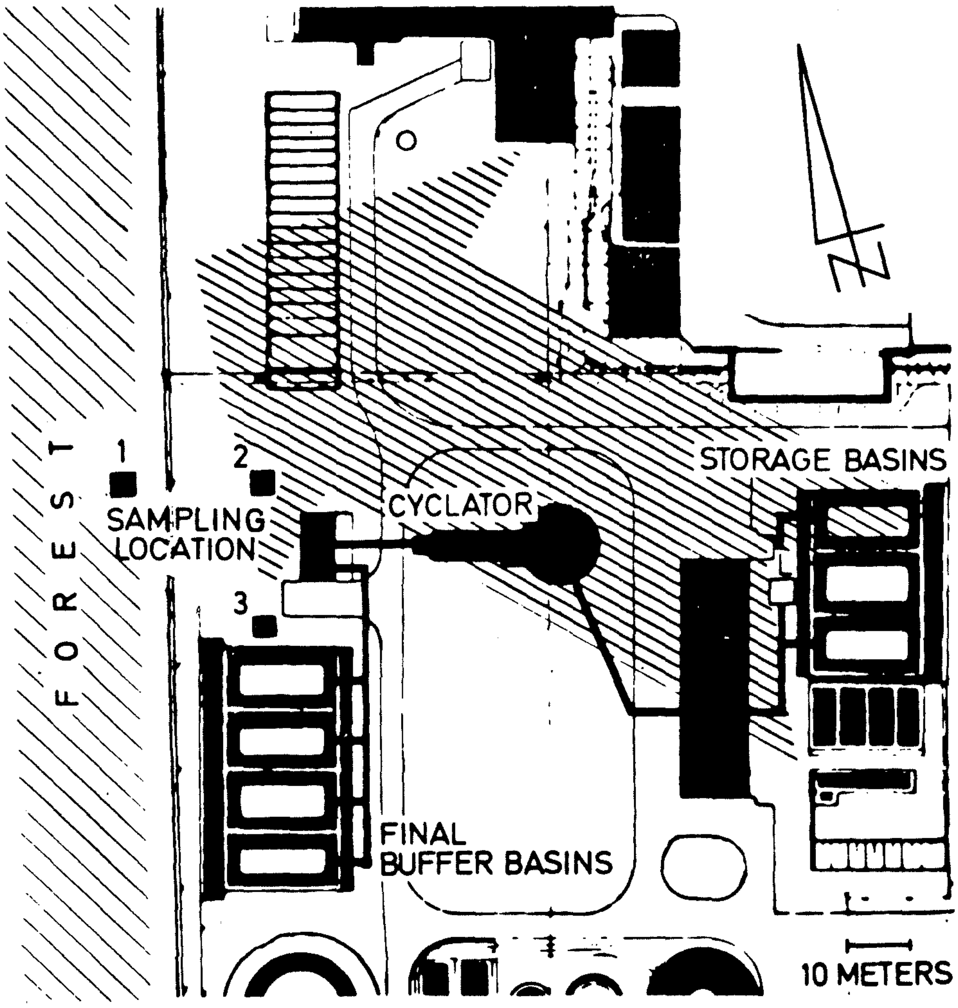


Fig. 3 Site plan of the 'West' sampling location

Sampling points:
1 - Ground water, spruce needles, oak and hornbeam leaves.
2 - Air humidity, precipitation, wind velocity and wind direction records.
3 - Precipitation - second point.

Fig. 3 shows the sampling points and the vicinity. The arrow represents the flow direction of ground water. The point specified by index 1 is situated on the edge of the forest surrounding the Karlsruhe Nuclear Research Center. Ground water and plant samples were taken here. The ground water is collected by means of drilling (drilling X). Samples of needles and leaves were collected from selected trees growing in the western part of the area having a radius of 5 m. The ground water drilling is situated in the centre of this area. Pine needles were taken from a height of about 12 m, the trees themselves being about 15 m high. The height of spruce and oak trees is about 4 m. However, the hornbeams are about 8 m high. Oak and hornbeam leaves, and spruce needles were taken from a height of about 1.5 to 2 m from the ground.

During the period in which the program was carried out samples were taken only from the trees selected. The point marked index 2 shows the air humidity and the precipitation sampling point. Here the equipment was installed to facilitate continuous wind measurements and to record wind velocity and wind direction.

Air humidity samples were taken twice a day (7-hour and 17-hour periods). The point marked index 3 situated close to the final buffer basins indicates an additional point for collecting precipitation.

The samples of air humidity, ground water, precipitation and plants were collected exclusively on weekdays. The tritium concentration in liquid effluents was controlled in the four final buffer basins. The tests were made simultaneously from the four basins at regular intervals during a period of 24 hours.

Type of sample	Frequency of sampling	Number of samples investigated
Pine	once a week	27
Spruce	three times a week	61
Oak	" " "	43
Hornbeam	" " "	58
Air humidity	twice a day	153
Ground water	once a week	24
Precipitation		56
Liquid effluents from final buffer basins	6 times a day 4 times a day 2 times a day	347
Total		769

Table 2 Survey of the sampling program

3.2 AIR HUMIDITY

Tritiated water vapour was collected from water vapour in air, condensed on the surface of dry ice. A container, 1 m above ground and filled with dry ice, was placed at the top of a tripod. The top of the tripod was securely covered with polythene just above the top of the container so that the ice would be protected from precipitation. At the same time there was enough space to allow the wind to make contact with the surface of the dry ice. Condensed water vapour was collected in a plastic bag, marked with the date and the period when the samples were collected. To avoid contamination in subsequent sampling, the ice and plastic bag were replaced after each sampling period.

As a consequence of the sampling method, average values of the tritium concentration in air humidity were obtained for the sampling period. The volume of the humidity collected is mainly a function of the dry ice surface and the absolute air humidity during the sampling period, expressed in g/m^3 of air, ignoring other parameters influencing the process of condensation.

The variation of the tritium concentration in the air represented in pCi/m^3 is shown in Fig. 8. This variation is obtained by calculating the average level of the tritium concentration in air humidity during the sampling period, expressed in pCi/ml, as well as the hourly values of absolute air humidity in g/m^3.

The program also included two sampling periods in air humidity during a period of 24 hours, at intervals of 7 and 17 hours. The tritium concentration level measured in air humidity is an average of the variation in time. The error of this average value arises from this particular sampling technique, resulting in changes affecting the surface of the dry ice during the sampling period. The varying intensity of the condensation of water vapour is due to changes in wind velocity and a short-term change in the tritium concentration in air with different values of absolute air humidity.

For the purpose of the program satisfactory results were obtained using the above mentioned method. The change in the tritium concentration in air quite definitely shows the correlation with the other values which have been measured and calculated (see Figs. 8, 12 and 13).

3.3 PRECIPITATION

For the collection of precipitations, a plastic container with a capacity of 1000 ml was used. The container was equipped with a rubber cork and plastic funnel. The effective surface area for collecting amounted to 176 cm^2. Each volume sampled was measured and calculations were made to determine the amount of precipitation in mm. The tritium surface load in nCi/m^2 was calculated from the tritium concentration in pCi/ml and the amount of precipitation.

3.4 GROUND WATER

This was collected by means of electrically driven pumps. Samples were collected after ten minutes of pumping. The optimal sampling time had previously been established at the Health Physics Division for the purpose of carrying out programs concerning the investigation of the tritium concentration in ground water.

Fig. 4 illustrates the change in the tritium concentration level with relation to the pumping time (drilling X). This relationship was evaluated while the program was being carried out. The early stages of pumping were characterized by the change of the tritium concentration in time. After 30 minutes of pumping the value became steady and was found to correspond to the tritium concentration level after ten minutes of pumping. This is illustrated in Fig. 4 and can be related to the turbulent movement of water at the beginning of the pumping period causing the mixing ot different tritium contamination levels in water. Subsequently, the average tritium concentration stabilized.

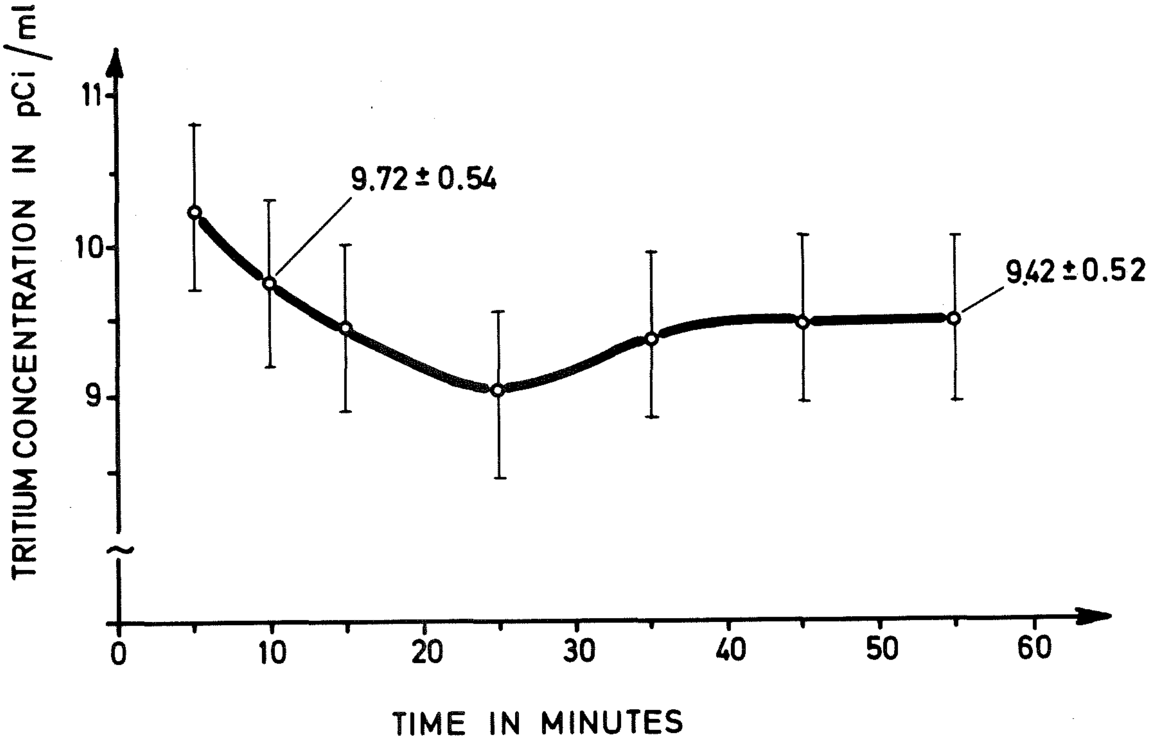


Fig. 4 Tritium concentration in ground water in relation to the pumping time.

3.5 LIQUID EFFLUENTS

The control of the tritium concentration in the four final buffer basins constituted the part of the program which was to establish the tritium concentration in liquid effluents in a short period. An average tritium concentration level over a period of 24 hours was calculated to obtain the rate of emission by evaporation from the 800 m^2 surface of the final basins.

The samples of water were collected simultaneously from four basins at regular intervals in a 24 hour period. Subsequently 10 ml were taken from each sample by means of a pipette and then mixed and distilled.

On account of the high concentration of tritium in the samples, the distilling process and the sampling preparation for the measuring tests were carried out separately in a laboratory designed for testing samples with high level tritium concentrations. The measurements were made by using a liquid scintillation spectrometer, applying dioxane scintillation solution and using a measuring time of 10 minutes. Typical measurement cocktail for samples with a higher tritium concentration level consists of 1 ml of water only and 19 ml of dioxane/PPO/POPOP-scintillation solution.

3.6 PLANTS

The tritium concentration in the tissue water of pine and spruce needles, oak and hornbeam leaves was investigated simultaneously by using azeotropic and vacuum distillation methods to extract the tissue water. A large number of the samples investigated were subjected to azeotropic distillation by xylene. This method enabled the distilled product to be obtained within a short time whereas the vacuum distillation process takes more time. Vacuum distillation supplied two products, a distillate and dry biological matter (dry samples) enabling the determination of biologically "bound tritium," which is not possible with the azeotropic method. One of the main reasons for using both methods was to compare the measuring results after azeotropic distillation and vacuum distillation. It was found that the azeotropic distillation process can be used for routine measurements of the tritium concentration in plants, soil, etc. A summary of the results obtained is given in Chapter 3.7.

Samples were taken three times a week. Larger samples were taken for both azeotropic and vacuum distillation, successively for spruce needles, pine needles and hornbeam leaves. The dry samples obtained from vacuum distillation were stored in sealed glass jars. Selected samples were sent to the Department of Radiobiology at CEN in Mol, Belgium, for the purpose of determining the "bound tritium."

3.7 VACUUM AND AZEOTROPIC DISTILLATION

The measured results of the tritium concentration in the tissue water of plants by using simultaneously the methods of vacuum and azeotropic distillation are included in Table 3. The measured results as well as the erroneous measurements are given to two decimal places. The results were calculated by a mini-computer in conjunction with a liquid scintillation spectrometer.

