CHARACTERIZATION OF ENVIRONMENTAL RADIOACTIVITY IN THE INFLUENCE ZONE OF IFIN-HH BUCHAREST, MAGURELE

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ABSTRACT

As a consequence of 40 years of nuclear related activities on the Bucharest Magurele site, the environment surrounding the area of the institute was significantly influenced. The main facilities acting as sources of radioactive pollution are inter alia the VVR-S research reactor, the U-120 cyclotron, the radioisotope production centre, the radioactive waste treatment plant, and spent fuel storage facility.

In the framework of the IAEA Co-ordinated Research Project entitled "Site characterization techniques used in environmental restoration activities", under research contract No.8735, methods for the characterization of radioactive contamination in the institute influence zone have been developed. The attention focused on the routes involved in radioactive waste and spent fuel management. Based on the environmental monitoring programme developed for the nuclear units on the site, the monitoring network was improved in area Reactor – Spent Fuel Storage – RWTP – railway station for shipping the drums to the national repository Baita-Bihor, an area with elevated radiological risks.

Additionally, the work has been extended to the temporary radioactive waste storage at the former Magurele military fort, which is now partially decommissioned.

The paper presents techniques, methods and instrumentation used for the radiological characterization of the site Magurele and its influence area, during the period of 1995 – 1999, as well as the respective quality assurance (QA) procedures. The results of this radiological survey presented here will be used to define the environmental restoration programme of the zone.

In addition the system for the information of the public developed in this project is discussed.

1. INTRODUCTION

Magurele Centre near Bucharest was the first nuclear site to be developed in Romania, starting in 1957 with the commissioning of the VVR-S research reactor and the U-120 cyclotron. Based on these installations a number of research and application programmes have been developed. These activities had some radiological impact on the Magurele area through radioactive emissions, as well as through the disposal of liquid and solid radioactive wastes.

Most significantly the wastes arose as by-product of the radioisotope preparation. The radioisotope production begun in hot cells and labs located in the underground level of the reactor building, at. In seventies this radiochemical production was transferred to a new dedicated building on the same site. The site was also upgraded with a new radioactive waste treatment plant (RWTP).

Before the treatment in the Magurele RWTP commenced, the wastes originating from the reactor operation and radiochemical labs, as well as in other applications developed on the site, were stored in an old military fort near the Institute of Atomic Physics. The institute was also in charge to collect all the radioactive wastes from country.

In 1977, after the serious floods of the Magurele fort, the wastes were transferred to the RWTP storage area and partially treated.

In the 1980s, the national repository Baita-Bihor, located in the Western Carpathians mountains, was legally commissioned. This repository is situated in an old Uranium mine and is designed to receive 20,000 standard 200 l-drums. The radioactive wastes are transported from the RWTP Magurele to the national repository Baita-Bihor by train. The site is provided with a special area for unloading of drums from the railway wagons.

Taking into account the growing public concern, the increased attention paid by international organizations [1] [2] [3], as well as the development of the national legislation on environmental protection and safe operation of nuclear installations, environmental monitoring in the vicinity of nuclear facilities is performed according to the following legal framework:

— Law of environmental protection [4];
— Law of safe operation of nuclear installations [5];
— Rules, instructions and legislative documents (regulations) [6];
— The environmental concept of IFIN-HH (the holder of the license) [7];
— Practices developed in different nuclear units and QA procedures.

This research programme for characterizing the environmental radioactivity in the influence area of IFIN-HH Bucharest Magurele, has been developed as a part of the Coordinated Research Programme of the International of Atomic Energy Agency entitled "Site Characterization Techniques Used in Environmental Restoration Activities".

2. PRESENT STATUS OF THE SITE

2.1. Geographical characterisation

2.1.1. Site location

The general plan of the zone given in Figure 1, and shows the geographical location of Magurele in the capital of the country. The site is situated on the Romanian Plain, between the rivers Sabar and Dambovita about 3 km to the SW. The city-center of Bucharest is some 8 km away. To the SSW of the site the Ciorogarla, Sabar and Arges rivers flow.

2.1.2. Geomorphology

The site belongs structurally to the Romanian Plain, forming a plateau at an altitude of 75–78 m above sea level, is situated on the left bank of Ciorogarla river, about 1500 m away from it. The site is generally flat, with little relief and thus allowing easy dispersion of released contaminants.

2.1.3. Surface waters

The catchment basin of Ciorogarla river has a surface area of about 116 km^2 and is entirely located within the Plain. The mean altitude of this catchment basin is 98 m above sea level.
The river has its origin in Brezoaiele. The minor waterway is 35–40 m wide and 3.5–4 m deep. Certain sections of the larger rivers are prone to flooding, in particular in the Plain.

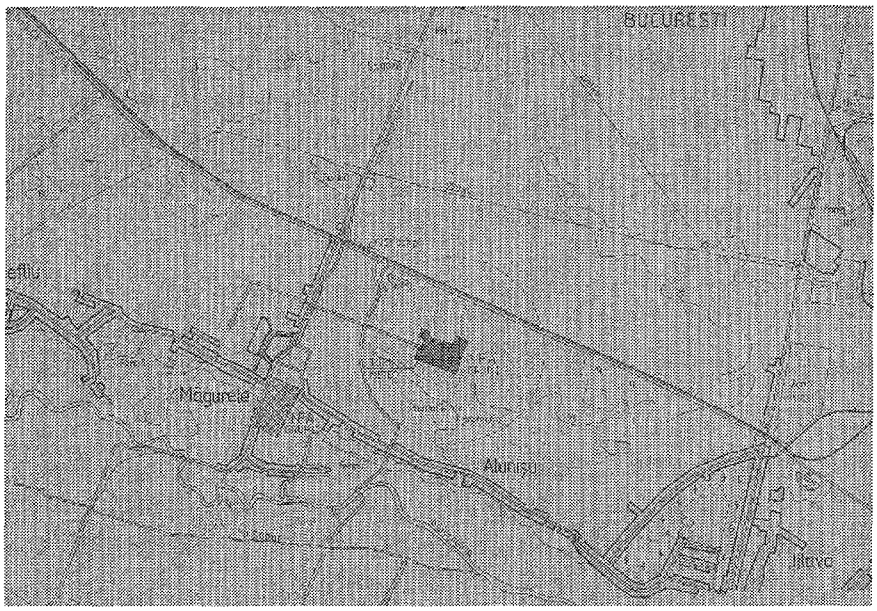


FIG. 1. General map of the area.

