



RADIATION PROTECTION AND DOSIMETRY

THE ACTIVITIES OF THE RADIATION PROTECTION MEASUREMENTS LABORATORY

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The Radiation Protection Measurements Laboratory (RPML) of the Institute of Atomic Energy is responsible for handling all the problems concerning radiation protection at the Institute and in the vicinity of Nuclear Centre (NC) Świerk and National Repository of Radioactive Waste (NRRW), located at Różan.

The main tasks are:

- Radiation monitoring of the Świerk and Różan sites.
- Surveillance of radiation safety.
- Radioactive waste control.
- Radiation protection in emergency conditions.
- Improvement of radiation protection measurements and methods.
- Calibration of radiation protection monitoring instruments.
- Personal dosimetry.
- Sewage and drainage water activity measurements.
- Environmental radiation monitoring.

The following laboratories and facilities are available in the Laboratory:

- Mixed radiation fields laboratory (MRF).
- Whole body counter (WBC).
- Counter of thyroid activity (TC).
- Calibration laboratory with standard radiation sources (Calibration Division, CD).
- Environmental measurements laboratory.
- Radiochemical laboratory (RL).

On December 31, 2005 the Laboratory employed 18 graduate staff members and 9 non graduated.

In 2005 RPML continued successfully the activities concerning improvement of measurement procedures in two main domains of Laboratory accredited by the Polish Centre for Accreditation (PCA):

- The determination of internal body contamination (whole body, thyroid and excretions) – accreditation No. AB 56;7.
- Calibration of dosimetric instruments (gamma, neutron and surface contamination monitors) – accreditation No. AP 070.

The improved versions of Quality Manual as well as all the procedures were elaborated and some technical and organizational activities undertaken, especially: validation, traceability and estimation of uncertainties of the methods used.

Several internal quality audits were performed, opinions collected from experts, and in September 2005 the yearly PCA audit took place for AP 070 with positive results.

The research activities of Laboratory are described in the next part of Annual Report.

An outline of the technical activities of the Laboratory is given below:

- Whole body, thyroid and “in vitro” monitoring were carried out for radiation workers from NC Świerk and for external customers as well 387 WBC, 146 TC and 152 RL measurements were made in the year 2005 (Table 1-3). The results of measurements of ^{137}Cs internal activity in people, from 1986 to 2005, are presented in Fig. 1.
- Regular monitoring of radiation workers was carried out with thermoluminescent dose meters (TLD). Values of individual dose equivalents registered are below the Annual Dose Limit.
- The environmental monitoring within or outside the NC and NRRW boundaries includes the measurements of direct or stray radiation due to the operation of reactors, accelerators, etc. and the measurements of radioactivity in samples of air, rivers and underground water, soil, sediment, mud and vegetation. In the year 2005 more than 1000 environmental samples were measured (table 4, 5 and 6).

Table 1. Whole Body Counter measurements.

Dose	measurements	persons
< 1% E _w	378	257*
> 1% E _w	9	9
Total	387	266

* - 26 persons were contaminated by ^{131}I including 8 persons measured by Thyroid Counter and calculated the committed dose equivalent.

E_w – limit of annual effective dose.

Table 2. Thyroid Counter measurements.

Dose	OBRI		OTHERS	
	I-131 measurements	persons	I-131 measurements	persons
< 1% E _w	29	22	1	1
> 1% E _w	18	16	2	1*
Total	47	38	3	1

* - One person after medical administration of ^{131}I .

Table 3. Measurements of biological probes.

	Measure- ments	Persons	<1% E _w	>1% E _w
Total α-activity*	3	3	-	3
Total β-activity	109	82	82	-
Activity of P-32	8	5	5	-
Activity of S-35	8	5	5	-
Activity of tritium (HTO)	14	7	7	-
Activity of Sr-90	7	3	3	-

* - Detection limit for α activity is > 10% of E_w

The results of measurements show that there is no registered influence on the environment and the population living in the vicinity of the NC and NRRW due to their activity.