Date 1976		Tritium Concentration in pCi/ml					
		Spruce needles		Pine needles		Hornbeam leaves	
		distillation vacuum	distillation azeotropic	distillation vacuum	distillation azeotropic	distillation vacuum	distillation azeotropic
Aug.	9	6.07±0.36	7.21±0.50				
	11			7.92±0.45	7.72±0.47		
	13					2.99±0.26	3.65±0.29
	16	3.74±0.28	3.72±0.31				
	18			13.27±0.57	13.76±0.60		
	20					3.90±0.29	5.21±0.34
	23	5.34±0.34	5.68±0.37				
	25			12.00±0.51	12.26±0.59		
	27					5.17±0.34	4.95±0.33
	30	3.89±0.30	3.58±0.35				
Sep.	1			7.73±0.40	8.31±0.44		
	3					1.39±0.20	2.47±0.33
	6	1.74±0.21	2.16±0.25				
	8			9.52±0.46	9.35±0.46		
	10					0.88±0.19	0.95±0.19
	13	1.55±0.21	1.71±0.22				
	15			6.95±0.37	7.21±0.40		
	17					1.52±0.22	1.53±0.22
	20	2.61±0.24	2.51±0.24				
	22			7.42±0.38	7.72±0.41		
	24					2.90±0.27	2.94±0.27
	27	1.62±0.22	1.93±0.25				
Oct.	1					2.39±0.25	2.69±0.25
	4	2.02±0.22	2.10±0.24				
	6			7.74±0.39	7.66±0.39		
	8					1.84±0.23	2.03±0.24
	11	2.77±0.27	2.94±0.28				
	13			5.88±0.35	5.81±0.38		
	15					12.74±0.56	13.87±0.60
	18	2.54±0.24	3.03±0.27				
	20			5.94±0.34	6.58±0.36		
	22					4.38±0.29	4.44±0.34
	25	8.22±0.41	8.70±0.45				
	29					31.14±1.05	30.48±1.03
Nov.	3			55.72±1.74	56.98±1.78		
	5					239.82±9.34	234.81±6.42
	8	85.42±3.44	71.19±2.87				
	10			61.00±2.46	63.55±2.57		
	*10			*0.81±0.18	*0.80±0.18		
	12					80.44±3.25	81.27±3.28

Table 3 Results of simultaneous measurements of the tritium concentrations in the tissue water of spruce and pine needles and hornbeam leaves by using the azeotropic and vacuum distillation methods. The values marked by an asterisk refer to the 'Reference' sampling location (see Fig. 2).

Accuracy to two decimal places is the convention for these mini-computer calculations. All results calculated by a mini-computer were used directly without any approximation of the results. The above mentioned comment refers to all the measured results in this program.

The measurements carried out by using both methods of distillation furnished better results than expected, considering the number of errors arising from (1) the different methods of distillation, (2) the procedures used in the preparation of the samples and (3) the measurements themselves. The results of the test methods show that the results in the subsequent part of this work are also accurate.

Caution: The process of azeotropic distillation must be optimized by means of temperature control or power distribution during the process of distillation.

4. MEASURING TECHNIQUE [4]

The tritium concentration is measured by means of the liquid scintillation technique. In this way it is possible to measure a large number of samples largely automatically with a satisfactory limit of detection.

The scintillator used is the commercial three component 'Insta-Gel' scintillator. The gel formation of the so-called measuring cocktail, which starts with a mixing ratio of at least one part of water (as the material to be measured) and three parts of scintillator, prevents demixing of the material to be measured and the scintillator in the course of the measurement after the sample has been prepared. A test series indicated that the most advantageous mixing ratio for the maximum possible sensitivity of detection was a composition of the sample of 10 ml of water as the material to be measured and 12 ml of Insta-Gel. Polyethylene plastic bottles with a volume of 23 ml were used for the measurement.

In tritium measurements in the low level range the reliable assessment of the background rate is a factor of special importance. The background rate, R_0, is the measured rate obtained on a completely tritium-free "background water" or a sample with a sufficiently low tritium content instead of the material to be measured, the other measuring conditions remaining unchanged. "Background water," for example, is water obtained by burning propane gas.

The counting efficiency necessary to calculate the sample activity results from the so-called quench correction curve, which describes the relation between the efficiency η and the so-called ESCR (external standard channel ratio). The ESCR is obtained from the pulse rates of two adjacent counting channels specially prepared for the purpose (so-called "standard counting channels") and is a measure of the degree of quenching of the sample. The pulse rates registered in these special counting channels correspond to the Compton spectrum of electrons produced by the radiation of γ-quanta from a radioactive specimen added from the outside, which in a way simulate a tritium activity for the rapid determination of the degree of quenching. An accurate measurement of the sample activity therefore requires the most accurate determination of the individual degree of quenching of the sample, the so-called ESCR, which will be called the S-value for short in this study. In order to generate a safe S-value, the samples are measured for 20 minutes each in 5 successive runs. The mean value is derived from the 5 S-values determined in each of these runs. This was found to be necessary because the samples prepared with Insta-Gel exhibit a time dependent drift towards lower S-values.

Measuring in five runs for successive periods of time both the "quenching series" (a series of samples prepared with calibration standards of different degrees of quenching to determine the quenching correction curve) and the routine samples largely compensates for this drift. The output unit, a printing mini-computer, is programmed in such a way that the results of each run of the 20 minute measurements (activity concentration and S-value) and the mean values after a total sample measuring time of 100 minutes are printed out. In this way it is easy to find out whether the measured values were constant or whether it would be advisable, because of some specific influences, to repeat the measurement. Moreover, in accordance with the accumulated measuring time, the 2σ-error and the limits of detection of the individual samples are computed and printed out.

4.1 SAMPLE PREPARATION

In order to avoid upsetting of the tritium measurement by other nuclides and to achieve the most uniform quality of the material to be measured, in principle all the samples are distilled. To prevent a memory effect in the system as a result of the distillation of samples with different tritium concentrations, the distillation apparatus is vacuum dried before each run. Distillation of the water to be measured e.g. ensures that the quench varies on such a small scale that the quench correction curve may safely be regarded as linear in this range. This simplifies the calculation of the sample activity, which is carried out by means of an on-line mini-computer.

In the preparation of the samples the 10 ml of the material to be measured are added 12 ml of Insta-Gel each in a sharply focused stream by means of dosing equipment so that thorough mixing and homogeneous distribution are ensured. If the substance is added without the necessary force, a gel plug may be formed between the material to be measured and the scintillator, which prevents further mixing and may falsify the measurements.

In order to avoid spurious luminescence phenomena (such as chemoluminescence or photoluminescence), the samples are prepared in the dark room in green light and subsequently kept for 2 hours at approximately 70 °C. In order not to disturb the temperature in the Liquid Scintillation Counter (10 °C) and avoid falsifications of the measured results by thermoluminescence effects, the samples are cooled to the temperature of the measuring room in a refrigerator before being introduced into the measuring set up.

4.2 DETECTION LIMIT

The limit of detection, a_N, is calculated by means of the following equation:

$$a_N = \frac{2k \cdot (R_0/T)^{1/2}}{\eta \cdot V \cdot 2{,}22 \text{ dpm/pCi}}, \qquad (1)$$

where R_0 is the background rate, T the total measuring time used to determine the sample and background measuring rates, V the volume of the material to be measured, and η the counting efficiency. In accordance with twice the standard deviation, the factor k is assumed to be equal to 2. Eq. (1) applies under the condition that the measuring times for determining the background measuring rate and the sample measuring rate are identical.

After optimization of the measuring channel setting, which depends upon the measuring gear used, the resultant background rates will be between 3 and 5 cpm and the counting efficiencies will be between 14 % and 19 %. For a measuring time selected of T/2 = 100 min and for 10 ml of material to be measured, the limits of detection achieved vary between 0.15 pCi/ml and 0.2 pCi/ml [4].

4.3 MEASURING ERRORS

The tritium concentration a of a water sample measured in the liquid scintillation spectrometer is obtained by the equation

$$a = \frac{R_M - R_0}{\eta \cdot V \cdot 2{,}22 \text{ dpm/pCi}}, \qquad (2)$$

where the gross pulse rate in cpm was denoted R_M.

The relative error r_a of the concentration a is made up for a statistical term r_{st} from the determination of the net pulse rate $(R_M - R_0)$, a term r_η from the determination of the counting efficiency η, and a term r_V from the determination of the volume V of the measured sample. The relation holds

$$r_a = (r_{st}^2 + r_\eta^2 + r_V^2)^{1/2} . \qquad (3)$$

For the relative error r_{st} of the net pulse rate $(R_M - R_o)$ we obtain

$$r_{st}^2 = \frac{1}{T_o} \frac{R_M + R_o}{(R_M - R_o)^2} . \qquad (4)$$

To determine the pulse rate R_M and R_o, the same counting times T_o were used.

The relative error r_η of the counting efficiency η is composed of three elements:

(a) Systematic error due to the use of an inaccurate calibration standard.

To take into account this error, the information about $r_E(\eta)$ is taken from the supplier.

(b) Error in the determination of the quenching correction line.

The quenching correction line reads

$$\eta = mS + n.$$

Using the quenching series already mentioned N pairs of values (η_i, S_i) are determined empirically. The optimum values for m and n can be calculated from these pairs of values. The relative error contribution from the inaccurate determination of the quenching correction line is obtained as

$$r_Q(\eta) = [\sum_i(\eta_i - mS_i - n)^2 / (N - 2)]^{1/2} \frac{1}{\eta} .$$

(c) Error in the determination of S.

In the determination of S an error σ_S is made which contributes to the relative error of η according to the relation

$$r_S(\eta) = \frac{m\,\sigma_S}{\eta} .$$

Thus, the relative error r_η of the counting efficiency reads

$$r_\eta = [r_E^2(\eta) + \frac{m^2\,\sigma_S^2}{\eta^2} + \frac{\sum_i(\eta_i - mS_i - n)^2}{\eta^2(N - 2)}]^{1/2}. \qquad (5)$$

According to information from the supplier three times the standard deviation of the calibration standard used here is 3.3 %. Since only the simple standard deviation is to be considered here to begin with, $r_E(\eta)$ has to be set 1.1 %. The error percentage $[r_Q^2(\eta) + r_S^2(\eta)]^{1/2}$ resulting from the determination of the quenching correction line and of the value S makes a contribution of 1.2 %. According to Eq. (5), r_η is obtained to be 1.6 %.

The relative volume error r_V of a is calculated according to the equation

$$r_V = \frac{\sigma_V}{V} , \qquad (6)$$

where σ_V is the standard deviation from V which can be determined in the familiar way. r_V is estimated at 1 %.

Introducing in Eq. (3) the expressions of Eqs. (4), (5), and (6), the relative error of the tritium concentration becomes

$$r_a = [\frac{1}{T_o} \frac{R_M + R_o}{(R_M - R_o)^2} + A]^{1/2}$$

$$\text{with } A = r_E^2(\eta) + \frac{m^2 \sigma_S^2}{\eta^2} + \frac{\sum\limits_i (\eta_i - mS_i - \eta)^2}{\eta^2 (N - 2)} + \frac{\sigma_V^2}{V^2} . \qquad (7)$$

Using the numerical values indicated above, one obtains $A = 3.65 \times 10^{-4}$. So, the error r_a is composed of a statistical portion arising from the determination of the net pulse rates and a practically constant portion A. At little net pulse rates the statistical portion dominates. At high net pulse rates the residual error is about 1.9 %.

5. RESULTS OF MEASUREMENTS

The results cover the period from August 9 to November 10 inclusive. This period includes the end of leaf growth. The measurements were carried out under very different conditions of tritium emission into the environment by gaseous and liquid effluents (see Chapter 5.5)

Such variation in the conditions of emission was the reason for the significant change of tritium concentrations in air humidity, ground water, precipitation and plants. Table 4 shows the maximum and minimum results of the tritium concentration measured in the samples investigated as well as the range of tritium concentration for each type of sample, through the ratio of maximum and minimum values.

Tritium Concentration	Air humidity	Ground water	Precipitation	
	pCi/ml	pCi/ml	pCi/ml	nCi/m^2/d
Maximum	277.48 ± 7.57	80.31 ± 3.23	61.03 ± 2.49	229.13 ± 9.73
Minimum	0.29 ± 0.18	7.02 ± 0.35	0.16 ± 0.16	0.18 ± 0.15
Maximum/ Minimum	956.8	11.4	381.4	1 272.9
Tritium Concentration	Needles		Leaves	
	Spruce	Pine	Hornbeam	Oak
	pCi/ml	pCi/ml	pCi/ml	pCi/ml
Maximum	71.19 ± 2.87	63.55 ± 2.57	234.81 ± 6.42	235.77 ± 9.17
Minimum	1.44 ± 0.21	5.42 ± 0.34	0.95 ± 0.19	1.11 ± 0.21
Maximum/ Minimum	49.4	11.7	247.2	212.4

Table 4 Results of measuring the tritium concentration in air humidity, ground water, precipitation, plants at the sampling location. Table 4 consists of maximum and minimum values measured during the investigation period.

The samples of air humidity, precipitation, ground water and tissue water of plants were treated as 'low level' samples. During the period of the program a sufficient quantity of all the samples mentioned above was taken in order to make three separate measurements. The measurements were repeated when the results obtained were doubtful.

5.1 TRITIUM IN PLANTS

The different types of plants investigated show the variations in time of the tritium concentration in tissue water of pine and spruce needles, oak and hornbeam leaves. The results of this investigation are shown in Fig. 5.