The Marguele site being on a high plateau above the river, it should be beyond the reach of the floods. It is worth noting that during severe winters, the river can freeze entirely and the flow then is considered zero.

2.1.4. Groundwaters

The first aquifer is found at 7 m in depth and is formed by sands and gravel layer 3–5 m in thickness. The aquifer is recharged by infiltration from the whole terrace, which extends to the East and up the river Dambovita. To the West, the aquifer discharges in springs at the bottom of slopes to the lower terrace of the river Sabar. The deeper groundwater drains through gravel layers into the same river. The groundwaters are used as drinking water for the neighborhood villages. The water table in the aquifer is 4 m above the river Sabar level and, therefore, the influence of the variations in river level upon the groundwater level is relatively limited. Variations in the groundwater levels are due to seasonal rainfalls and amount to about 2 m.

2.1.5. Climatic conditions

The IFIN-HH site, being located in the central part of the Romanian Plain, is influenced by the large masses of continental air, which are characterized by extreme differences between the maximum and minimum values of the same meteorological parameter. The current frequency distribution of dominant winds is presented in Table I.

The annual quantity of precipitation in its various forms sums up to about 500 mm in this area. The highest average monthly precipitation (80 mm) is falling in June, but it may also occur in May and August. However, during the summer, particularly in June, heavy local downfalls may occur, which may exceed 250 mm for a single event. The lowest average monthly quantities are falling in February (30 mm). The maximum annual quantity of precipitation may exceed 800 mm during years with intense cyclonic activity. In winter, the maximum monthly precipitation may exceed 100 mm.

Annual average temperatures are in the range of 10–11 °C, the long term annual average temperature being 10.4 °C. The variations of the average monthly air temperatures from month

to month are the ones characteristic of continental areas in the temperate region. The maximum value recorded in July exceeds 22 °C, while the minimum in January is below -4 °C). The monthly average values of the daily maximum and minimum temperatures include external momentary values, constituting important characteristics of the thermic regime. The monthly average maximum temperatures may reach its highest values (above 35 °C) in July and August, and its lowest one (below -10 °C) in January.

2.1.6. Land use

The Magurele District covers an area of 43.39 km^2, and land use is distributed as indicated in Table II.

It is clear from Table II that the largest surface area is taken up by agricultural land. However, the cultivated land is located outside the sanitary protection area, which is defined by a radius of 800 m around the Reactor. This area is surrounded and planted outside the young forest limits, the access in this area being strictly controlled.

2.1.7. The distribution of population and activities in the IFIN-HH area

Within a radius of 1 km, there is no inhabited land, the only area which reaches this limit is Magurele being situated to the West of unit I. The inhabitants of the western area, one of the most densly populated areas, are distributed between several villages within a 6 km radius: Magurele, Varteju, Bulgaru and Bragadiru, which have a total of 7242 inhabitants. In the SE area, the population of about 8020 is distributed between two villages: Jilava and Odaile. The closest limit of Bucharest city is about 4 km away to the NE, in wind direction from the SW. The part of town being located to the North, is not situated in the direction of dominant winds. The main activity of the inhabitants living in the neighbouring villages is agriculture, particularly the cultivation of vegetables. At present, IFIN-HH has some 2200 non-residential employees, and there are also a number of high school and college students [8].

2.2. Radiological status of the site

IFIN-HH Bucharest is the legal owner of nuclear site, which comprises the following nuclear installations:

- the nuclear reactor VVR-S Bucharest;
- the RP01-zero power reactor (PUB);
- the subcritical assembly HELEN (UB);
- the neutron generator TEXAS;
- the cyclotron U-120;
- the TANDEM accelerator;
- the radioactive waste treatment plant (RWTP;
- the radioisotopes production center (RPC); and
- the nuclear medicine center (NMC).

The estimated maximum emissions to the atmosphere from these installations are between 0.1 and 1000 Ci/year. For the liquid effluents, the major contribution arises from the RPC, the nuclear reactor (including wet storage of spent fuel) and the RWTP. The solid wastes arise from in particular the RPC, the research reactor VVR-S Bucharest, the radioisotopes applications laboratories and some other nuclear units in the country.

In the IPNE influence zone nuclear activities have been ongoing for about 40 years, beginning with the startup of the research reactor VVR-S and the radioisotope production laboratory. This activity inherently led to environmental contamination by the release of the gaseous products to atmosphere and also due to the manipulation of liquid and solid radioactive materials.

Within the influence area of IPNE there is also the old Magurele Fort used as temporary storage for radioactive wastes. The storage in the fort was partially decommissioned in the seventies, but there are no records on the actual decommissioning activities.

Systematic measurements were performed in the area affected by the research reactor decommissioning in order to provide a reference status for site. This environmental survey will continue during the research reactor decommissioning and RWTP modernizing, taking into account possible impacts on the environment of these activities. Another important aspect in this context is the long term monitoring of decommissioned nuclear installations.

The permanent shut down of the reactor at the end of 1997 led to a significant decrease of contamination from the gaseous radioactive discharges. At presently, the estimated radioactivity of the inventory due the activation is about 1900 Ci, distributed over 150 t of different materials [8]. The contaminated inventory is contained in about 50 t of various materials, e.g. experimental installations, tubes, pipes, etc. The radioactive inventory of VVR-S research reactor (calculated as of 31.12.1999) is summarized in Table III.

The major radioactive inventory is provided by spent fuel stored in a deposit far away from reactor, on the site [9]. This deposit has 4 ponds, with 240 fuel assembly spaces. The radioactive inventory from spent fuel is estimated to be 106900 Ci as of 31 December 1999. At present there are 152 fuel assemblies of the EK-10 and 74 of S-36 type in this wet storage. The claddings of the fuel are affected by the fast development of corrosion. The content of ^{137}Cs in pond water is around 40000 Bq/l. The radioactive inventory in the spent fuel from research reactor, also calculated for 31.12.1999 is given in Table IV.