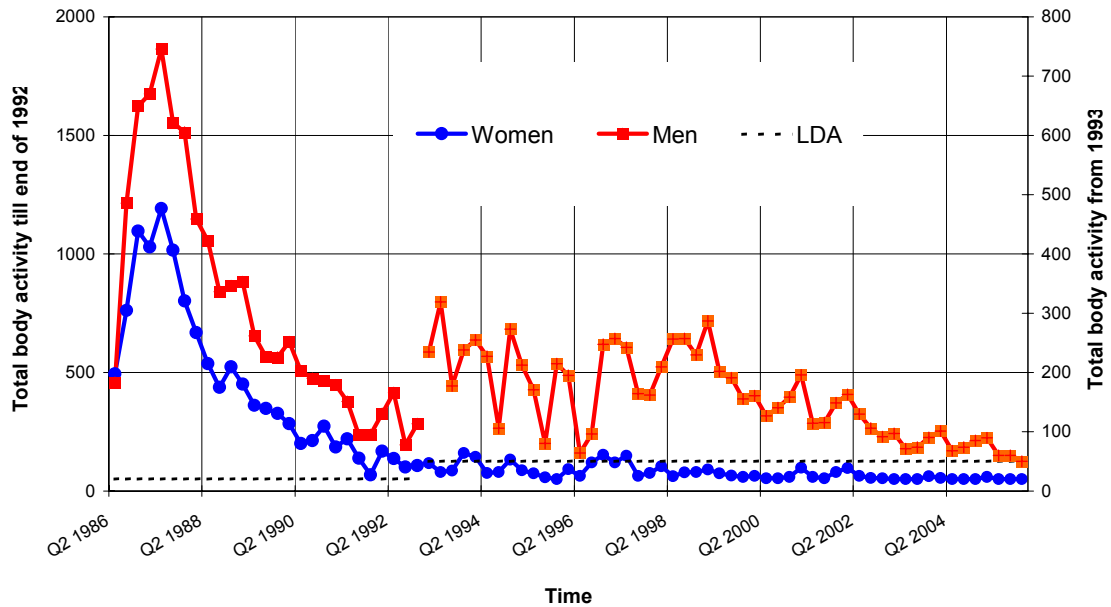


Fig. 1. The activity of ^{137}Cs in people after the Chernobyl accident (mean per person).

Table 4. Total activity of β -radiation environmental materials inside and outside of National Repository of Radioactive Waste – NRRW Rózan.

Type of probe and place of collection	Number of probe	Average value 2004	Concentration [Bq/dm^3]		
			min 2005	max 2005	medium 2005
Ground waters inside NRRW Rózan	10p	0.08	< 0.08	< 0.08	< 0.08
	11p	0.12	< 0.08	0.10	0.09
	12p	0.28	0.15	0.25	0.18
	17p	0.13	< 0.08	0.12	0.10
	18p	0.08	< 0.08	< 0.08	< 0.08
Tap water (inside NRRW)	F-R	0.63	0.77	0.95	0.89
		0.08	< 0.08	< 0.08	< 0.08

Table 5. Activity of tritium (HTO) in waters inside and outside of National Repository of Radioactive Waste – NRRW Rózan.

Type of probe and place of collection	Number of probe	Average value 2004	Concentration of trytium [Bq/dm^3]			
			I Q 2005	II Q 2005	III Q 2005	IV Q 2005
Ground waters inside NRRW	10p	< 7	< 4	< 4	< 4	< 4
	11p	480	180	370	390	370
	12p	3300	5100	3000	2300	3800
	17p	330	750	750	750	730
	18p	< 7	9	7	16	< 4
	130p	210	150	220	200	170
	131p	17000	18000	17000	19000	20000
	132p	62	480	65	27	100
Ground waters outside NRRW	F-1	36	43	57	56	35
Tap water (inside NRRW)	F-R	< 7	< 4	< 4	< 4	< 4

Table 6. Activity of environmental probes (soil and grass) inside and outside of National Repository of Radioactive Waste – NRRW Rózan in 2005 [Bq/kg].

Type of probe and place of collection		K-40	Cs-137	Ac-228 (Th-232)	Ra-226 (U-238)
<u>Soil - II quarter</u>					
<i>inside</i>	G 706	290	30	10	11
	707	490	110	21	24
<i>outside</i>	701	560	250	27	25
	703	470	45	21	23
<u>Soil - III quarter</u>					
<i>inside</i>	G 706	440	35	12	17
	707	550	85	16	24
<i>outside</i>	701	640	1400	20	28
	703	510	52	17	24
<u>Grass - II quarter</u>					
<i>inside</i>	R 706	760	15	< 6	< 3
	R 707	1200	57	< 6	< 3
<i>outside</i>	R 701	1300	23	< 6	< 3
	R 703	1200	1,7	< 6	< 3
<u>Grass - III quarter</u>					
<i>inside</i>	R 706	350	15	< 6	< 3
	R 707	200	230	< 6	< 3
<i>outside</i>	R 701	550	96	< 6	< 3
	R 703	370	< 0,8	< 6	< 3

The Calibration Laboratory is maintaining and using the standard fields of neutron and gamma radiation. The ^{137}Cs is the main calibration source of gamma radiation. Standard neutron fields, traceable to primary standard laboratory National Physical Laboratory (NPL, Great Britain) were established at the Institute of Atomic Energy (IAE) almost ten years ago. The fields are formed by calibrated sources of ^{252}Cf and $^{241}\text{Am-Be}$. For routine use, there is also $^{239}\text{Pu-Be}$ neutron source available calibrated against standard source of $^{241}\text{Am-Be}$. Additionally, spherical filters made of iron or paraffin can be used for modification of the neutron spectrum and gamma component of absorbed dose.