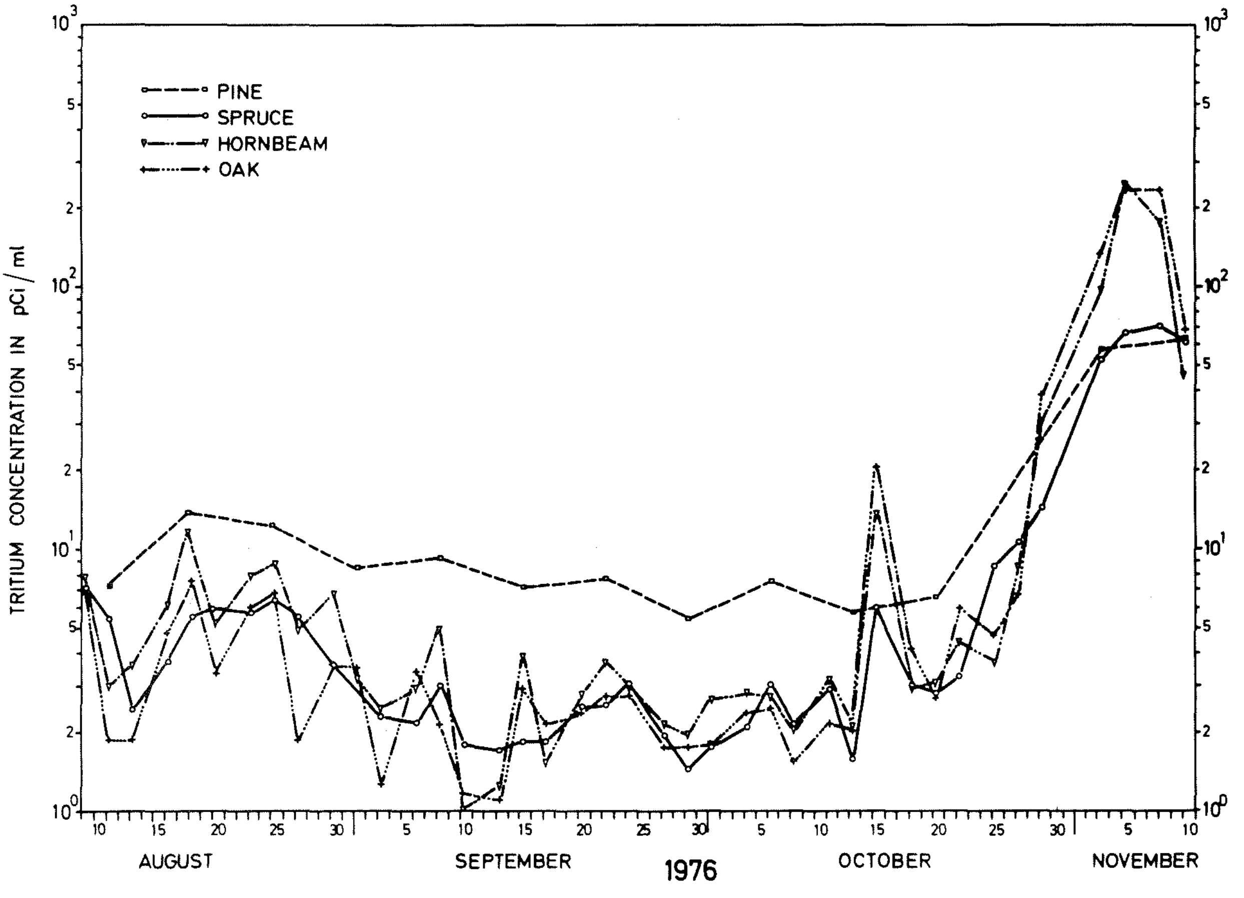


Fig. 5 Representation of the variation with time of the tritium concentration in pine and spruce needles, hornbeam and oak leaves.

This presentation gives an impression of the existing tritium contamination level and its short time variations. The detailed results of the tritium concentration in the tissue water of plants are shown in Table I in the Appendix. Two periods are distinguished when analysing the character of the tritium contamination. The first period from August 9 until September 30 is characterized almost exclusively by gaseous effluents from MZFR, FR 2, FERAB. The second period until November 10 includes a significant emission of gaseous effluents from reactor stacks and the evaporation from final buffer basins (see Figs. 12 and 13). A certain difference in the conditions of tritium contamination in plants has to be taken into account. This follows from the conditions for carrying out the sampling program, for example:

(1) the difference in the heights of sampling, about 12 m for pine needles, 1.5 - 2 m for spruce needles, oak and hornbeam leaves;

(2) the different species of trees (pine, spruce, oak, hornbeam);

(3) the different ages of the trees. In the case of old pine trees, the height is about 15 m, hornbeam 8 m, spruce and oak about 4 m;

(4) the different development in the root system related to the period of tree growth.

The first period (see Fig. 5) is characterized quite clearly by the dominant level of tritium contamination in pine needles (one sample per week). The average level of tritium contamination in hornbeam, oak leaves and spruce needles is lower. The variation in tritium concentrations is characterized by the distinction between maximum and minimum peaks (three samples per week).

The highest level of contamination occurs in the peaks for hornbeam leaves, a lower level for oak leaves and the lowest level for spruce needles. The change in contamination levels is particularly rapid in hornbeam and oak leaves, as is evidenced by the increase and decrease in the contamination level of tritium as a function of time. In the case of spruce and pine needles, however, the times are considerably longer (time constants and half-lives, respectively, of tritium). Compared with the other plants tested the lowest peaks of tritium contamination are found in oak leaves.

A precise correlation with the tritium concentration in air was found in the three kinds of tree from which samples of leaves and needles were collected three times a week. The characteristic peaks of high and low tritium concentrations in oak and hornbeam leaves and spruce needles correspond with the maximum and minimum values of tritium concentration in air (see Fig. 6). This relationship is not so clear in the case of pine, however, as the change represents the average tritium concentration in air for the sampling period of one week. The highest tritium contamination is to be found in pine needles, one of the reasons being that the water is absorbed by the root system and transported to the branches and leaves of the tree from varying depths of soil having different contamination levels.

The second period from October 1 to November 10 is characterized by a significant emission from reactor stacks and through evaporation from final buffer basins (see Figs. 12 and 13). The high concentration of tritium in air humidity produced a significant contamination of tritium in all the plants investigated. The influence from the four final buffer basins is particularly strong as a result of the evaporation of tritiated water vapour into the air.

The variation of tritium contamination in plants is indicated by two sharp peaks of high concentrations. The range of variation in the tritium concentration of plants is about a factor of 1000. The reason for the high peak on October 15 is the emission through evaporation from the final basins. The next peak in the November 5 to 8 period is due to the simultaneous emission of gaseous effluents from reactor stacks and the evaporation from the final basins.

There are certain characteristic variations in the process of tritium contamination in oak and hornbeam leaves. In the successive peaks of high tritium concentration on October 15 and 22 as well as during the period of increasing tritium concentration up to the moment when the maximum values were reached on November 5 to 8, the level in oak leaves was found to be higher than the level in hornbeam leaves. This contrasts with the first period discussed where the level in hornbeam leaves reaches a higher level.

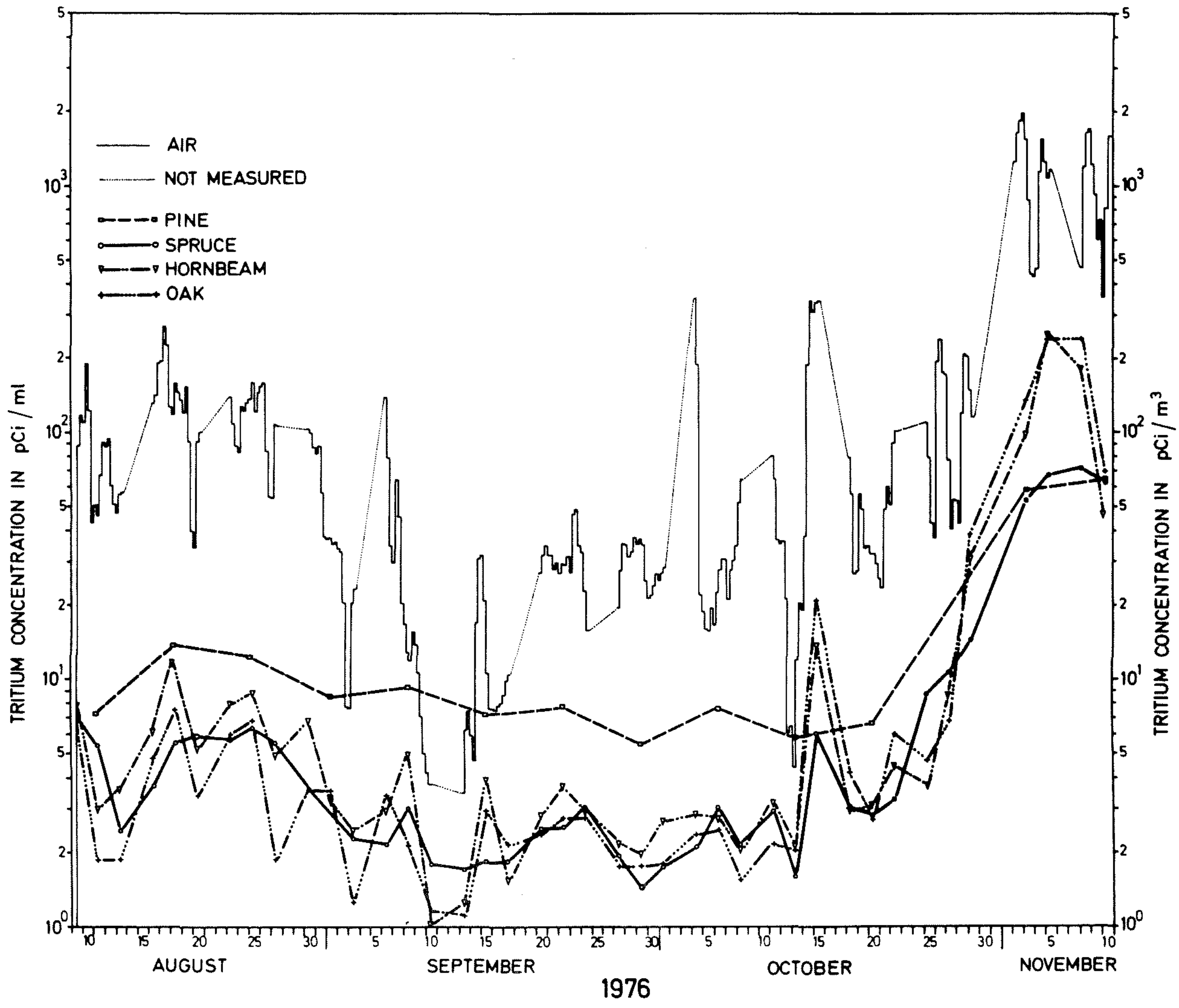


Fig. 6 Representation of the variation with time of the tritium concentration in air, pine and spruce needles, hornbeam and oak leaves.

The last peak on November 5 to 8 is characterized by a certain kind of 'saturation' - the tritium contamination levels in oak and hornbeam leaves are identical, analogous to the identical levels occurring in the case of pine and spruce needles. The levels of tritium contamination are different for leaves and needles. The values of tritium concentration in oak and hornbeam leaves exceed the levels in pine and spruce needles by about a factor of 3. Figs. 5 and 6 show the different character of tritium contamination for different kinds of trees. The fact that the levels of tritium contamination are the same in pine and spruce needles can be interpreted as being due to the considerable tritium emission at ground level caused by the evaporation from the final basins, and to two different heights of sampling for spruce needles, i.e. about 12 m, and for pine needles, 1.5 - 2 m. This is also borne out by the balancing out of the tritium concentration in pine and spruce needles in the peak on October 15.

The period discussed is characterized by the slow vegetative process of the tree leaves including their entire loss after November 10.

The leaf samples were taken during the second half of October, which explains the gradual disappearance of the green colour. On November 10 the colour change comprised 90 - 100 % of the leaf surface. In the discussion of tritium contamination the term 'saturation' is used which, in the case of leaves, can be linked with the accumulation of tritium during the end of the vegetation period.

The appearance of maximum and minimum peaks of the tritium concentration in leaves has a longer rate of increase and decrease and shows a smaller amplitude, contrasting with the character of the change in spruce needles (twice the value of tritium concentration in spruce needles reached a lower value than in leaves). The character of the tritium contamination in leaves is different in the second period, the maximum values occurring in oak leaves.

The variation of the tritium concentration in the tissue water of pine needles by taking one sample per week is similar to the change of the tritium concentration in ground water (see Fig. 8). The variation of the tritium concentration in spruce needles, oak and hornbeam leaves by taking three samples per week provides a precise correlation with the change of tritium concentration in air (see Fig. 6).

Three new curves were obtained by connecting only those points of tritium concentration in spruce, oak and hornbeam in Fig. 5 which correspond to the sampling dates for pine. These new curves are related to sampling once a week and therefore analogous to the sampling frequency for pine. These values were obtained from the influence of average tritium concentrations in air. As already shown, this representation eliminates all information about the maximum and minimum values of tritium concentration in plants, which correlates precisely with the maximum and minimum values of tritium concentration in air. The new graph is shown in Fig. 7.