In the yard of the RWTP, there is a significant amount of historical wastes stored in drums (more then 800) in an advanced state of corrosion, being a serious source of radioactive contamination of the site. For example, RWTP treated up to 1997 the following wastes:

- LLW liquids 25000 m^3
- MLW liquids 2 m^3
- LLW solids 2000 m^3
- MLW solids 2 m^3
- Total 5300 standard 200 l drums were sent to Baita-Bihor

Another problem, in terms of contamination, is connected with the railway platform for dispatching of the drums to the national repository Baita-Bihor. Preliminary measurements in the fort Magurele area indicate also a spreading of radioactive contamination due to wood wastes from the Scrovistea site stored near the facility, and also due partial decommissioning of this storage site following the floods in 1977. The Radioisotopes Production Centre reduced its activity, but there are still many sources of contamination resulting from its operation.

3. ENVIRONMENTAL MONITORING PRACTICES

3.1. Site monitoring

IFIN-HH has developed an environmental monitoring concept [7]. Nineteen monitoring points for the sampling of vegetation, soil and waters were established. IFIN-HH also established the sampling frequency and the methods applied, including their respective detection limits.

Significant amounts of radioactive wastes (in both, liquid and solid forms) are result from the routine nuclear activities on the Magurele site. All nuclear activities are grouped into nuclear units. Their monitoring is performed using the above mentioned environmental concepts [7] and subject to various QA procedures:

ACPL 0812 – Monitoring of total β and γ radioactivity of the environmental factors for nuclear units of IFIN-HH;
ACPL 0821 – Monitoring of total β and γ radioactivity of the liquid effluents (released by the nuclear units of IFIN-HH);
ACPL 0813 – Monitoring of total β and γ radioactivity of atmospheric aerosols and fallout.

The monitoring places and the sampling procedures are defined by internal documents. These sampling locations cover a large area, taking into account the meteorological factors and nuclear activities. On Figure 2 the sampling points are marked, a description of which, the type material sampled and the compass sector from the site are given in Table V.

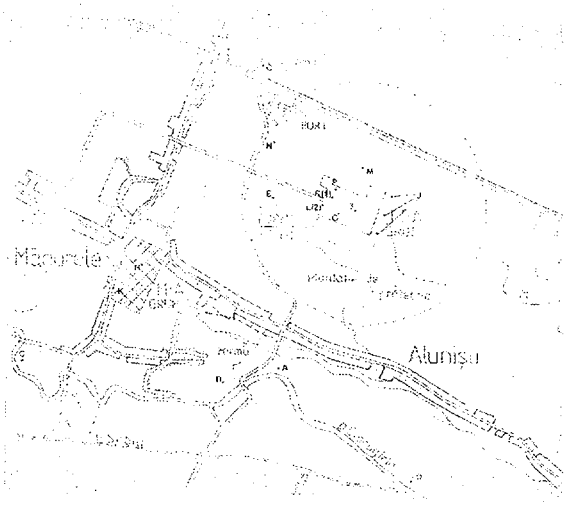


FIG. 2. IFIN-HH and the influence zone.

The sampling frequency depends on the characteristic average time of residence along an exposure route for each nuclide. Total β and γ measurements are the methods used for the characterization of the radioactivity and its influence area around IFIN-HH. Table VI indicates the sampling frequency for different contaminants.

3.2. Monitoring of the reactor area

Taking into account the future development of the nuclear activities in the IFIN-HH zone [10], including the decommissioning of the VVR-S research reactor, modernizing of RWTP, the decontamination of the old fort site, there is an absolute necessity for an improvement of the environmental monitoring system outlined above. As part of the nuclear activities large

amounts of liquid and solid radioactive wastes are manipulated, resulting potentially in airborne radioactive contamination in the IFIN-HH influence zone. The required radiological site characterization must become more detailed by the increasing of the number of sampling points and the use of new measuring techniques.

To this end, in 1996 nine new sampling points were established, which are listed in Table VII. In 1997 we considered four additional points in the RWTP yard. In 1998 the surveyed area was enlarged in order to cover the waste routes up to railway facility used for the dispatching of drums to the National Repository Baita-Bihor. In Figure 3 all sampling points are indicated (with the exception of those at the railway facility) [11] [12].

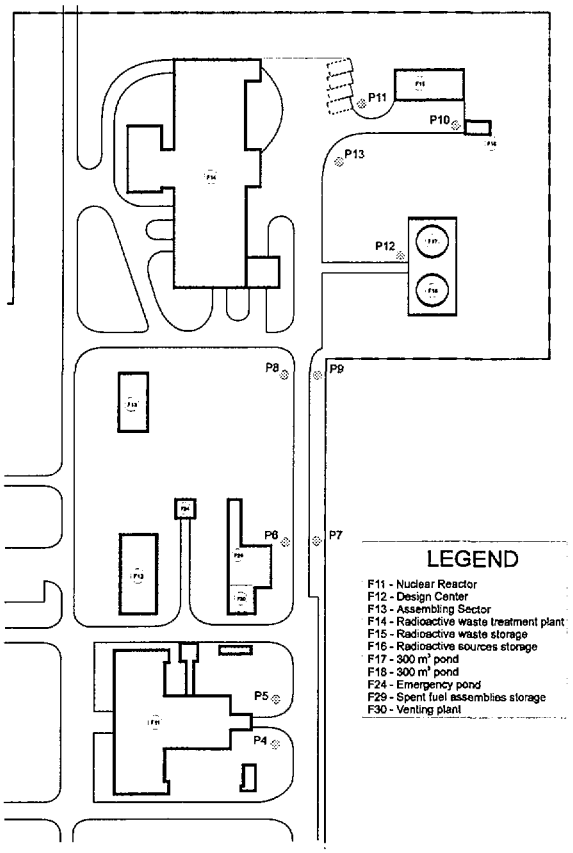


Figure 2

FIG. 3. Sampling locations.

Eighty one sampling points were established in the area around the reactor spent fuel storage for investigating its radiological status. At 48 of these points, including the access way to the reactor and the radioactive waste treatment plant (RWTP), the doses and contamination have been measured. Some sampling points were set up in the area of the pond for storing possibly contaminated waters.

In Figures 4 and 5 the measuring points for dose rates and contamination, on the asphalt covered roads, as well as on the vegetation of the green verges along the wastes transportation routes, are indicated.