The neutron fields are used mostly for research but they are also used as the only fields in Poland, suitable for calibration of neutron dose meters used in radiation protection. Maintenance of the fields includes some periodic assessment of the dosimetric parameters, development of measuring methods and international inter-laboratory comparisons. In 2005 the calibration of transfer instrument (2202D neutron remmeter) has been done in NPL. The parameters of neutron fields in the IAE calibration hall have been periodically checked.

In the field of ^{137}Cs gamma source the periodical check measurements were performed applying specially designed and constructed reference instrument, ZR-101.

Within the PHARE project No PL 632.07.01 following issues have been completed

- installation and start-up of the gamma irradiator, containing ^{137}Cs , ^{60}Co and ^{241}Am sources,
- installation of neutron standard source ^{252}Cf ,
- implementation of new neutron measuring probe FHT 752 together with FH 40 dose rate measuring unit.

Calibration Laboratory performs also calibrations of surface contamination monitors, using reference sources of beta and alpha radiation, calibrated by Radioisotope Production Centre at Świerk.

Total number of monitors calibrated in 2005 is given below:

- Surface contamination monitors - 116
- Gamma dose and dose rate monitors - 176
- Neutron dose equivalent monitors - 4

In 2005 the staff of CD performed also the periodical check of dosimetric monitoring system of MARIA reactor together with calibration of data lines of the system with the detectors.

The calibration of radiation monitors in liquid radioactive waste storage tanks of Radioactive Waste Management Plant has been performed as well as calibration of radiation monitoring personal gate.

GAMMA RADIATION FIELD IN CALIBRATION HALL OF RADIATION PROTECTION MEASUREMENTS LABORATORY

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Isotope sources of ^{137}Cs are applied in Radiation Protection Measurements Laboratory (Laboratorium Pomiarów Dozymetrycznych, LPD) for calibration of dosimetric instruments, as recommended by International Standard Organisation (ISO) [1]. Three different ^{137}Cs sources are used at LPD. The “big” source of activity ca. 70 GBq is remotely controlled and stored in an underground channel. For the measurements, the source is transferred into working position at the centre of lead spherical shield. The 42 cm diameter shield is equipped with series of exchangeable beam collimators. The radiation beam is oriented along the calibration stand; with the beam axis 70 cm above the floor. Two other sources, “medium” and “small” one, of activities of ~ 4 GBq and 0.4 GBq, respectively, are placed manually in the same shield.

The parameters of gamma radiation fields for all three ^{137}Cs sources in the LPD calibration stand were carefully determined, resulting in standardisation of gamma fields for dosimetric calibrations [2].

Air kerma (or air kerma rate) at the reference point is the main metrological parameter for gamma radiation in LPD. This value is directly related to the exposure, ambient dose equivalent and kerma in other materials, e.g. soft tissue. With this parameter the calculation of the dose absorbed in various irradiated objects is possible.

Standard fields of gamma radiation in LPD are traceable to Central Office of Measures, Poland (Główny Urząd Miar, GUM). The measurements of air kerma have been performed for “big” ^{137}Cs source in 9 points by GUM officers, using secondary standard ionisation chamber. According to GUM Certificate, the air kerma rate in 1 m was 4.23 ± 0.09 mGy h^{-1} on 31 December 2005. Moreover, the standard, tissue equivalent chamber designed in LPD [3] was calibrated in GUM, in standard field of ^{137}Cs . The chamber as well as other chambers of various size and sensitivity [4] was

used for determination of dose values vs. distance in the calibration stand for all three ^{137}Cs sources. Careful analysis of the experimental data yielded some important corrections. Real source-detector distance was found to be 0.5 cm larger than assumed for “big” source and 2.7 cm smaller for “medium” and “small” sources. In the measurements at distances larger than 1.2 m an ionisation chamber of REM-2 type was applied. It was found that the active centre of that chamber is not exactly at the geometrical centre but shifted by 2.8 cm in the direction opposite to the radiation field [5]. The corrections for air absorption (0.011 m $^{-1}$) and floor and wall scattering were also discussed and introduced.

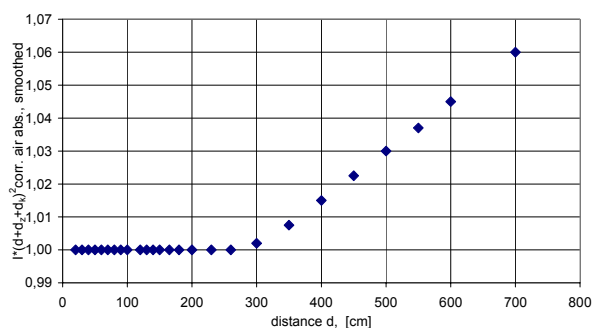


Fig. 1. Smoothed curve of ionisation current multiplied by squared distance, corrected for air absorption, vs. distance.