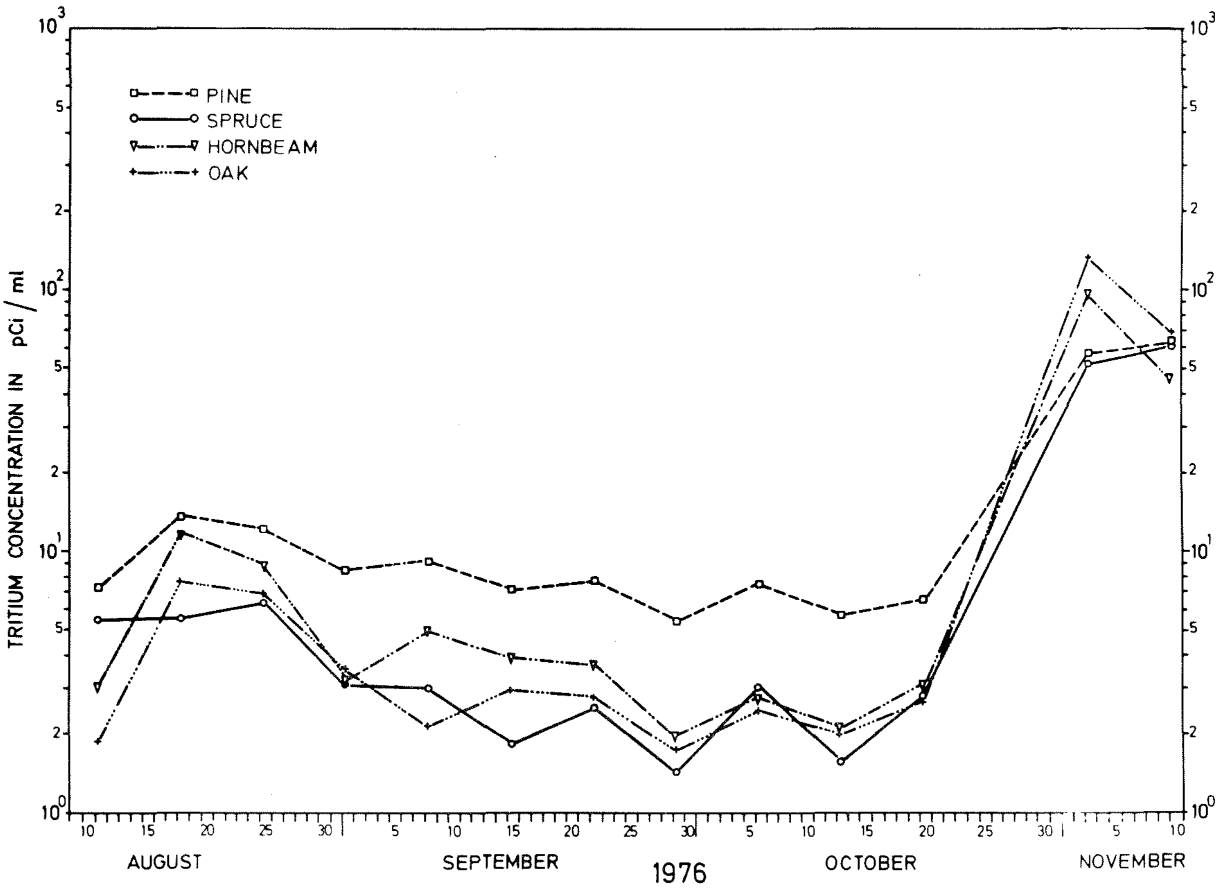


Fig. 7 Representation of the variation with time of the tritium concentration in pine and spruce needles, hornbeam and oak leaves for a sampling frequency of once a week.

Sampling once a week made up for the lack of information concerning short term changes of the tritium concentration in pine needles; the influence of the tritium concentration in air is less clear than in the other plants. These curves, however, represent the influence of the average tritium concentrations in air in the periods between the sampling dates.

The minimum values of the tritium concentration in plants correspond with periods of rainfall, a particularly clear effect in the case of oak and hornbeam leaves during the first period of the program (see Figs. 5, 6, 9).

The variation of the tritium concentration in tissue water of plants allows one to determine the time constants and the half-live nature of the process. The following values are found: for oak and hornbeam leaves 2 ± 1 days, for spruce needles 3 ± 1.5 days, for pine needles 6 ± 3 days.

Some samples were taken on November 10 at the 'Reference' location to show clearly the fundamentally different conditions in tritium contamination at this location compared with the 'West' location. Table 5 shows the measured results of the samples taken simultaneously with the locations mentioned above.

Sampling Location	Ground water pCi/ml	Leaves Hornbeam pCi/ml	Needles Spruce pCi/ml	Needles Pine pCi/ml
'West'	35.15±1.09	45.92±1.91	60.96±2.48	63.55±2.51
'Reference'	0.17±0.17	0.85±0.20	0.94±0.20	0.80±0.18

Table 5 Results of simultaneous measurements of the tritium concentrations at the 'West' and 'Reference' sampling locations

5.2 TRITIUM IN AIR

The curve representing the change of the tritium concentration in air is shown in Figs. 6 and 8. This curve is in fact the variation of the tritium concentration in air in pCi/m^3 and is obtained by calculating the average values of the tritium concentrations in air every 6 hours. Table II in the Appendix contains the average values of the tritium concentration in air humidity obtained from the results measured in two sampling periods within 24 hours.

The calculated values of the tritium concentration in air for every hour amount to a significant volume of material, the publication of which would serve no purpose.

On the basis of the measured results the background level of the tritium concentration in air was established for the sampling location. The value was obtained as an average of the three measured results on September 13 and 14 as well as October 13 (see Table 6).

Date	Tritium concentration in air humidity in pCi/ml	Absolute air humidity in g/m^3	Wind direction in degrees	Deviation of wind direction in degrees
Sep. 13	0.29 ± 0.18	12.17	231.7	± 23.30
Sep. 14	0.36 ± 0.17	10.04	220.2	± 5.26
Oct. 13	0.35 ± 0.18	9.50	281.4	± 5.85

Table 6 Average values of the tritium concentration in air humidity, absolute air humidity, wind direction and deviation of wind direction in selected air humidity sampling periods.

These values correspond to the background value in air of 3.5 pCi/m^3. The wind direction in selected air humidity sampling periods was opposite to the main NE direction, resulting in a high tritium concentration level in the vicinity of the sampling location.

The background level of the tritium concentration in air humidity can be changed to the limits 0.25 to 0.88 pCi/ml, corresponding to the change in absolute air humidity between 4 and 14 g/m^3 during the period of investigation.

The direct influence of the tritium concentration in air on the tritium concentration in plants has been discussed above. The results confirm that the tritium concentration in air is the most significant source of contamination of plants. Certain inaccuracies occur due to the small scale of the diagrams when attempting to represent precisely the influence of the tritium concentration in air. An additional factor is the calculation of the average tritium concentrations in air over periods of six hours. The reason for this calculations is to enable the figures to be fitted into the format of this publication.

The sampling point for collecting air humidity was located in the area of the Karlsruhe Nuclear Research Center, less than 15 m from the sampling point for plants (see Fig. 3). The angular deviation of both points in relation to the emitter area of the four final basins amounts to 13 degrees. A typical value for the wind direction over a period of several hours exceeded ± 15 degrees. It can be established that the same tritium concentration occurs in the air at both points. In the case of tritium emission from stacks the distance between the sampling points for air humidity and for plants does not affect the results at all.

Table III of the Appendix shows the daily changes of the tritium concentration in air on selected days. This table corresponds to Table 10 which shows the tritium concentration in air humidity at the sampling point and the relationship of this value with the emission rate and the frequency of wind directions in the angular sector for the individual emitters.

The measuring results indicate very precisely the correlation between the tritium concentration in air and plants as well as with the product of the frequency of the wind direction and the emission rate. Further information will be given below about the methods of estimating the influence of individual emitters on the tritium concentration in air at the sampling location.

5.3 TRITIUM IN GROUND WATER

Fig. 8 shows the change of the tritium concentration in ground water. The measured results are included in Table IV of the Appendix. The ground water in the area of the Karlsruhe Nuclear Research Center flows from south-east to north-west (see Fig. 2). The ground water is contaminated by tritium while slowly flowing through the area of the Karlsruhe Nuclear Research Center. Normally, the source of tritium contamination in ground water is precipitation wash-out; however, the dominant influence here is contamination through liquid effluents from the Sewage Treatment Plant. The tritium concentration in the ground water at the 'Reference' sampling location situated south-east of the Karlsruhe Nuclear Research Center has a level approximating the detection limit (see Table 5).

The tritium contamination in ground water occurs through the slow infiltration of precipitation into the soil. The tritium concentration in precipitations has different values as a result of varying contamination levels due to wash-out. This causes variations in the tritium concentration at different depths of soil. Liquid effluents from the final buffer basins also infiltrate into the soil close to the surface of the final basins below the ground level. It is difficult to evaluate this pathway of tritium contamination. Assessing the relationship between the tritium concentration in ground water and the tritium concentration in plants calls for a more elaborate long-term program.

During the period of investigation the changes of the tritium concentration in ground water and plants do not show any distinct relationship. The influence via the ground water not doubt has a characteristic long-term effect and takes place by means of capillary water. This kind of influence is dependent on the uptake of water through the root system at varying depths of soil and on the levels of tritium contamination in these depths.

In the case of leafy trees the loss of water to the air through the effect of surface evaporation from leaves over a 24 hour period is several times greater than the volume of water in leaves. The leaves are

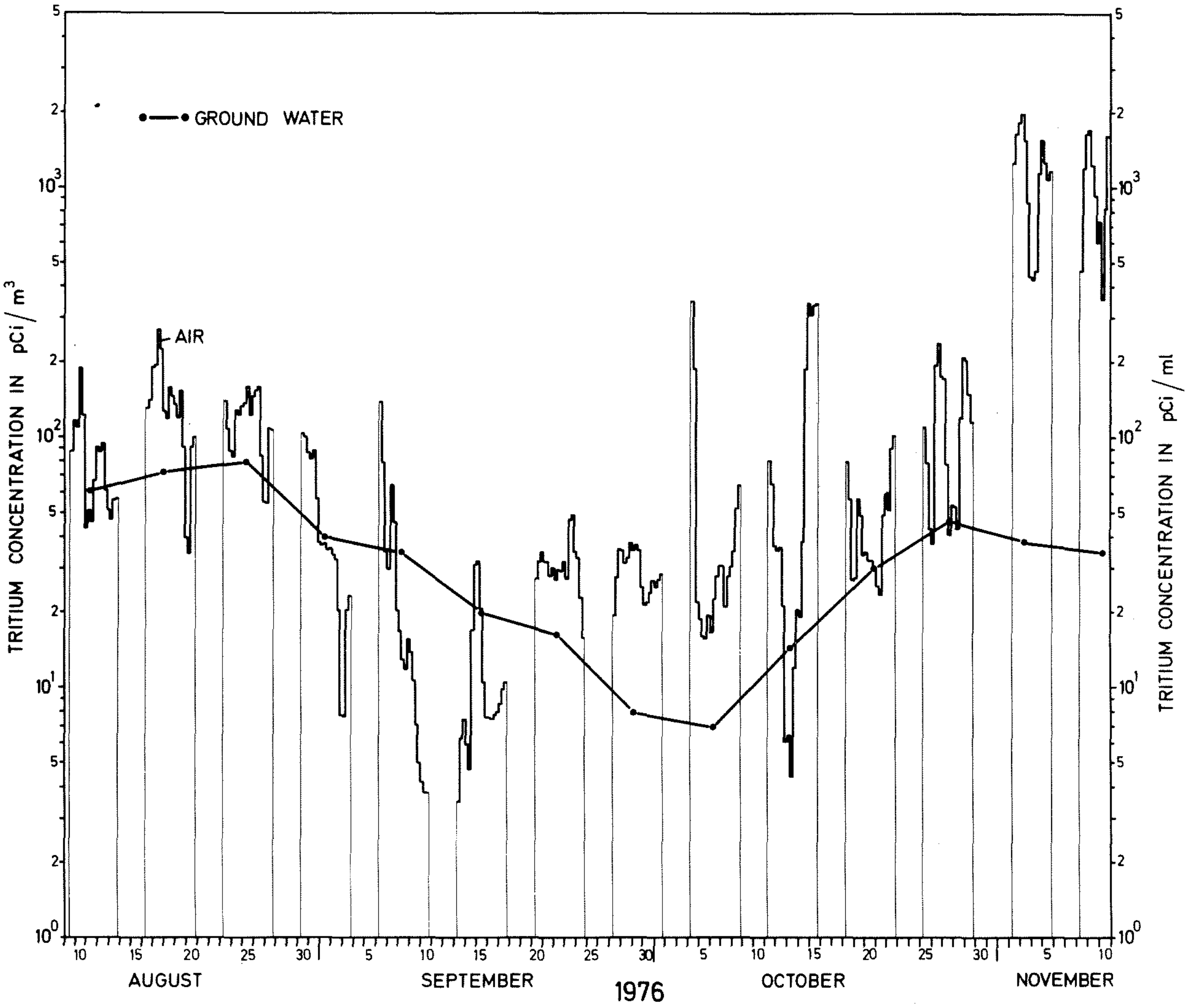


Fig. 8 Representation showing the variation with time of the tritium concentration in air and ground water

supplied water by the root system. Tritium contamination by the water taken from the soil should therefore be dominant. But characteristic minimum peaks of the tritium concentration in leaves have values close to the tritium background level in air humidity and are therefore about a factor of 10 to 30 lower than the tritium concentrations in ground water (see Figs. 5 and 8). The effect mentioned above is difficult to interpret clearly.

5.4 TRITIUM IN PRECIPITATIONS

Fig. 9 shows the tritium concentration levels in precipitations as well as the amounts of precipitation. The specific tritium activity calculated in nCi/m^2 is given in Table IV in the Appendix. Precipitation samples were collected from point 2 (see Fig. 3).