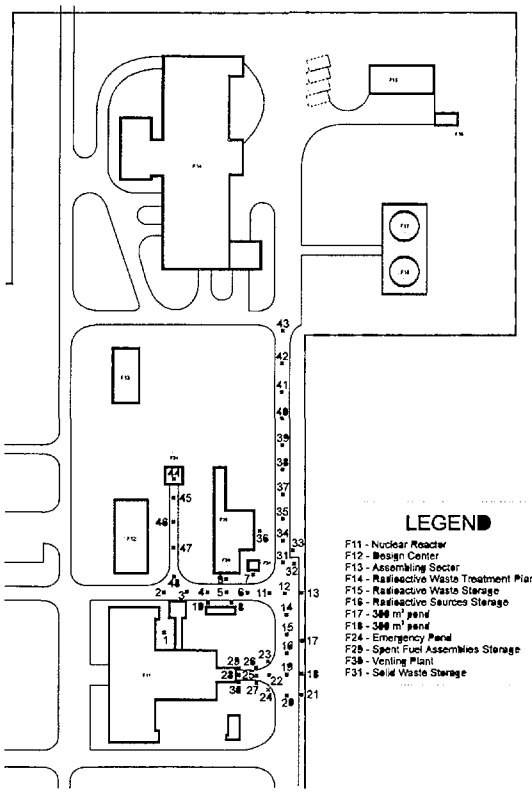


FIG. 4. Locations for dose rate and contamination measurements.

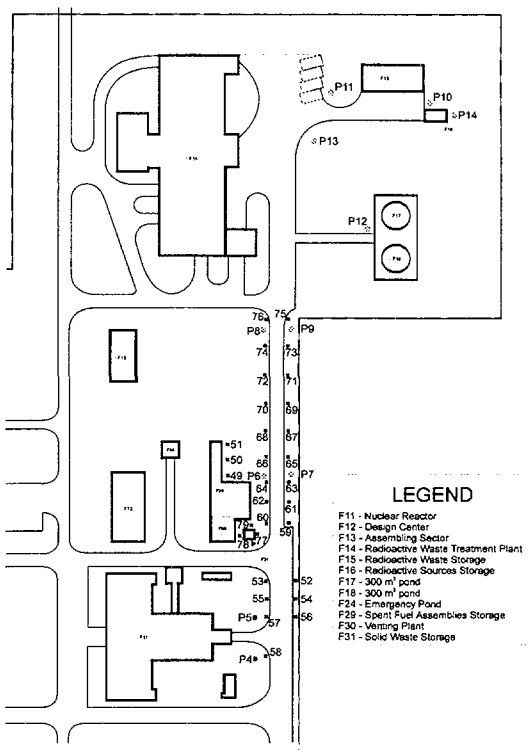


FIG. 5. Locations for dose rate measurements.

3.3. Monitoring Magurele Fort

The Magurele Fort, located near the Institute, was used in the 1960s as a temporary storage for radioactive sources and wastes. In 1974, a few tonnes of trees contaminated with ^{60}Co from biological research, performed in sixties at Scrovistea, were stored near the Fort, outdoors and without weather protection. In 1975, it was first tried to remove the radioactive materials from the Fort, which had accumulated due to flooding; but the operation was not completed. The windows were safely closed by concrete walls. In 1979, it appears that the physical barriers had been destroyed, but they were rebuilt. In 1998 the Regulatory Body (CNCAN) inspected the area. The physical barriers were, again, broken and then the decision for ecological restoration of the zone was taken. In this context, the institute performed some preliminary measurements for radiological characterization of the site [13] [14].

In early spring 1998 doses have been measured in one room of the fort, where radioactive wastes had been stored. Doses have also been measured at a number of points in the near neighborhood of the fort and at the storage area of the contaminated wood. Samples were taken from different depths and analyzed using γ-spectrometry in order to identify the contaminants.

In summer 1998 a new measurement was performed in the contaminated wood storage area. The measurements included dose rates and the determination of contaminants on a 2 m-grid, covering about 72 m^2. At the central point of the grid *in situ* γ-spectrometry measurements were performed. Another γ-spectrum was determined in front (outside) of the fort gate. The distribution of soil radioactivity was determined in depths up to 35 cm.

4. METHODS

4.1. Instrumentation

In situ measurements were performed using portable instrumentation (type SMART 200), with the associated detectors, and detailed in Table VIII. The high resolution γ-spectrometry measurements were performed using a NOMAD spectrometer, with absolute calibration. The main characteristics of the spectrometer are given in Table IX.

In accordance with the Romanian national legislation referring to metrology, all the instrumentation, which was obtained through generous assistance by the IAEA in the framework of the Technical Assistance Projects ROM/9/017 and ROM/9/017 EXTENDED, must be certified by National Bureau of Legal Metrology. Also, the personnel involved in standardizing measurements is to be authorized by above mentioned organization. The Investigator's laboratory is authorized to perform standardizing measurements for radioactive soils, vegetation and waters. The metrological calibration of α-, β- and γ-dosimeters is also to be performed by the National Institute of Metrology Bucharest.

QA procedures for sampling, calibration of instrumentation, measuring and reporting (bulletins) were developed.

4.2. Calibration of the spectrometer

In the following paragraph are presented the calibration results for the NOMAD installation working with the following parameters:

HV (+) = 2300 V;
Gain 0.8752x40=35.00;
Shaping time = LONG;
Preamplifier type = Resistive feedback;
Automatic Pole Zero Adjustment;
Digital Spectrum Stabilizer;
ADC Conversion Gain = 4096;
Digital Offset = Automatic PZC setting up was performed.

The energy calibration

An ^{152}Eu point source has been used for the determining of the function of energy vs. channel with the following geometries given in Figure 6.

Maximum nonlinearity

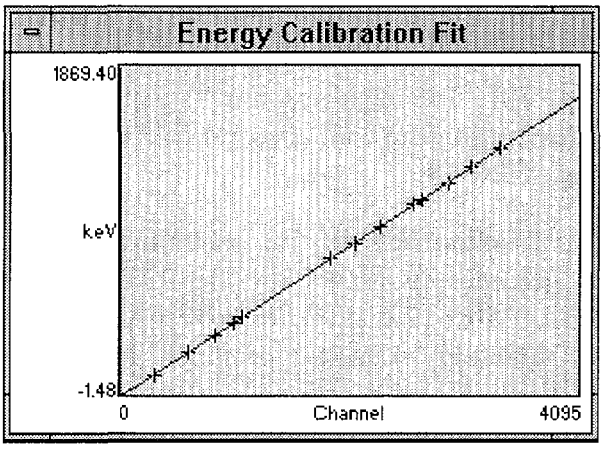
0,025% for the range (20...1800) keV
Linear calibration constant: 0,415 keV/channel; ±0,2% for P*=99,73%, in the range (35...1600) keV.