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IONISATION CHAMBER FOR CONTINUOUS MONITORING OF THE DIAMETER AND DIRECTION OF THERAPY PROTON BEAM FOR EYE MELANOMA TREATMENT

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Proton therapy is an optional treatment of the eye melanoma, competitive to the eyeball extraction in the cases of big tumours or the tumours located in the back extreme of the eyeball. A facility for the proton therapy is currently under construction in the Institute of Nuclear Physics in Kraków. The aim of this work was to design an ionisation chamber for monitoring of the diameter and direction of therapeutic proton beam.

The double chamber consists of two parts (gas cavities) with thin walls combined together in one enclosure that joins together two ionisation chambers - the ring and the quadruple (Fig. 1).

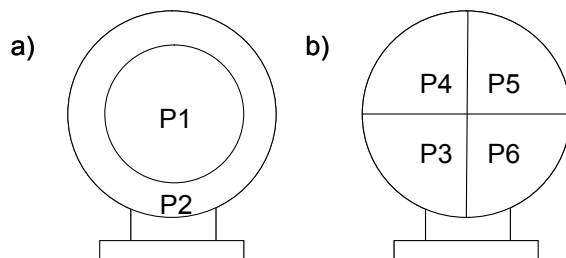


Fig. 1. Scheme of electrodes of the ring part of the chamber (left) and the quadruple part (right).

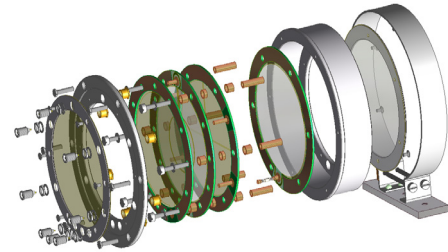


Fig. 2. Elements of the chamber.

The electrodes were made of 50 μm thick polyimide foil, according to a specially developed technology. One side of the foil was coated with Al conductive layer. The foil is attached to a ring made of two-side laminate, commonly used for printed-circuit boards. The chamber housing is made of aluminium alloy PA6.

The chamber was tested and calibrated in the calibration hall of the Institute of Atomic Energy in the reference gamma radiation field of ^{137}Cs source. The main parameters of interest were: leakage current and sensitivity of all parts of the chambers. The determined mean value of leakage current was 3 fA, with maximum deviation of 15 fA, while the acceptable leakage can reach 250 fA [1].

The results of calibration measurements of ionisation current at the distance of 0.5 m from the source are given in Table I.

Table 1. Results of measurements of ionisation current for single electrodes and for the ring part and the whole chamber.

Electrode	P1	P2	P3	P4	P5	P6
Ionisation current [pA]	5.25 ± 0.01	16.857 ± 0.008	6.122 ± 0.007	5.88 ± 0.02	5.891 ± 0.008	5.770 ± 0.008
Electrodes	P1+P2		P1+P2+P3+P4+P5+P6			
Ionisation current [pA]	22.154 ± 0.009		45.63 ± 0.02			
Sum of currents from single electrodes [pA]	22.11 ± 0.02		45.77 ± 0.03			

The difference between the ionisation currents measured for each of the chamber parts and the appropriate sum of ionisation currents measured at the single electrodes (P1+P2 for the ring chamber, P3+P4+P5+P6 for the quadruple chamber and P1+P2+ P3+P4+P5+P6 for the whole chamber) were negligible (below 0.5%) . This confirmed very high accuracy of geometrical parameters of the chamber. After testing and calibration at

IAE the chamber successfully passed tests in the 60 MeV proton radiotherapy beam of the isochronic cyclotron AIC-144 at the Nuclear Physics Institute.

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THE EFFECTIVE CENTRE OF IONISATION CHAMBERS

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Many ionisation chambers are of rather large size and complex design and therefore are not point detectors. Despite of this, they are often used for determination of the absorbed dose in a given point of the medium. As a result of different densities of the gas and solid elements of the chamber the effective centre of the chamber may not coincide with its geometrical centre. The displacement of the effective centre from the geometrical one is a well known factor in case of in-phantom ionisation chambers. In this work the case of large ionisation chambers, used mainly in radiation protection was considered.

A simple ionisation chamber, which practically does not disturb the radiation field, usually shows a displacement of the effective centre, when placed near a point radiation source, because the absorbed dose is different in different parts of the chamber volume. The displacement Δ can be calculated when the ionisation is dominated by particles created in the gas:

$$\int_V [r(x, y, z)]^{-2} dV = (d + \Delta)^{-2}$$

where d is the distance from the geometrical centre of the chamber to the point source, and r is the distance from that source to the (xyz) point inside the chamber gas volume V .