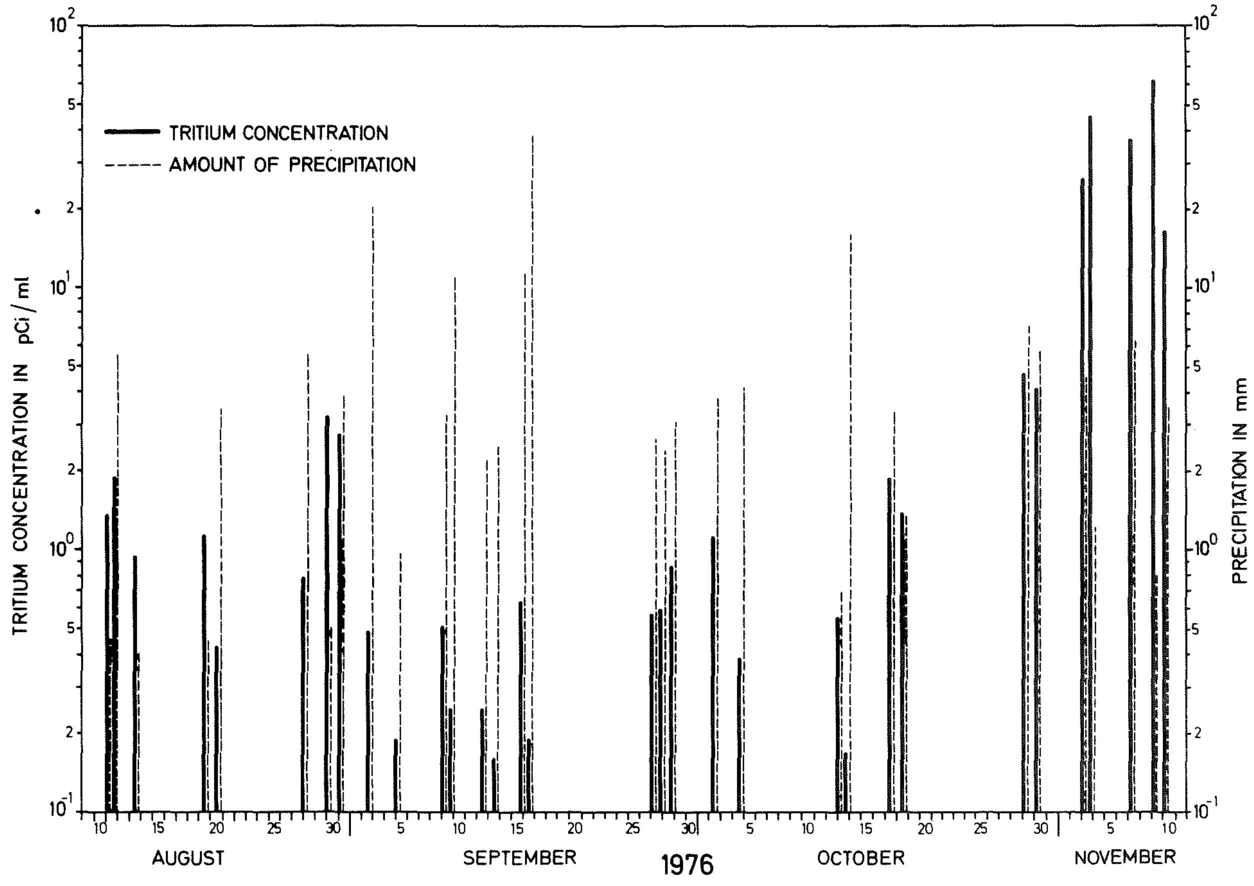


Fig. 9 Tritium concentration in precipitations and amount of precipitation during the period under investigation.

As a result of the analysis of the measured results of the tritium concentration in precipitations, the emission rates and meteorological data can establish the individual emitters giving rise to the tritium contamination in precipitations.

The analysis of the plots shown in Figs. 9, 12 and 13 enables more cause-effect relationships to be determined. Thus, as an example of the increase in the tritium concentration in precipitations on August 19, the cause was the emission from the MZFR reactor stack; on August 13, 30 and 31 the cause was evaporation from the final basins. When short-term rainfall occurs, a precise analysis is indispensable. Short-time measurements of the wind direction, velocity and amount of precipitation were carried out and calculated by computer at 10 minute intervals in specific angular sectors of 20 degrees each for the full circle of 360^0.

The meteorological data analysed in the program establish the volume of significant material and certain details for the purpose of illustrating their use in this program.

The high tritium concentration in the liquid effluents at the end of October and November caused by the evaporation of high tritium concentrations of water vapour in the air produced a significant tritium contamination in the precipitations. During this period there was a prevailing southern wind. For investigation of the effect of wash-out an additional sampling point (marked index 3) for precipitations was located right next to the four final basins (see Fig. 3).

At point 2, collections were made at regular intervals and the precipitation samples were measured every day. At point 3, the precipitation samples were taken at intervals over a period of several days and as a result of the measurements the average value of tritium concentration was obtained in the sampling period. To compare the results at both sampling points average values of the tritium concentration in precipitation samples collected at point 2 were calculated for analogous periods as at point 3 (see Table 7).

The average value $\overline{a}_2$ of the tritium concentration at point 2 was estimated according to the relation:

$$\overline{a}_2 = \frac{\sum_{i=1}^{n} a_{2_i} V_i}{\sum_{i=1}^{n} V_i} \qquad (8)$$

a_{2_i} - tritium concentration in samples collected during selected periods

V_i - amount of precipitation in samples collected during selected periods

n - number of samples .

Table V in the Appendix offers the data on which the calculation of the average tritium values at sampling point 2 is based.

If the effect of wash-out of the water vapour from the final basins is the main reason for the tritium contamination of the precipitations at both sampling points, the following relation can be used:

$$\frac{a_2}{a_3} = \frac{\sum_k^m V_k(\phi_2)}{\sum_k^m V_k(\phi_3)} \quad . \qquad (9)$$

a_2 - tritium concentration at sampling point 2

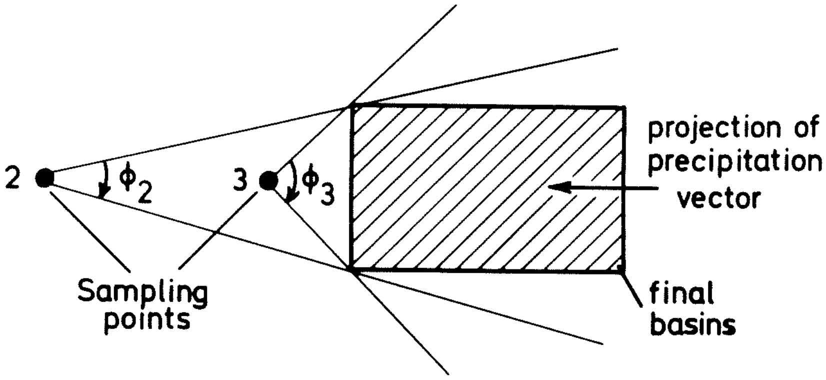
a_3 - tritium concentration at sampling point 3

$V_k(\phi_2)$, $V_k(\phi_3)$ - amounts of precipitation for precipitation directions inside angular sectors ϕ_2 and ϕ_3 (see Table 7 and Table VI in the Appendix)

m - number of precipitation events within selected periods .

To demonstrate the validity of Eq. (9) the tritium concentrations a_2 to be expected at sampling point 2 were calculated by using Eq. (9) and compared with the measurement results $\bar{a}_2$ for 4 selected periods. The calculations agree with the premise that tritium contamination in precipitations collected at the sampling points 2 and 3 occurs only if the wind directions have angles ϕ_2 and ϕ_3. Precipitation vectors cross the space above the final basins. Their projections on the plane of the basins are directed to the vertex of angle ϕ_2 and ϕ_3, which are in fact the precipitation sampling points 2 and 3. The angle arms form tangents to the edges of the basins (see graph in Table 7). The amount of preci-

Selected periods	Tritium concentration in precipitation in pCi/ml		
	Sampling point 3	Sampling point 2	
	a_3 (single measured results	$\bar{a}_2$ (calculated by Eq. (8))	a_2 (calculated by Eq. (9))
1	65.80 ± 2.69	6.71	6.49
2	135.53 ± 5.35	32.96	58.45
3	74.18 ± 3.00	14.97	13.25
4	33.05 ± 1.43	5.68	7.96



Selected periods	Amounts of precipitation in mm in angular sectors	
	ϕ_2 170° - 210°	ϕ_3 150° - 250°
1	0.80	8.10
2	4.40	10.20
3	3.20	17.90
4	7.30	30.30

Table 7 Measured results and calculated values of the tritium concentration at sampling points 2 and 3 and amounts of precipitation in angular sectors ϕ_2 and ϕ_3.

pitation for directions inside the angular sectors ϕ_2 and ϕ_3 calculated from computer data are shown in Table 7. Values of the amounts of precipitation in specific angular sectors obtained during the period of investigation are shown in Table VI in the Appendix.

The upper part of Table 7 consists of tritium concentration levels at the sampling points 2 and 3 for four selected periods. While, for point 3, only one concentration value a_3 is presented for each period, the table shows two values for point 2: the measured value $\overline{a}_2$ and the calculated value a_2. The results of the comparison show tolerable agreement between measurement and calculation.

5.5 TRITIUM RELEASES AND METEOROLOGICAL DATA

Some information about the tritium emitters and meteorological data has been given in the previous discussion of the relationship between tritium emissions and contamination of plants, air, precipitation and ground water as well as the influence of meteorological data on the results investigated. More results are not given in tables and diagrams showing the position of emitters, the daily emission rates from controlled emitters and correlations between tritium emission rates and wind directions.

Table 8 indicates the position of controlled emitters in relation to the sampling location.

Emitter	ϕ in ^{o}	r in m	h in m
MZFR	33	700	99.5
FERAB	55	100	70
FR 2	97	450	99
final buffer basins	165-190	40	2

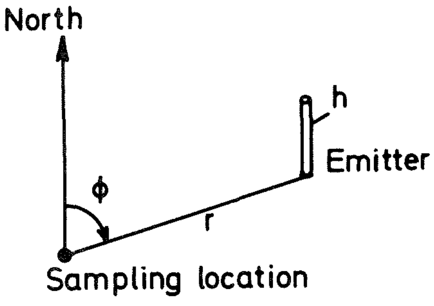


Table 8 Position of emitters in relation to sampling location.

Emission data of the different emitters are reported routinely by the operators to the Health Physics Division. The emission rates from MZFR and FR 2 were presented in Ci/d. The report from FERAB gave a total emission for a weekly period in Ci/week. The average daily emissions by MZFR and FR 2 are about 100 times higher than the weekly emission from FERAB.

Owing to the location of FERAB (see Table 3) this emitter has a minimum influence on the tritium contamination in the vicinity of the sampling location. However, FERAB has to be taken into account when the emission rate is significant, the wind velocity is low and the diffusion category is A or B.

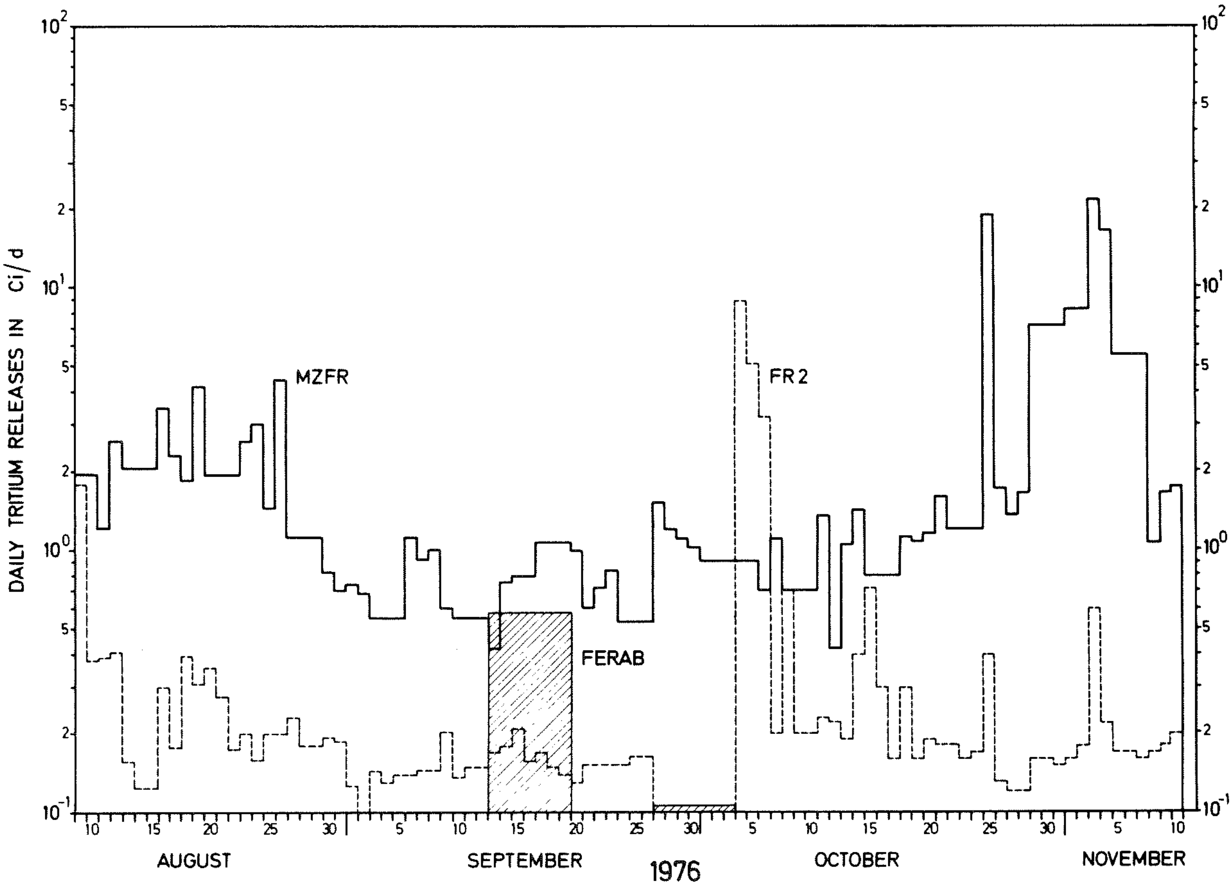


Fig. 10 Representation showing daily tritium emissions by gaseous effluents from stacks of MZFR, FR 2 and FERAB.