Measured energy resolution

0,62 keV for 59,54 ke V ^{241}Am (0,96 keV from fit)
1,39 keV for 661,62 keV ^{137}Cs (1,392 keV from fit)
1,82 keV for 1331,52 keV ^{60}Co (1,841 keV from fit)

See also Figure 7.

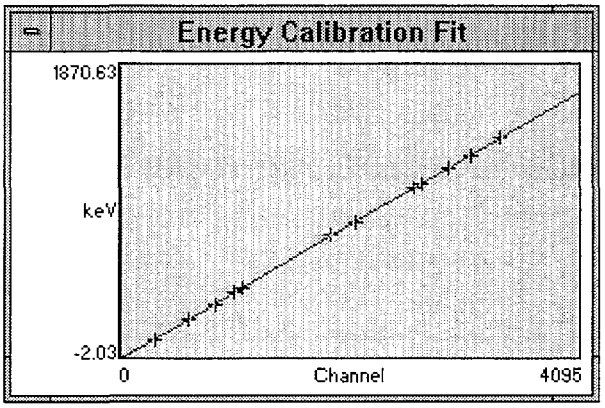
A) point source



Energy Table

keV	Channel	Fit keV	Delta
121.78	297.01	121.81	-0.03%
244.70	593.02	244.71	-0.00%
344.28	832.79	344.25	0.01%
411.12	993.80	411.10	0.00%
444.00	1072.94	443.96	0.01%
778.90	1879.54	778.92	-0.00%
867.38	2092.58	867.40	-0.00%
964.00	2325.30	964.06	-0.01%
1085.83	2618.38	1085.80	0.00%
1112.08	2681.56	1112.05	0.00%
1212.94	2924.42	1212.94	0.00%
1299.12	3131.87	1299.12	-0.00%
1408.03	3394.00	1408.03	0.00%

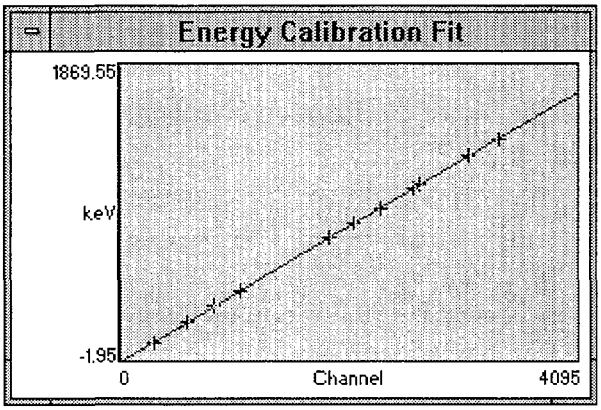
B) volume source



Energy Table

keV	Channel	Fit keV	Delta
121.78	297.99	121.80	-0.02%
244.70	593.75	244.71	-0.01%
344.28	833.28	344.26	0.01%
411.12	994.07	411.09	0.01%
444.00	1073.21	443.98	0.00%
778.90	1879.01	778.94	-0.00%
867.38	2091.81	867.40	-0.00%
1085.83	2617.14	1085.81	0.00%
1112.08	2680.24	1112.05	0.00%
1212.94	2922.93	1212.96	-0.00%
1299.12	3130.15	1299.13	-0.00%
1408.03	3392.01	1408.02	0.00%

C) Marinelli source



Energy Table

keV	Channel	Fit keV	Delta
121.78	298.01	121.80	-0.02%
244.70	593.96	244.71	-0.00%
344.28	833.62	344.25	0.01%
444.00	1073.72	443.97	0.01%
778.90	1880.02	778.92	-0.00%
867.38	2092.99	867.40	-0.00%
964.00	2325.64	964.06	-0.01%
1085.83	2618.62	1085.80	0.00%
1112.08	2681.78	1112.05	0.00%
1299.12	3131.94	1299.12	0.00%
1408.03	3394.00	1408.03	-0.00%

FIG. 6. Calibration of nomad: energy vs. channel for (a) point, (b) volume, and (c) marinelli sources.

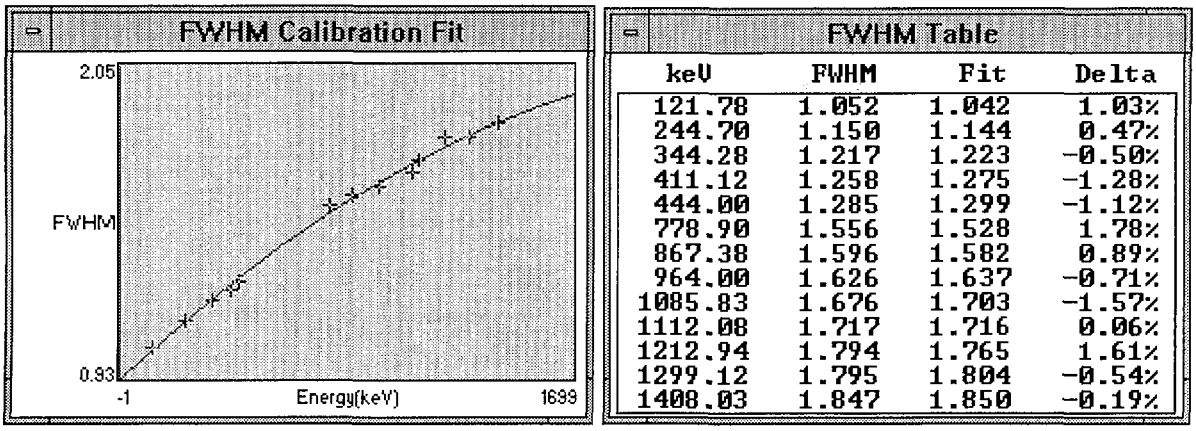


FIG. 7. Calibration of nomad: measured energy resolution.