This kind of displacement depends on the source-to-chamber distance and the shape and size of the chamber. For cylindrical ionisation chambers it depends also on the direction of the chamber axis relatively to the radiation field. The displacement has the opposite direction when the chamber is placed parallel or perpendicularly to the beam axis. For large ionisation chambers of spherical symmetry, the effective centre of the chamber is always displaced toward the radiation source.

Another type of displacement is observed in the chambers of complex construction, when some parts of the gas volume are shielded by the chamber elements like thick central electrode. This kind of the displacement is often independent of the source-to-chamber distance. It can be determined experimentally in a radiation field of known spatial distribution.

As an example of the big chamber of complex design a high pressure ionisation chamber of REM-2 type (Fig. 1) was chosen here. The chamber has 25 tissue-equivalent electrodes, the volume of 1800 cm³ and is filled with tissue equivalent gas (1 MPa). The measurements were performed in a collimated reference beam of

¹³⁷Cs gamma radiation source in the calibration hall of the Institute of Atomic Energy.

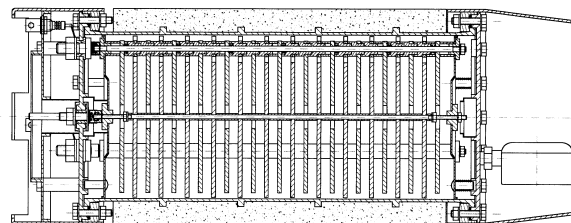


Fig. 1. Cross section of the REM-2 chamber.

It was established, that for the distances from the source smaller than 3 m, the product of the dose rate, D and the square of the distance, Dd^2 , decreases proportionally to the distance, with the slope of -0.011 m^{-1} , due to attenuation of the radiation in air (solid line in the Fig. 2).

Since the radiation beam is divergent, the radiation scattered from the hall floor produces considerable deviations from that linear dependence for distances exceeding 3 m. Those deviations are discernible for the product of the ionisation current, i , of REM-2 chamber, and d^2 (Fig. 2). together with the Dd^2 curve, normalized to the i curve at the distance of 1 m.

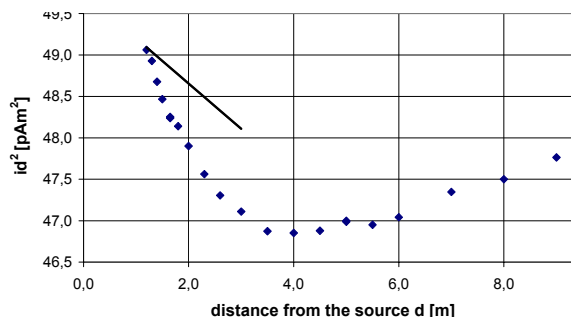


Fig. 2. Dd^2 (solid line) and id^2 (dots) dependence on d for REM-2 chamber.

It should be noted (Fig. 2) that the id^2 dependence on d does not reproduce the Dd^2 dependence on the distance. The value of the displacement Δ was found using the requirement that the slopes of the $i(d + \Delta)^2$ and the Dd^2 dependence on d should be equal. For the tested REM-2 chamber the displacement of 2.8 cm was found.

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MEASUREMENTS OF $H^*(10)$ AND ESTIMATION OF NEUTRON DOSE AT 15 MV VARIAN CLINAC MEDICAL ACCELERATOR

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Radiation fields around photon medical accelerators, operating at electron energy of 15 MeV or higher, are slightly contaminated with neutrons, generated by photon-neutron nuclear reactions. Practically, almost no neutron measurements are performed in radiotherapy departments because of lack of convenient measuring equipment for the routine use. The aim of this work was to develop a relatively simple methods for radiation protection measurements of ambient dose equivalent $H^*(10)$ and neutron dose rate outside the irradiation field of medical accelerators.

As the result, three recombination methods were elaborated, using ionisation chambers of different types. The first chamber is a recombination chamber i.e. a high-pressure, tissue-equivalent, ionisation chamber operating under condition of initial recombination of ions. The total absorbed dose and the recombination index of radiation quality are measured. Then, $H^*(10)$ can be determined with accuracy of about 15%, for any neutron contribution to the absorbed dose. Additionally, the neutron dose can be determined with accuracy of about 20% when the neutron contribution to the total absorbed dose, d_n , is above 3% and with accuracy of 40% when d_n is of about 1% [1-4].