Fig. 10 shows the variation with time of the daily tritium releases by the different emitters during the period under investigation. A plot of the tritium concentration of the liquid effluents in the final buffer basins over the same period is given in Fig. 11.

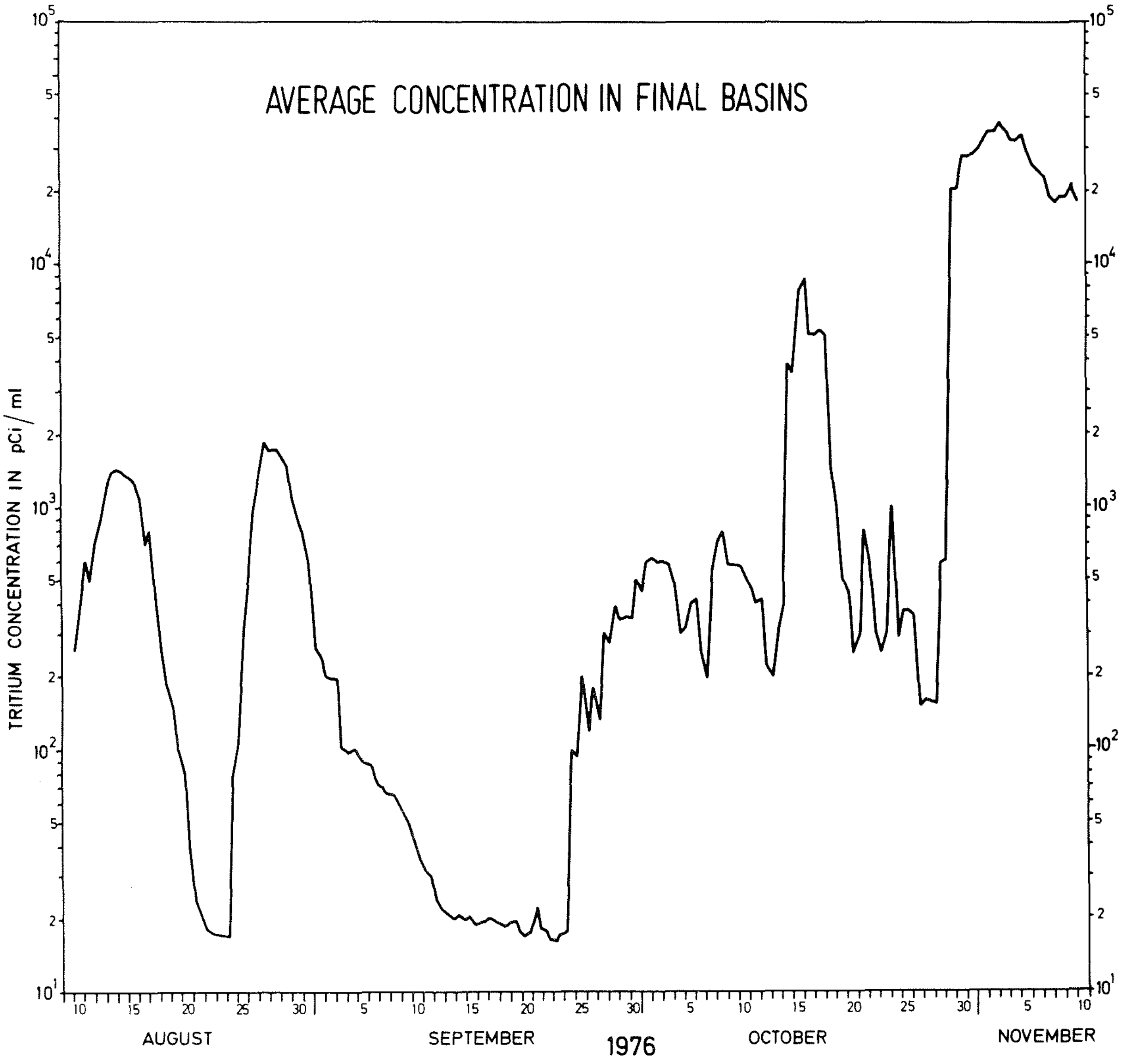


Fig. 11 Average tritium concentration levels in the four final buffer basins of the Sewage Treatment Plant

Table 9 gives the maximum and minimum values of tritium emitted by controlled emitters.

Emitter	MZFR Ci/d	FR 2 Ci/d	FERAB Ci/d	Sewage treatment plant Liquid Effluents pCi/ml	 Evaporation mCi/d
Maximum	21.7	8.9	0.59*	38 800	15.2
Minimum	0.4	0.1	0.002*	6	0.007
Maximum/ Minimum	54.3	89	295	6 466	2 171

Table 9 Results of maximum and minimum values of the tritium emission rates and tritium concentrations in liquid effluents

*values calculated from weekly emissions

In order to determine the relationship between tritium emissions by gaseous effluents and tritium concentrations in air humidity at the sampling location it was found necessary to correlate the emission data with meteorological parameters, such as wind direction, categories of atmospheric diffusion and absolute air humidity [5-11].

A meteorological tower 200 m high situated on the premises of the Karlsruhe Nuclear Research Center is used for different meteorological research programs. Essential data were received from the Meteorological Department, some of which were specially produced for this program:

(1) wind direction and velocity at a height of 40 m

(2) wind direction and velocity at a height of 60 m

(3) absolute value of air humidity

(4) diffusion category

(5) daily frequency distribution of wind directions given as percentage values (wind directions measured at 10 minute intervals per day in 18 specific angular sectors of 20 degrees each)

(6) precipitation amounts correlated with the daily frequency distribution of wind directions .

Data from (1) to (4) were calculated and printed out by computer at hourly intervals (for example, see Table VII in the Appendix), data from (5) and (6) at daily intervals (for example, see Table VIII in the Appendix).

To show the different influences of tritium emissions and the "appropriate" wind directions on the tritium concentration of the air humidity at the sampling location, data of four selected days are presented in Table 10.

	Date	Aug. 17	Oct. 4	Oct. 6	Oct. 15
MZFR	Ȧ Ci/d	2,38	0,93	0,71	0,69
	F in % Δϕ 10° - 50°	25,38	2,79	0	0
FR 2	A Ci/d	0,18	8,9	3,4	0,72
	F in % Δϕ 70° - 110°	5,23	11,12	0	0
FERAB	A Ci/d	$8.3\ 10^{-3}$	$3.8\ 10^{-3}$	$3.8\ 10^{-3}$	$6.8\ 10^{-3}$
	F in % Δϕ 30° - 90°	14,19	4,87	0	0
Final basins	A Ci/d	$1,20\ 10^{-3}$	$0,17\ 10^{-3}$	$0,14\ 10^{-3}$	$2,34\ 10^{-3}$
	F in % Δϕ 150° - 210°	0.75	11,85	61.12	45.15
Sampling location. Average tritium concentration in air humidity pCi/ml.		37.44±1,24	33,97±1,12	2,89±0.26	52,15±1,64

Table 10 Relation between tritium concentration in air humidity, emission rate and percentage value of the frequency of wind directions from different tritium emitters on four selected days (Ȧ - tritium emission rate; F - percentage value of the frequency of wind directions in angular sectors Δϕ related to the individual emitter; Δϕ - special angular sector related to the emitter and the sampling location).

This table contains both the emission rates of the different tritium emitters and the frequencies of wind direction in specific relevant angular sectors for each emitter as percentage values. The average tritium concentration of air humidity at the sampling location is given in the last line of Table 10. The data presented will help to find out which emitter mainly caused the tritium contamination of the air at the sampling location on the selected days.

To give this information for the full period of investigation, the product of the tritium emission rate and the frequency of exposure to tritium from the stacks of MZFR, FR 2 and FERAB has been represented in Fig. 12. Fig. 13 shows the equivalent representation for the final buffer basins.

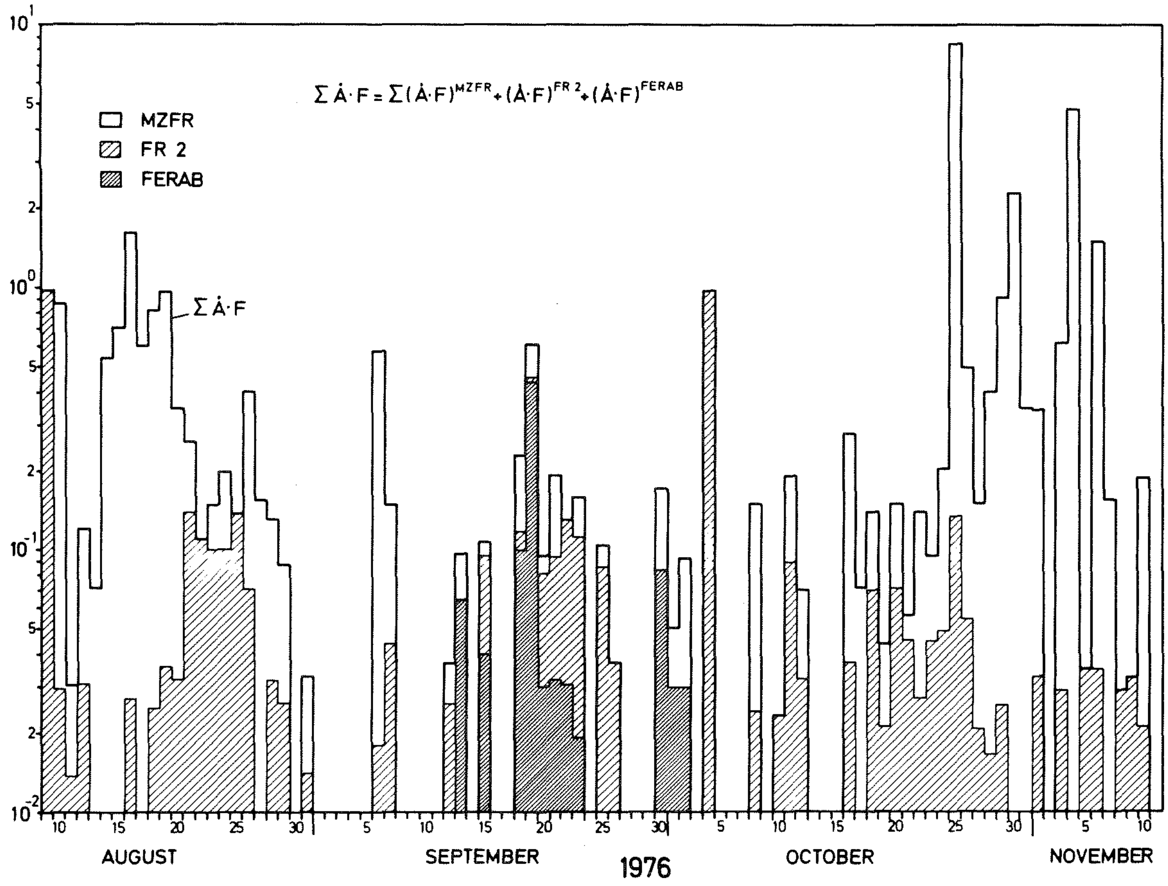


Fig. 12 $\Sigma\,\dot{A}\cdot F$ - sum of the products formed as a result of the tritium emission rate ($\dot{A}$) of MZFR, FR 2, FERAB and the frequency (F) of those 10 minute intervals per day in which exposure of the sampling location under consideration was possible on account of the wind direction. A special angular sector $\Delta\phi$ is used for each emitter (see Table 10).

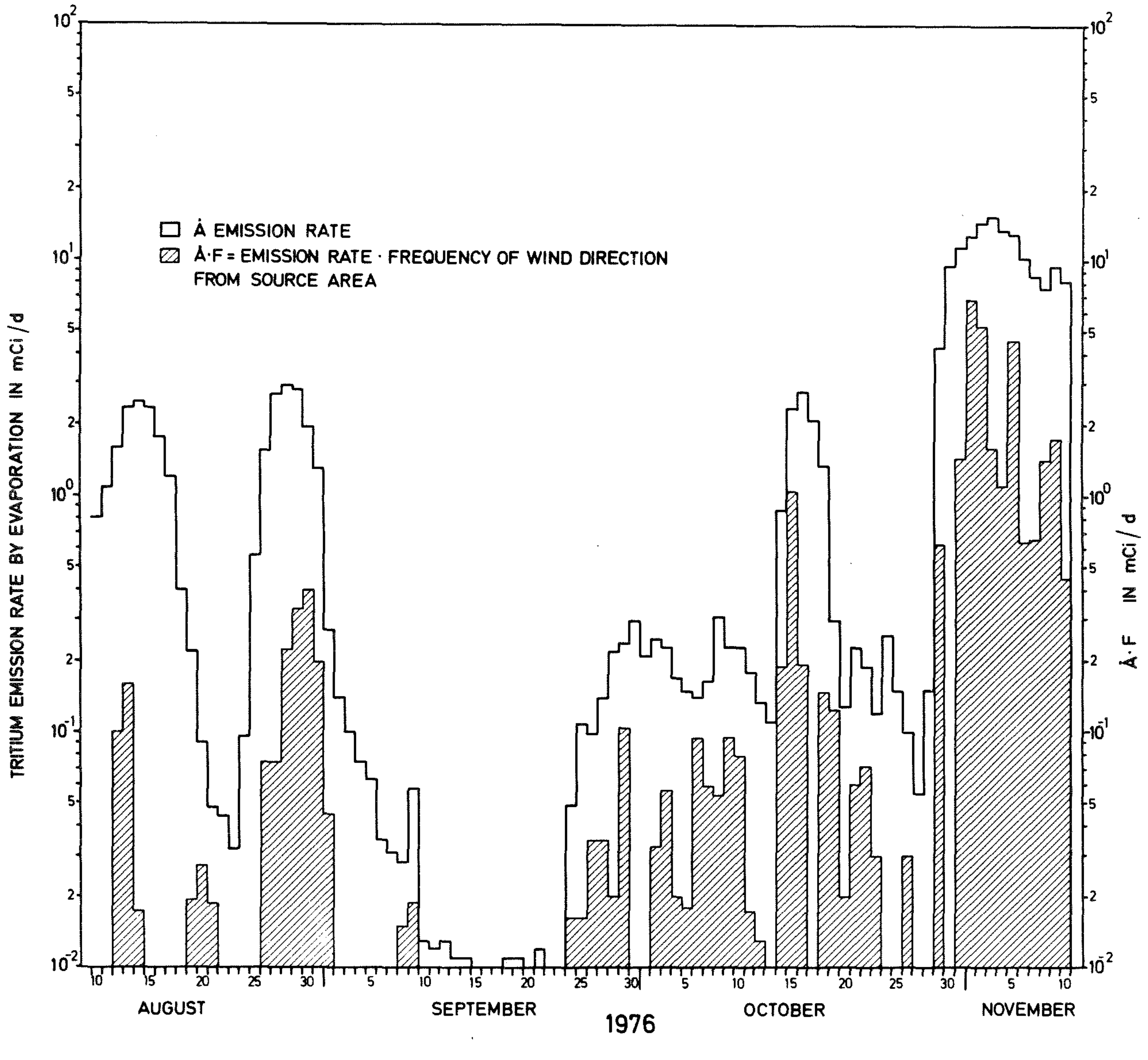


Fig. 13 Tritium emission rate by evaporation from the four final buffer basins of the Sewage Treatment Plant and product formed as a result of the tritium evaporation rate (Ȧ) and the frequency (F) of those 10 minute intervals per day in which exposure of the sampling location under consideration was possible on account of the wind direction. The specific angular sector $\Delta\phi$ for final basins was used (see Table 10).