Time stability of the peak position

The time stability was determined over the duration of 8 hours by 1 hour repeated measurements at the energies of 121.7 keV and 1408.03 keV. The spectrometer was run with a peak stabilizer, the shifting stability being lower than the tolerances accepted by the analyzing program.

Minimum detectable activity

This parameter is defined by the relationship MDA= $3 \cdot S_{background}/Eff$, where MDA is the minimum detectable activity, $S_{background}$ the error in background counting and Eff the efficiency. The values determined are given in Table X.

Efficiency calibration

Efficiency calibrations for various geometries are illustrated in Figure 8.

Errors

NOMAD Calibration errors are given in Table XI.

Time stability

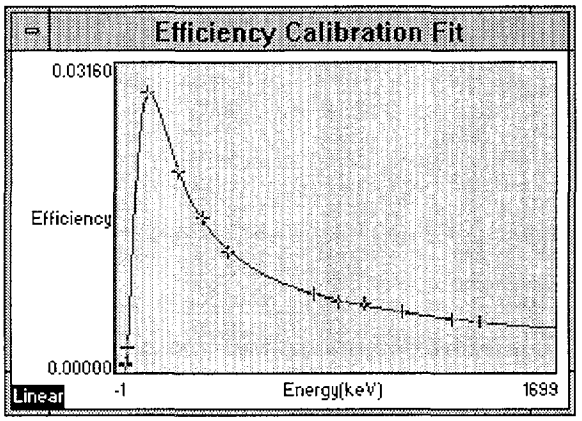
The time stability of the NOMAD calibration is illustrated in Figure 9.

4.3. Calibration for *in situ* measurements

For the determination of gamma-spectrometer calibration factors to be used for *in situ* measurement a circular geometry (1 m radius) was chosen. The ring was divided into 24 equal sectors. The reference sources used were the following:

^{152}Eu with an activity of 370.0 kBq
^{60}Co with an activity of 306.9 kBq
^{137}Cs with an activity of 255.7 kBq
^{241}Am with an activity of 338.1 kBq
all as of 1 July 1985.

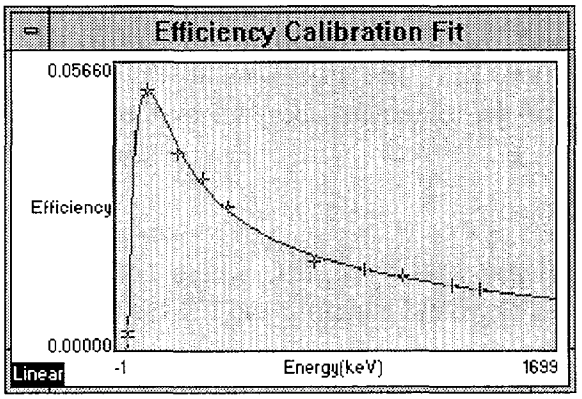
A) point sources



Efficiency Table

Energy	Effic.	Fit	Delta
39.52	0.000846	0.000846	0.00%
40.12	0.000973	0.000983	-1.04%
45.40	0.002752	0.002747	0.18%
121.78	0.028667	0.028664	0.01%
244.70	0.020577	0.020775	-0.96%
344.28	0.015954	0.015605	2.19%
444.00	0.012478	0.012595	-0.93%
778.90	0.008079	0.008126	-0.58%
867.38	0.007331	0.007511	-2.46%
964.00	0.007077	0.006959	1.66%
1112.08	0.006418	0.006279	2.17%
1299.12	0.005558	0.005609	-0.90%
1408.03	0.005268	0.005285	-0.32%

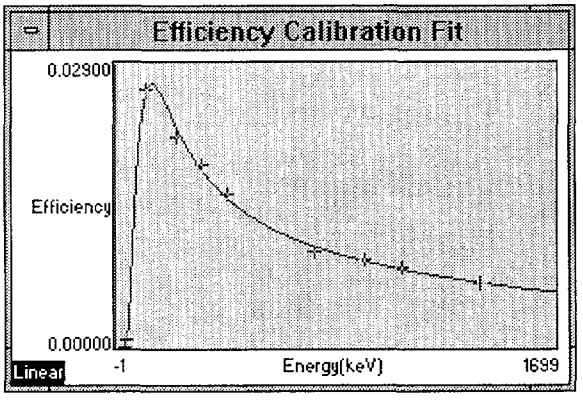
B) volume sources (of cylindrical shape)



Efficiency Table

Energy	Effic.	Fit	Delta
45.40	0.002612	0.002612	0.00%
46.60	0.003842	0.003855	-0.33%
121.78	0.051429	0.051124	0.59%
244.70	0.038904	0.040464	-4.01%
344.28	0.033874	0.032713	3.43%
444.00	0.028364	0.027568	2.81%
778.90	0.017753	0.018714	-5.41%
964.00	0.016076	0.016078	-0.01%
1112.08	0.014855	0.014465	2.62%
1299.12	0.012755	0.012824	-0.54%
1408.03	0.012037	0.012013	0.20%

C) volume Marinelli sources



Efficiency Table

Energy	Effic.	Fit	Delta
39.52	0.000160	0.000160	0.00%
45.40	0.001025	0.001026	-0.06%
121.78	0.026291	0.026146	0.55%
244.70	0.021637	0.022487	-3.93%
344.28	0.018720	0.018111	3.25%
444.00	0.015721	0.015231	3.12%
778.90	0.009778	0.010369	-6.04%
964.00	0.008973	0.008936	0.41%
1112.08	0.008267	0.008060	2.50%
1408.03	0.006712	0.006727	-0.22%

FIG. 8. Calibration of nomad: efficiency calibration for (a) point, (b) volume, and (c) volume marinelli sources.