The second chamber is also tissue equivalent but with much higher gas pressure, above 1 MPa. The chamber has small electrode gap of 0.4 mm. It also operates under conditions of local recombination, so the ion collection efficiency does not depend on dose rate and the chamber can be used in non-saturated mode. First, the chamber is calibrated in the reference radiation fields of gamma and neutron radiations. Then, the measurements of ionisation current at two different voltages are performed, in the investigated radiation field. The neutron dose can be determined with accuracy of 15% for $d_n > 3\%$, and $H^*(10)$ with accuracy of 30% for any value of d_n [3,4].

The third chamber is a graphite one, filled with $^{10}\text{BF}_3$. The chamber also operates in non-saturated mode. During the measurements it is placed on a phan-

tom and covered with a polyethylene hemisphere. The sensitivity to fast neutrons of that arrangement is about 100 times higher than its sensitivity to X-rays. In result d_n can be determined with accuracy of 15%, for the radiation fields with very low contribution of neutrons to the total absorbed dose ($0.5\% < d_n < 3\%$) [3, 4].

The used chambers practically do not suffer from saturation and dead-time effects. Therefore, they can be employed in intense radiation fields. The other advantage is that ionisation chambers are common devices in radiotherapy departments. This makes it relatively easy to connect the chambers to the electronic devices that already exist in radiotherapy centres.

All three chambers were used for the determination of $H^*(10)$ and d_n at the 15 MV Varian Clinac 2300C/D medical accelerator. The measurements were performed on the therapeutic couch at the distances from 17 cm to 1 m from the beam axis, with irradiation fields of 10×10 cm and 4×4 cm. The beam was directed either on the phantom or on the floor, in order to create the radiation fields with different levels of scattered X-rays. The measured values of d_n ranged from 0.9% to 26% and the total dose rate ranged from 8.5 mGy h^{-1} to almost 4 Gy h^{-1} . As it was expected, no neutrons were detected during the 6 MV runs of the accelerator.

The work was partly supported by the Polish State Committee for Scientific Research, under the project number 4T11E 006 25.

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INITIAL RECOMBINATION OF IONS IN IONISATION CHAMBERS FILLED WITH HYDROCARBON GASES

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Although recombination chambers have been successfully used for many years, some basic data on ion recombination in pressurized gases are still lacking, in order to design the recombination chambers with given parameters. This is because of complex and usually not calculable dependence of the ion collection efficiency on gas pressure and on electrical field strength in high-pressure ionisation chambers.

The aim of this work was to determine the gas pressure dependence of initial recombination in some hydrocarbon gases. The gases selected for studies were most suitable for filling the tissue-equivalent recombination chambers. The hydrogen content in the gases selected is similar or slightly higher than that in soft human tissues.

The experiments were performed with the REM-2 ionisation chamber filled with ethane or propane at various pressures.

The important finding is that in the first approximation the shape of the saturation curve does not depend on the kind of the hydrocarbon gas used but only on its density in the chamber (Fig.1). The experiments revealed that the addition of few (weight) percent of air to the hydrocarbon gas produced only very small chan-

ges in the shape of the saturation curve. Thus there is no need to use the gases of high purity.

It was found that the enhancement of the sensitivity with the increasing gas pressure is limited to some range of the gas density. At the densities larger than $\sim 50 \text{ kg/m}^3$, the loss of ions due to initial recombination may overbalance the increase of number of ions generated in the chamber. The effect takes place in detection of neutron radiation. Therefore, at very high gas densities, the sensitivity of the chamber may decrease when the gas pressure is increased.

The gases with high content of hydrogen (e.g. CH_4) are the most convenient for high pressure recombination chambers used in mixed neutron + gamma radiation fields, because with such gases it is easier to get the similar sensitivity of the chamber to neutron and gamma radiations. At low gas pressures (about ambient pressure) the dominance of the initial recombination can be reached only in gases of high molecular weight, e.g. butadiene (C_4H_6) which can be used for determination of the dose equivalent $\text{H}^*(0.07)$.

The obtained results [1] provide the basic data, which can be directly used for designing the recombination chambers, according to the needs specified by the user.