6. FINAL REMARKS

The conclusions contained in the measured results discussed arise from the accepted model of tritium transport in the environment. The model is represented in Fig. 14. This is a simplification of the complex model and shows the main pathways of tritium contamination in the plants included in this survey and the illustration contained in the conclusion.

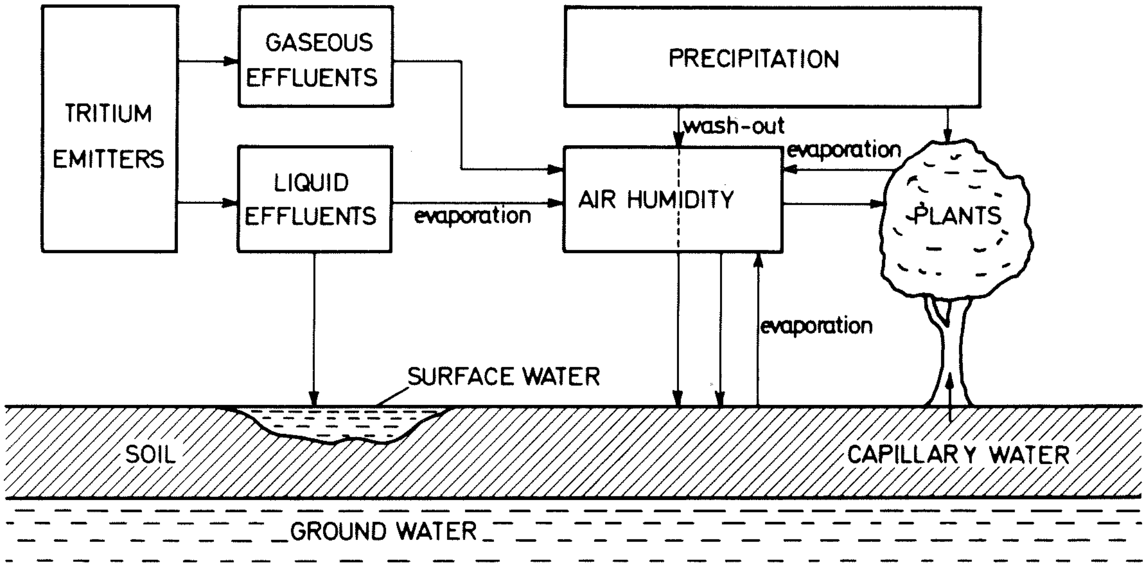


Fig. 14 Simplified model of the transport of tritium in the environment

Several conclusions were reached in the discussion of the measurement results. Other conclusions are purely hypothetical. Certain gaps in the measurement program can be seen from the analysis of the measurement program, because the full practical program was carried out essentially by one person.

However, the following general conclusions can be drawn:

Variations of the tritium concentration in air humidity affect the variations of the tritium concentration in the tissue water of plants. These changes correlate with each other. The tritium concentration level in the tissue water of plants is close to the tritium concentration in air humidity.

The decisive element concerning the character of the tritium contamination in leaves and needles is the influence of the water vapour exchange, as well as the direct influence of precipitation and dew on the surfaces of leaves and needles.

The variation of the tritium concentration in leaves and needles as a function of time depends on the water circulation in the root system, branches and the process of water evaporation through the leaves and needles into the air.

In the period of leaf fall on November 8 a change of 80 to 90 % of the colour of leaf surfaces was reached. This period does not seem to be affected by the loss of exchange of water between the atmosphere and the volume of the leaves because, through all this period up to the incidence of leaf fall on November 12, there is a process of change in the tritium concentration in leaves.

Precipitation has a direct influence on the changes in tritium concentration in leaves and needles. The changes in these levels depend on the tritium concentration in leaves and needles in relation to the tritium concentration in precipitations.

The measured results do not indicate any direct relationship between the tritium concentrations in ground water and in plants. The influence of tritium in the soil works through the capillary water at different tritium contamination levels arising from the slow penetration of precipitations into the soil and through capillary water contaminated by tritium in the ground water. The water taken up through the root system at different depths with varying levels of tritium contamination has an average tritium concentration resulting from the different levels of contamination in the soil.

The minimum levels of tritium concentration in the leaves are about 10 to 30 times lower than the tritium concentration of the ground water. At the same time, the tritium level in leaves is close to the background level of tritium concentration in air humidity. On the other hand, in accordance with the contamination level of air humidity there are maximum levels of tritium concentration in the tissue water of plants much higher than the tritium level in ground water. The fact that tritium levels in leaves are close to the tritium levels of air humidity throughout demonstrates a quick exchange of water vapour between the atmosphere and the leaves.

The question which still remains to be answered concerns the level of tritium contamination in the root system and the branches and the relationship between the tritium contamination in different parts of the trees and in the air, soil and ground water.

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S. Rosinski, Karlsruhe, July 1977

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APPENDIX

Date 1976		Tritium Concentration			
		Oak pCi/ml	Hornbeam pCi/ml	Spruce pCi/ml	Pine pCi/ml
Aug.	9	6.84 ± 0.38	7.78 ± 0.40	7.00 ± 0.50	-
	11	1.71 ± 0.25	2.99 ± 0.30	5.45 ± 0.41	7.72 ± 0.47
	13	1.73 ± 0.23	3.65 ± 0.29	3.49 ± 0.34	-
	16	4.77 ± 0.33	6.18 ± 0.37	3.72 ± 0.31	-
	18	7.52 ± 0.41	11.48 ± 0.52	5.55 ± 0.37	13.76 ± 0.60
	20	3.35 ± 0.28	5.21 ± 0.34	5.97 ± 0.52	-
	23	5.99 ± 0.38	7.92 ± 0.42	5.68 ± 0.37	-
	25	6.84 ± 0.38	8.84 ± 0.43	6.39 ± 0.37	12.26 ± 0.59
	27	1.83 ± 0.26	4.95 ± 0.33	5.57 ± 0.39	-
	30	3.51 ± 0.29	6.82 ± 0.39	3.58 ± 0.35	-
Sep.	1	3.53 ± 0.31	3.20 ± 0.26		8.31 ± 0.44
	3	1.24 ± 0.20	2.47 ± 0.23	2.31 ± 0.27	-
	6	3.39 ± 0.28	2.95 ± 0.25	2.16 ± 0.25	-
	8	2.22 ± 0.26	4.99 ± 0.34	3.03 ± 0.27	9.35 ± 0.46
	10	1.14 ± 0.22	0.95 ± 0.19	1.81 ± 0.25	-
	13	1.11 ± 0.21	1.26 ± 0.20	1.71 ± 0.22	-
	15	2.93 ± 0.26	3.80 ± 0.28	1.86 ± 0.24	7.12 ± 0.40
	17	2.13 ± 0.24	1.53 ± 0.22	1.83 ± 0.26	-
	20	2.34 ± 0.25	2.80 ± 0.25	2.51 ± 0.24	-
	22	2.73 ± 0.26	3.69 ± 0.28	2.53 ± 0.26	7.72 ± 0.41
	24	2.75 ± 0.27	2.94 ± 0.27	3.06 ± 0.27	-
	27	1.74 ± 0.23	2.16 ± 0.25	1.93 ± 0.25	-
	29	1.75 ± 0.22	1.96 ± 0.22	1.44 ± 0.21	5.42 ± 0.34
Oct.	1	1.77 ± 0.23	2.69 ± 0.25	1.76 ± 0.22	-
	4	2.35 ± 0.25	2.84 ± 0.26	2.10 ± 0.24	-
	6	2.46 ± 0.25	2.72 ± 0.24	3.04 ± 0.28	7.66 ± 0.39
	8	1.52 ± 0.24	2.03 ± 0.24	2.14 ± 0.25	-
	11	2.15 ± 0.25	3.18 ± 0.28	2.94 ± 0.28	-
	13	2.02 ± 0.24	2.10 ± 0.24	1.59 ± 0.24	5.81 ± 0.38
	15	20.33 ± 0.78	13.87 ± 0.60	5.95 ± 0.37	-
	18	4.26 ± 0.31	2.95 ± 0.31	3.03 ± 0.27	-
	20	2.73 ± 0.25	3.13 ± 0.26	2.82 ± 0.25	6.58 ± 0.36
	22	5.99±0.43	4.44±0.34	3.28±0.31	-
	25	4.69±0.31	3.70±0.27	8.70±0.45	-
	27	6.73±0.38	8.57±0.43	10.62±0.51	-
	29	38.53±1.26	30.48±1.03	14.43±0.59	-
Nov.	3	132.56±3.83	90.86±2.70	53.25±1.78	56.98±1.78
	5	233.03±6.37	234.81±6.42	67.10±1.89	-
	8	235.77±9.17	179.59±7.02	71.19±2.87	-
	10	68.21±2.77	45.92±1.91	60.96±2.48	63.55±2.57

Table I Tritium concentration in the tissue water of oak and hornbeam leaves, spruce and pine needles.

Date		Sampling Period in Hours	
		9 am-4 pm	4 pm-9 am
Aug.	9	-	12.31±0.60
	10	23.56±0.91	4.42±0.35
	11	3.17±0.31	6.95±0.44
	12	7.31±0.41	4.07±0.31
	13	5.35±0.35	-
	16	14.29±0.60	20.92±0.79
	17	37.44±1.24	12.94±0.57
	18	17.10±0.68	12.61±0.55
	19	15.60±0.65	3.09±0.27
	20	10.00±0.48	-
	23	16.72±0.69	9.12±0.47
	24	16.30±0.64	17.64±0.68
	25	21.10±0.77	19.83±0.74
	26	19.07±0.74	5.93±0.37
	27	10.45±0.49	-
	30	7.20±0.40	6.30±0.37
	31	7.43±0.39	3.42±0.27
Sep.	1	3.13±0.26	2.97±0.26
	2	2.81±0.25	0.78±0.18
	3	2.82±0.25	-
	6	17.51±0.70	4.39±0.32
	7	10.58±0.50	2.19±0.25
	8	1.09±0.20	1.48±0.22
	9	0.56±0.18	0.44±0.18
	10	0.53±0.18	-
	13	0.29±0.18	0.70±0.20
	14	0.36±0.17	3.79±0.28
	15	1.49±0.22	0.78±0.20
	16	0.90±0.20	0.90±0.20
	17	1.11±0.19	-
	20	2.87±0.24	4.04±0.29
	21	3.75±0.27	4.06±0.29
	22	3.47±0.27	3.63±0.27
	23	6.42±0.38	3.34±0.28
Sep.	24	1.43±0.22	-
	27	1.40±0.20	2.51±0.24
	28	2.06±0.22	2.73±0.24
	29	3.04±0.26	2.29±0.24
	30	1.99±0.23	2.23±0.24
Oct.	1	2.30±0.24	-
	4	33.97±1.12	2.14±0.23
	5	1.64±0.21	2.62±0.24
	6	2.89±0.26	2.80±0.26
	7	1.52±0.22	2.97±0.27
	8	5.13±0.34	-
	11	7.87±0.42	3.38±0.29
	12	3.41±0.28	0.70±0.28
	13	0.35±0.18	2.15±0.24
	14	5.44±0.35	36.30±1.22
	15	52.15±1.64	-
	18	10.66±0.48	3.26±0.26
	19	7.75±0.39	4.24±0.29
	20	3.62±0.32	3.74±0.32
	21	2.97±0.30	8.12±0.47
	22	13.80±0.56	-
	25	16.68±0.65	6.37±0.36
	26	43.53±1.39	24.01±0.85
	27	3.74±0.28	7.01±0.38
	28	5.20±0.32	27.06±0.94
	29	12.95±0.55	-
Nov.	2	165.45±4.69	257.32±7.17
	3	187.51±5.30	73.37±2.22
	4	84.79±2.36	277.48±7.57
	5	192.29±7.50	-
	8	71.00±2.86	268.89±10.45
	9	146.18±5.76	92.08±3.69
	10	19.95±0.93	170.80±6.71
	11	157.05±6.18	139.09±5.49

Table II Tritium concentrations in air humidity, in pCi/ml.