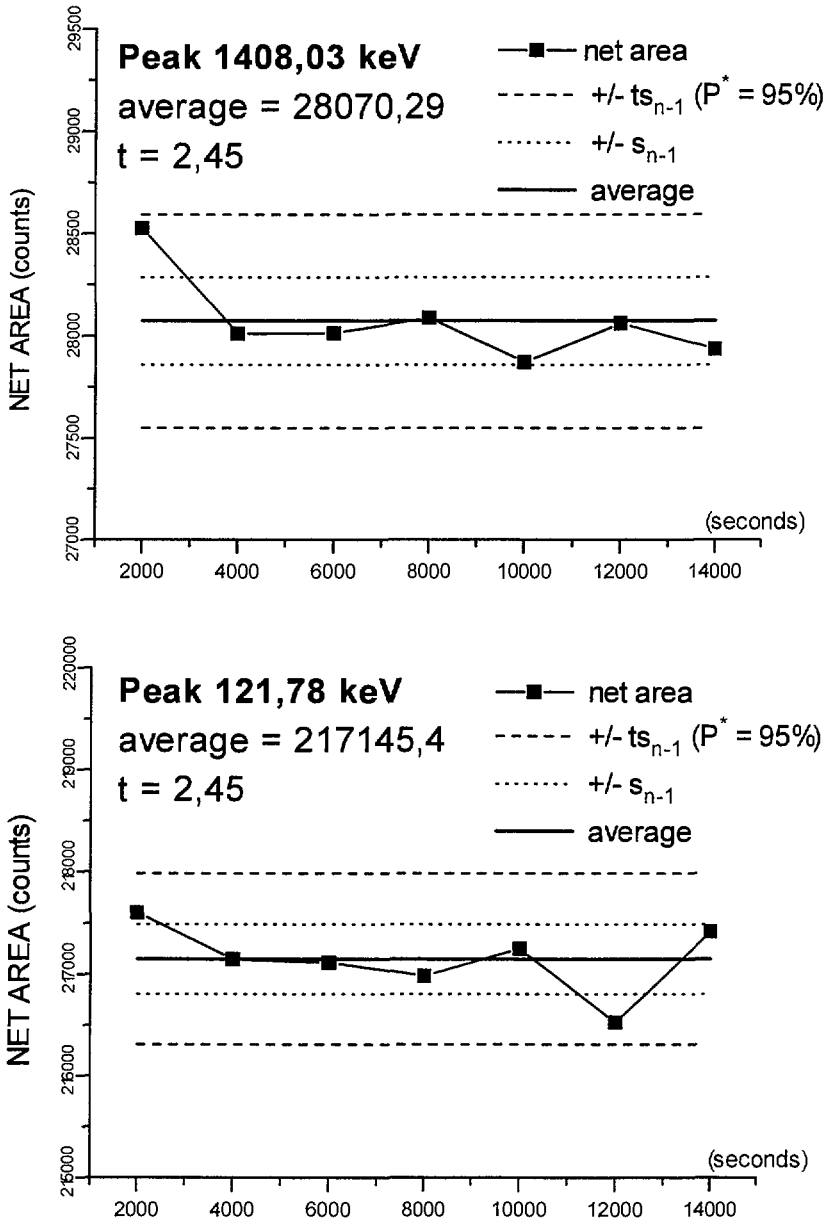


FIG. 9. Calibration of nomad: Time stability.

A field calibration was performed by a combined method (experimental and theoretical) as recommended by Helfer and Miller [15]. Field calibrations differ from those for laboratory sample counting in that no spiked samples are used; rather, a combination of experimental and theoretical methods are applied. The procedure can be summed up as follows:

The basic calibration equation for *in situ* spectrometry can be expressed in terms of the peak count rate N, the activity or inventory in the soil A, and the uncollided flux Φ as:

$$N_f/A = (N_f/N_0)(N_0/\Phi)\,(\Phi/A) \qquad (1)$$

where the fundamental calibration parameters are expressed in ratios as follows:

N_f/A is the total-absorption peak count rate (cpm) in the spectrum at the energy of a particular nuclide γ transition per unit inventory ($Bq \cdot m^{-2}$) or concentration ($Bq \cdot g^{-1}$) of that nuclide in the soil,

N_f/N_0 is the angular correction factor of the detector at that energy for a given source distribution in the soil,

N_0/Φ is the peak count rate (cpm) per unit uncollided flux ($\gamma \cdot cm^{-2} \cdot s^{-1}$) for a parallel beam of γ rays of the same energy that is incident-normal to the detector face, and

Φ/A is the total uncollided flux ($\gamma\ cm^{-2} \cdot s^{-1}$) at that energy arriving at the detector per unit inventory or concentration of the nuclide in the soil.

In order to obtain the calibration factor (N_f/A) for a particular nuclide, the three quantities (N_f/N_0, N_0/Φ and Φ/A) are determined separately. The first two terms are detector dependent and can be determined experimentally, while the latter can be calculated on a purely theoretical basis.

The value of Φ/A at a particular energy is obtained by counting a γ-emitting point source of known strength, placed at a distance of at least 1m from the detector face to simulate a parallel beam of normally incident radiation.

The value of N_f/N_0 for a particular energy and source distribution is calculated from:

$$N_f / N_0 = \frac{\int R(\theta)\Phi(\theta)d\theta}{\int \Phi(\theta)d\theta}, \qquad (2)$$

where $R(\theta)$ is the peak count rate for γ-rays of energy E at angle θ, relative to the peak count rate at $\theta = 0^\circ$ (normal incidence) and $\Phi(\theta)$ is the γ-ray flux at energy E at angle θ.

5. RADIOLOGICAL CHARACTERIZATION

5.1. Reactor area — RWTP — spent fuel storage — platform

The techniques developed in the framework of this project have been applied to the radiological characterization of the reactor area, the spent fuel storage facility, the RWTP, and the railway platform for dispatching of drums for transport to Baita-Bihor national repository.

The following types of measurements have been performed:

— measurements of radioactivity on the soil and vegetation samples, collected in the period 1996–1997, in places indicated in Figure 6;
— measurements of doses, and β- and γ-contamination on the waste transport routes, as well as at the spent fuel manipulation facility;
— *in situ* spectrometry in order to determine the radioactivity distribution in the soil [16] [17].

The samples of soil and vegetation have been collected in autumn 1996, at the points P1 to P9. The samples have been processed and measured by the procedures presented in the previous progress reports [11] [12]. The results are given in Table XII. The measurements show a ^{137}Cs contamination at locations P6 and P7, and in the neighbourhood of the spent fuel storage, the soil radioactivity there being two times higher than in other areas of the site. This contamination appeared due to the diffusion of fission products from ponds (e.g. through cracks in the lining). The volatile fission products are dispersed outside of the building.

The measurements in the water from the spent fuel storage ponds showed during the same period the presence of 40.000 Bq/l of ^{137}Cs. The decision that the venting in the spent fuel storage was to be stopped (for cost reasons) led to an increase of radioactivity in the soil near the facility. Other measuring places show a radiation levels comparable to those at control points P1 and P2 (see Figure 6) far away from the reactor.