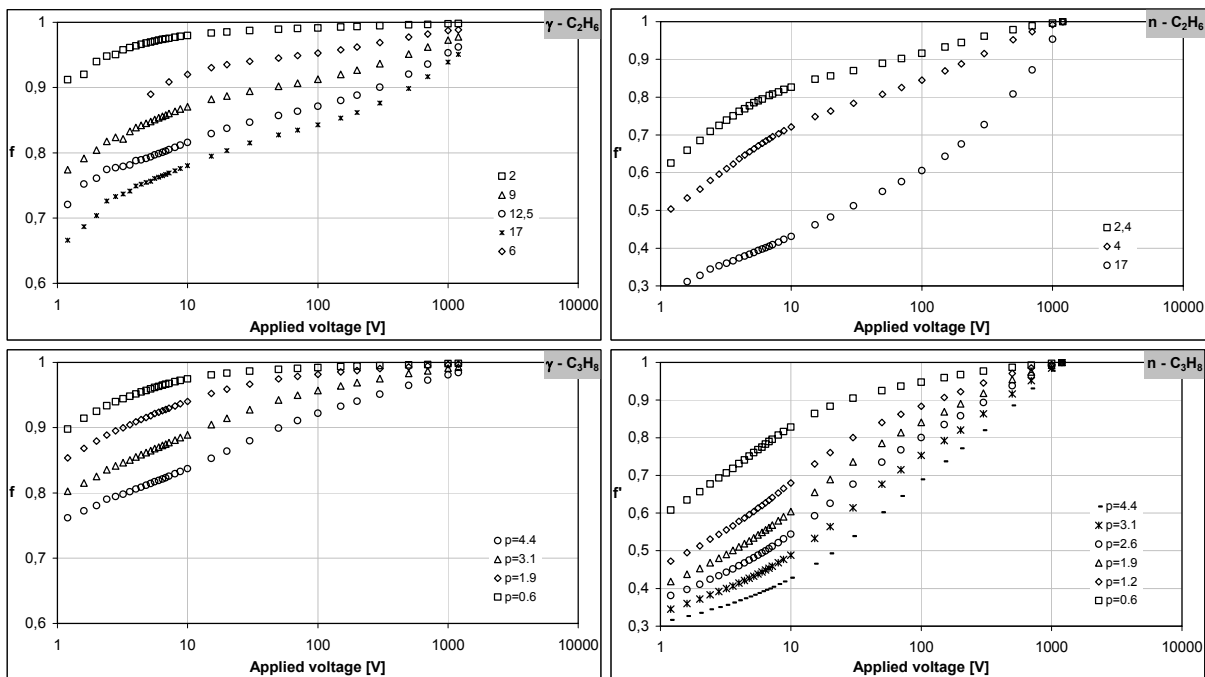


Fig. 1. Ion collection efficiency for gamma ^{137}Cs source on the left and relative ion collection efficiency for ^{239}Pu -Be neutron source on the right, in the REM-2 ionisation chamber filled with ethane (upper figures) and propane (lower figures).

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NEW METHOD FOR DETERMINATION OF GAMMA AND NEUTRON DOSE COMPONENTS IN MIXED RADIATION FIELD

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A new method is proposed for determination of dose components in mixed radiation fields (gamma + neutrons) using a recombination chamber. In this method, unlike other recombination methods, there is no need to determine the saturation current, neither in the investigated radiation field, nor during the calibration. Therefore, the chamber can be filled with gas under the pressure much higher than used in recombination chambers up to now. The method consists in the determination of the ratio of ionisation currents at two different voltages applied to the chamber, first during the calibration in neutron and in gamma radiation fields and then in the investigated mixed radiation field.

The method is based on the additivity of electrical charges generated in the chamber by gamma and neutron radiation. The gamma and the neutron dose rates are determined in terms of the relative ion collection efficiency f and sensitivities of the chamber to gamma radiation A_γ and neutron radiation A_n . The relative ion collection efficiency

$$f = \frac{i(U)}{i(U_S)}$$

where $i(U)$ and $i(U_S)$ are the ionisation currents measured at the specified polarising voltage U and at the reference voltage U_S .

Sensitivity of the chamber to radiation is defined as the ratio of ionisation current $i_{Cs-137}(U_S)$ or $i_n(U_S)$ at the voltage U_S to the dose rate D in gamma

$$A_{Cs-137} = \frac{i_{Cs-137}(U_S)}{D}$$

and neutron radiation field

$$A_n = \frac{i_n(U_S)}{D}$$

For gamma radiation the ^{137}Cs source was used. Since the reference neutron radiation field may be contaminated with gamma the care should be taken to identify the current due to neutrons.

The gamma D_γ and neutron D_n dose components of mixed radiation field are given by [1]

$$D_\gamma = \frac{i(U_S)}{A_\gamma + x \cdot A_n}$$

$$D_n = \frac{x \cdot i(U_S)}{A_\gamma + x \cdot A_n}$$

where

$$x = \frac{A_\gamma \cdot f_\gamma - f}{A_n \cdot f - f_n}$$

Subscripts γ and n relate to the gamma and neutron radiation fields, A_γ , A_n , f_γ and f_n are determined during calibration (for a chosen voltage U).

The method was proved in series of tests performed with tissue equivalent recombination chamber of REM-2 type filled with methane, ethane, propane, ethylene and tissue equivalent gas at different gas pressures [1]. It was found that the most suitable electrical field strength range for measurements is between 15 V/cm and 100 V/cm (Fig. 1).