Date Hour	Aug. 17	Oct. 4	Oct. 6	Oct. 15
1	192.46 ± 7.26	-	17.29 ± 1.58	330.33 ± 11.0
2	194.55 ± 7.34	-	16.77 ± 1.53	323.07 ± 10.85
3	192.46 ± 7.26	-	16.24 ± 1.48	308.55 ± 10.37
4	190.37 ± 7.18	-	15.98 ± 1.46	312.18 ± 10.49
5	192.46 ± 7.26	-	15.72 ± 1.44	308.55 ± 10.37
6	190.37 ± 7.18	-	16.50 ± 1.51	286.77 ± 9.63
7	194.55 ± 7.34	-	17.29 ± 1.58	275.88 ± 9.27
8	182.00 ± 6.87	-	18.60 ± 1.70	286.77 ± 9.63
9	336.87 ± 11.16	281.95 ± 9.29	22.25 ± 2.00	385.91 ± 12.06
10	-	366.88 ± 12.09	24.27 ± 2.18	375.48 ± 11.80
11	344.35 ± 11.40	377.06 ± 12.43	25.72 ± 2.31	359.83 ± 11.31
12	366.81 ± 12.15	387.25 ± 12.76	26.29 ± 2.36	354.62 ± 11.15
13	329.38 ± 10.91	363.48 ± 11.98	25.43 ± 2.28	338.97 ± 10.66
14	306.92 ± 10.16	353.29 ± 11.64	26.29 ± 2.36	349.40 ± 10.98
15	351.84 ± 11.65	343.09 ± 11.31	27.16 ± 2.44	338.97 ± 10.66
16	119.04 ± 5.94	24.18 ± 2.59	28.90 ± 2.60	-
17	111.28 ± 4.90	26.32 ± 2.82	29.12 ± 2.70	-
18	129.40 ± 5.70	26.18 ± 2.80	29.96 ± 2.78	-
19	117.75 ± 5.18	22.89 ± 2.46	30.52 ± 2.83	-
20	117.75 ± 5.18	22.89 ± 2.46	30.52 ± 2.83	-
21	130.69 ± 5.75	22.47 ± 2.41	29.96 ± 2.78	-
22	131.98 ± 5.81	22.26 ± 2.39	30.80 ± 2.86	-
23	131.98 ± 5.81	21.18 ± 2.27	30.24 ± 2.80	-
24	129.40 ± 5.70	20.76 ± 2.23	30.52 ± 2.83	-

Table III Daily variation of the tritium concentration in air, in pCi/m^3.

Date 1976		Specific Tritium Activity		
		Precipitation pCi/ml	Precipitation nCi/m^2	Ground Water pCi/ml
Aug.	11	1.38 ± 0.25	1.24 ± 0.23	62.12 ± 1.82
	11	1.91 ± 0.26	10.41 ± 1.42	-
	13	0.96 ± 0.21	0.38 ± 0.08	-
	18	-	-	72.21 ± 2.10
	19	1.14 ± 0.21	0.51 ± 0.09	-
	20	0.43 ± 0.19	1.49 ± 0.66	-
	25	-	-	80.31 ± 3.23
	28	0.79 ± 0.23	4.44 ± 1.29	-
	30	3.25 ± 0.28	1.66 ± 0.14	-
	31	2.81 ± 0.26	10.96 ± 1.01	-
Sep.	1	-	-	51.13 ± 1.53
	2	0.48 ± 0.16	9.89 ± 3.29	-
	5	0.19 ± 0.16	0.18 ± 0.15	-
	8	-	-	35.36 ± 1.10
	9	0.51 ± 0.18	1.65 ± 0.58	-
	9	0.25 ± 0.17	3.32 ± 2.26	-
	12	0.25 ± 0.17		
	13	0.16 ± 0.16	0.39 ± 0.39	-
	15	0.64 ± 0.19	13.57 ± 4.03	20.09 ± 0.69
	16	0.19 ± 0.17	7.37 ± 6.59	-
	22	-	-	16.46 ± 0.77
	27	0.57 ± 0.20	1.48 ± 0.52	-
	27	0.60 ± 0.17	1.44 ± 0.40	-
	28	0.88 ± 0.18	2.73 ± 0.56	-
	29	-	-	7.90 ± 0.37
Oct.	2	1.13 ± 0.21	4.29 ± 0.79	-
	4	0.49 ± 0.17	2.00 ± 0.69	-
	6	-	-	7.02 ± 0.35
	13	0.56 ± 0.20	0.39 ± 0.14	14.49 ± 0.54
	13	0.17 ± 0.17	2.76 ± 2.76	-
	17	2.92 ± 0.27	9.96 ± 0.92	-
	18	1.39 ± 0.20	1.89 ± 0.27	-
	20	-	-	30.04 ± 0.96
	27	-	-	47.32 ± 1.43
	29	4.77 ± 0.31	7.15 ± 0.46	-
	30	4.24 ± 0.30	24.55 ± 1.74	-
Nov.	3	26.73 ± 0.79	122.96 ± 3.63	39.71 ± 1.22
	3	46.95 ± 1.34	53.52 ± 1.53	-
	7	36.72 ± 1.56	229.13 ± 9.73	-
	9	61.03 ± 2.49	48.21 ± 1.96	-
	10	16.50 ± 0.80	57.09 ± 2.76	35.15 ± 1.09

Table IV Tritium concentrations of precipitations and ground water.

Period	Date	Number of Sample	Tritium Concentration in pCi/ml	Amount of Precipitation in ml
1	Nov. 11- Nov. 19	347	7.73 ± 0.45	100
		351	1.08 ± 0.19	18
2	Nov. 19- Nov. 29	361	42.17 ± 1.80	15
		367	50.38 ± 2.10	52
		369	76.63 ± 3.11	45
		372	4.59 ± 0.34	106
3	Nov. 29- Dec. 3	376	16.71 ± 0.81	55
		379	11.61 ± 0.61	120
		383	12.73 ± 0.65	274
		386	28.15 ± 1.25	70
4	Dec. 3- Dec. 13	388	5.80 ± 0.39	91
		391	0.41 ± 0.18	130
		395	2.41 ± 0.24	126
		397	4.75 ± 0.33	72
		402	10.13 ± 0.56	260

Table V Amount of precipitation and tritium concentrations in precipitation samples collected at point 2 (see Fig. 3).

Period	Date	Specific angular sectors in degrees of the wind direction				
		150 170	170 190	190 210	210 230	230 250
1	Nov. 11	-	-	0.50	5.10	-
	Nov. 13	-	-	0.30	1.20	0.70
	Nov. 14	-	-	-	-	0.30
2	Nov. 24	-	-	-	0.70	1.30
	Nov. 25	-	-	4.20	0.20	0.20
	Nov. 27	-	-	-	0.30	0.40
	Nov. 29	-	-	0.20	1.60	1.10
3	Nov. 30	-	-	1.70	6.60	0.10
	Dec. 1	0.40	0.70	0.30	0.20	0.60
	Dec. 2	0.10	0.10	0.20	3.00	1.70
	Dec. 3	-	-	0.20	1.40	0.60
4	Dec. 4	-	0.10	0.80	0.60	1.10
	Dec. 5	0.10	0.20	0.60	0.60	0.30
	Dec. 6	-	0.20	0.10	0.80	-
	Dec. 7	-	0.10	3.40	2.60	1.00
	Dec. 8	-	-	0.10	2.80	-
	Dec. 9	-	-	1.70	3.00	0.80
	Dec. 10	-	-	-	0.40	0.10
	Dec. 11	-	-	-	3.60	3.00
	Dec. 12	-	-	-	0.10	2.10
		Amount of precipitation in mm in specific angular sectors				

Table VI Amounts of precipitation in special angular sectors of the wind direction related to the sampling points 2 and 3 (see Table 7).

DAY	MONTH	YEAR	HOUR	U 40	U 60	PHI 40	PHI 60	CATEGORY	AIR HUMIDITY
				IN M/S		IN DEGREES			IN G/M**3
13	10	76	1	2.9	3.4	254.0	250.5	C	9.0
13	10	76	2	1.7	2.0	264.3	268.8	C	9.2
13	10	76	3	1.9	2.3	251.8	256.7	C	9.3
13	10	76	4	2.0	2.4	237.8	236.8	C	9.3
13	10	76	5	2.4	2.9	260.0	259.7	E	9.3
13	10	76	6	2.1	2.7	258.3	261.7	C	9.5
13	10	76	7	2.2	2.5	238.8	242.7	E	9.4
13	10	76	8	2.4	3.0	268.7	269.2	E	9.3
13	10	76	9	2.3	2.9	273.5	279.0	C	9.3
13	10	76	10	2.1	2.6	281.2	284.5	C	9.5
13	10	76	11	1.9	2.3	279.7	284.3	-	9.6
13	10	76	12	2.2	2.7	288.3	290.7	C	9.5
13	10	76	13	2.8	3.3	279.5	282.0	C	9.5
13	10	76	14	3.2	3.9	271.8	272.8	C	9.5
13	10	76	15	2.9	3.6	275.3	276.8	C	9.6
13	10	76	16	2.9	3.5	263.0	263.2	C	9.7
13	10	76	17	2.9	3.6	251.2	250.5	E	9.7
13	10	76	18	3.1	3.8	252.2	250.2	C	9.7
13	10	76	19	3.1	4.0	253.3	251.7	C	9.8
13	10	76	20	3.2	4.1	251.3	250.3	C	9.7
13	10	76	21	3.4	4.3	253.3	252.3	E	9.6
13	10	76	22	3.2	4.1	251.7	250.3	C	9.6
13	10	76	23	2.8	3.6	249.8	250.0	C	9.5
13	10	76	24	3.1	3.8	245.5	244.2	C	9.3
14	10	76	1	3.4	4.3	250.5	249.0	C	9.1
14	10	76	2	3.4	4.2	245.9	245.2	C	8.9
14	10	76	3	3.7	4.6	247.3	245.7	C	8.9
14	10	76	4	3.4	4.3	243.8	248.2	C	8.8
14	10	76	5	3.3	4.2	230.2	225.0	C	9.0
14	10	76	6	3.5	4.3	230.5	225.2	C	8.8
14	10	76	7	3.5	4.4	223.2	218.5	C	8.7
14	10	76	8	2.9	3.8	222.5	218.7	C	8.6
14	10	76	9	2.7	3.5	225.5	220.7	C	8.9
14	10	76	10	3.8	4.3	214.0	207.2	C	9.1
14	10	76	11	3.6	4.2	230.0	222.2	C	8.7
14	10	76	12	3.3	3.6	230.2	223.0	C	8.7
14	10	76	13	2.9	3.1	250.5	242.5	E	8.7
14	10	76	14	2.4	2.6	250.3	243.3	E	8.8
14	10	76	15	1.7	1.8	216.3	208.3	E	8.9
14	10	76	16	2.6	3.1	231.2	223.3	C	9.3
14	10	76	17	3.8	4.8	222.0	215.2	C	8.8
14	10	76	18	3.8	4.8	225.5	219.5	C	9.2
14	10	76	19	3.6	4.8	218.5	212.0	C	9.5
14	10	76	20	3.2	4.2	210.7	204.3	C	9.5
14	10	76	21	2.7	3.8	196.3	195.2	C	9.7
14	10	76	22	2.2	2.9	172.8	176.5	C	9.5
14	10	76	23	1.9	2.5	138.2	160.0	C	9.4
14	10	76	24	3.0	4.1	180.2	182.5	C	9.2

Table VII Hourly average values of wind velocity and wind direction at heights of 40 m and 60 m (U40, U60; PHI40, PHI60), diffusion category and absolute air humidity.

Precipitation events in sectors of wind direction (number of 10 minute intervals).

SECTORS OF WIND DIRECTION

N 1/100MM	10 30	30 50	50 70	70 90	90 110	110 130	130 150	150 170	170 190	190 210	210 230	230 250	250 270	270 290	290 310	310 330	330 350	350 10	
0 0	0	0	0	0	0	0	0	0	0	0	1	20	22	7	1	0	0	0	51
0 20	0	0	0	0	0	0	0	0	0	0	2	16	25	16	4	0	0	0	63
20 40	0	0	0	0	0	0	0	0	0	0	0	1	11	11	1	0	0	0	24
40 60	0	0	0	0	0	0	0	0	0	0	0	0	1	3	2	0	0	0	6
60 100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100 200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
200 400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SUMME	1	1	1	1	1	1	1	1	1	1	3	37	59	37	8	1	1	1	144

Amount of precipitations in sectors of wind direction in mm

First line = frequency distribution of wind directions in percent in intervals without rain

N 1/100MM	10 30	30 50	50 70	70 90	90 110	110 130	130 150	150 170	170 190	190 210	210 230	230 250	250 270	270 290	290 310	310 330	330 350	350 10	
0 0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70	13.89	15.28	4.87	0.70	0.00	0.00	0.00	35.42
0 20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.20	1.60	2.50	1.60	0.40	0.0	0.0	0.0	6.30
20 40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.30	3.30	3.30	0.30	0.0	0.0	0.0	7.20
40 60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.50	1.50	1.00	0.0	0.0	0.0	3.00
60 100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100 200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
200 400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SUMME	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.20	1.90	6.30	6.40	1.70	0.0	0.0	0.0	16.50

Table VIII Correlation between wind direction and precipitations on October 13, 1976