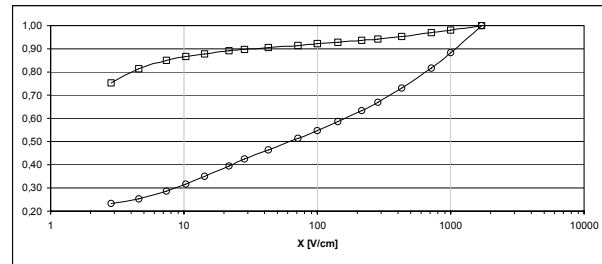


Fig. 1. Relative ion collection efficiency in REM-2 chamber filled with methane (\square — gamma ^{137}Cs , \circ — neutrons $^{239}\text{Pu-Be}$).

The method can be used for determination of neutron and gamma dose components in the environment, especially in the vicinity of nuclear centres. It is also suitable for estimation of the neutron dose component outside useful beams of medical accelerators [2].

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INVESTIGATIONS OF COMPONENT MATERIALS AND OPTIMISATION OF GAS PRESSURE FOR BF₃ FILLED RECOMBINATION CHAMBERS

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Recombination chambers are useful instruments for characterization of radiation quality of mixed radiation fields, also in therapeutic beams of high intensity. The chambers are usually tissue equivalent (TE), in order to simulate the so called standard soft tissue, but their response can be, to some extent, adjusted by the use of different filling gases, e.g. in order to simulate the composition of a particular tissue. Such a problem becomes drastically important in case of boron neutron capture therapy (BNCT), because even small amount of ¹⁰B introduced to tissue, changes considerably the absorbed dose, as compared to the dose measured using TE ionisation chamber of standard composition. Moreover, the radiation effects of BNCT are associated with four-dose-component radiation field - boron dose from ¹⁰B(n,γ)⁷Li reaction, proton dose from the ¹⁴N(n,p)¹⁴C reaction, neutron dose (mainly fast and epithermal neutrons) and gamma-ray dose.

It was shown [1-3] that the dose components mentioned above can be determined using a set of three recombination chambers - TE chamber and two graphite recombination chambers - one filled with N₂ and the second filled with ¹⁰BF₃. The design of the graphite chamber was not optimized up to now, mainly because of lack of data concerning the operation of recombination chambers filled with ¹⁰BF₃. The aim of present work was to optimize the pressure of ¹⁰BF₃ for BNCT dosimetry and to investigate which materials can be used for the construction of the chambers, taking into account the high chemical activity of BF₃ [5].

The gas pressure in the chamber should be high enough to ensure that the chamber works under conditions of initial recombination of ions. Also discrimination between high-LET and low-LET radiation is generally better at high pressures. On the other hand, the ion recombination may influence determination of saturation current at high pressures. The optimum gas pressure was determined from measurements of saturation curves of graphite chamber filled with ¹⁰BF₃ at gas pressures up to 0.6 MPa. The measurements were performed with the chamber of G59 type [4] in neutron-gamma radiation field of ²³⁹Pu-Be source and in gamma radiation field of ¹³⁷Cs source, in the Radiation Protection Measurements Laboratory of the IAE.

It was found that the ionisation current at 500 V (maximum applied voltage) increases linearly with gas

pressure for gamma radiation, while for neutrons it attains a maximum at ~0.35 MPa (Fig. 1). For higher gas pressure, the ion recombination compensates the increase of the BF₃ mass in the chamber cavity and the ratio of neutron to gamma sensitivity diminishes. Therefore, there is no reason to increase the BF₃ pressure above this value.

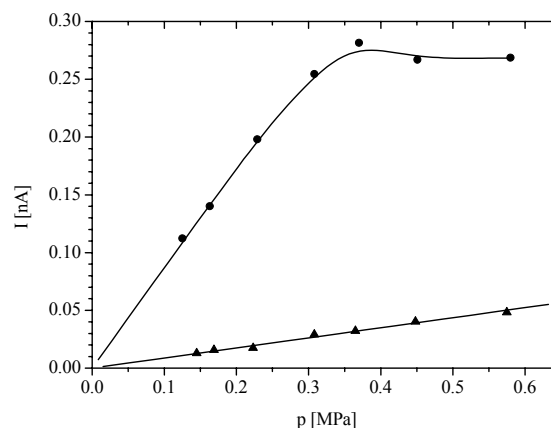


Fig. 1. The dependence of the ionisation current of ¹⁰BF₃ filled graphite chamber on gas pressure for neutron radiation field of ²³⁹Pu-Be source (circles) and gamma radiation field of ¹³⁷Cs source (triangles).

The second part of the work was concerned with the chemical influence of BF₃ on mechanical and electrical properties of materials used for the chamber construction. It was confirmed that graphite, steel, aluminium, Teflon and copper parts did not suffer from contact with BF₃ during reasonably long time (more than one year). Other materials, especially insulation tapes and silver coated wires should be strongly avoided [5].

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