The RWTP yard was included into the monitoring area in 1997. The soil and vegetation samples were taken at points P1 to P13. The results are given in Table XIII for the vegetation and soil samples respectively. A decrease of Cs presence can be observed for the spent fuel storage area, which is due the use of the venting. A serious contamination with Cs (about 1800 Bq/kg) was identified in the RWTP yard (point P11). At points P11 and P13 a significant contamination with ^{60}Co (up to 6000 Bq/kg) was found. In this area ^{241}Am at a level of 1240 Bq/kg is also present.

The vegetation samples, taken in 1997, identified the presence of ^{137}Cs at points P8 and P9, located near the access gate to the RWTP. In the historical storage areas for wastes the vegetation is contaminated with ^{60}Co, the results of measurements being in good agreement with those on the soil samples [18].

In March 1998 soil samples for 9 points in reactor area were collected. The results are given in Table XIV. There are no significant values, except for points P6 and P7 (near the spent fuel pond).

During the summer of 1998 samples have been collected in a wider area, determined on the basis of results obtained in 1997. Additionally, the platform for dispatching the drums to the Baita-Bihor national repository was included into the sampling network.

The results from measurements on the soils are presented in Table XV. The presence of Cs at point P10 indicates a contamination in the RWTP area. The results for points P15, P16, P17 located in the area of drum transfer into wagons show a 5 times increase of Cs contamination compared to average values on the site. In 1998 a reduction of Co contamination in the RWTP yard could be observed, which is due the removal of same historic wastes in this area. Point P10 remains a "hot spot" (1000 Bq/kg).

In Table XVI the results of measurements on the vegetation collected in the same places are presented. One can be observe an ^{131}I contamination at all points for this period, which was due the radioactive iodine production in the CPR. ^{60}Co is present in the RWTP yard, the results being similar to those for the soils [19].

In 1999, the soil samples have been taken at all points previously established. These results are presented in Table XVII. Examining the results, one can observe that the radioactivity in the reactor area was not significantly modified. But in the RWTP zones have arisen with high contamination, particularly at points P11, P13 and P14. In this area old drums containing

historical wastes have been recovered. The drums were in an advanced state of corrosion, allowing the spread of contaminants. At point P11 the contamination with ^{60}Co is high: 22.000 Bq/kg. Also, the values determined for ^{137}Cs and ^{241}Am are very high, 2600 and 1800 Bq/kg respectively. For point P13, the radioactive inventory is 1400 Bq/kg ^{60}Co, 3600 Bq/kg ^{241}Am, and 1400 Bq/kg^{137}Cs. At sampling point P14, near the reactor filter storage, the Co and Cs content also is significant.

In Table XVIII the results of dose and β-, and γ-contamination measurements on the asphalt surfacing along the waste and spent fuel transport routes are presented. Table XIX presents the results of dose rate measurements performed on the vegetation along the green verges of the roads. The measuring points are indicated in Figures 4 and 5.

Examining the results from the measurements, one can see that the maximum value of contamination is about 0.19 Bq/cm^2, the minimum value being 0.05 Bq/cm^2. The point of maximum contamination is No.1, corresponding to the access into Experimental Building, near Reactor.

Referring to dose values, these are relatively low in this area. The minimum value was been determined for point No.14, on the access way to the reactor ramp: 0.02 μSv/h. The point with the highest dose value is point No.75, near the RWTP gate and close to the access way: 0,3°μSv/h.

5.2. Magurele Fort area

The characterization of the radioactive contamination in the temporary waste storage Magurele Fort began in 1998. Preliminary results have been reported in June 1998 in a progress report [12]. The radiological assessment of the area was performed by the measurement of doses, β-, and γ-contaminations, γ-spectra, and the depth distribution of contamination.

The dose rates in some places outside of the Magurele Fort were in the range of 0.9 – 4 mR/h.

Sample were taken at three locations outside the facility: at one point at the main gate, and at two points in the contaminated wood storage area. At all three points samples were taken to depths of up to 9 cm. Table XX are summarizes the results of these measurements. A ^{60}Co-contamination is present in all samples. At point P3M, on the access way, there is an additional contamination by ^{137}Cs.

In July 1998, a new survey of contaminants in soil was performed in the neighborhood of the Fort. The results are presented in Table XXI. The main contaminant is ^{60}Co. The maximum depth of sampling was 35 cm, where ^{60}Co was found. The measuring grid for doses and contamination is outlined in Table XXII. The maximum β-, and γ-contamination is 5 Bq/cm^2. The maximum dose at the same location is $4.8 \cdot 10^{-3}$ mSv/h (point 1C).

In situ γ-spectrometry was been performed at the point 0C, together with soil sampling, and at the second point at the main gate of the Fort.

The γ-flux (per square centimeter and per second) was determined using the method described above [15]. The measured values of efficiency (*vs.* solid angle) have been used to determine the required parameters for calculations. The results are presented in Table XXIII as a function of the relaxation factors AS mentioned in the table. The γ-flux values for ^{60}Co, at the first point, are in the range of 7.5 to 39 particles s^{-1}cm^{-2}, depending on relaxation parameters. Comparing these values with those obtained in the reference [20], measured in 1993 for three point in the

same area, one observe a good agreement. The values reported in reference [20] are in the range of 25 to 56 particles $s^{-1}cm^{-2}$.

6. OTHER ACTIVITIES

QA system. For environmental monitoring of the Magurele site and its influence zone, the QA system of the Institute was extended to the work performed under this research contract.

Public acceptance. Some activities to increase public acceptance [21] have been developed during the course of this IAEA CRP project. Based on the results obtained from the radiological characterization of the Magurele Fort area a public information sheet was produced. Another one was prepared referring to the decommissioning of the VVR-S research reactor and its environmental impact. A TV presentation on spent fuel management was also prepared, in order to explain the associated problems to the public.

International intercomparison exercises. Based on the practices developed under this project, an intercomparison between the IFIN-HH Magurele and VKTA Rossendorf (Germany) sites is in progress.

7. CONCLUSIONS

(1) The work performed in the framework of the coordinated research programme led to the development of specific methods for the investigation of radioactive contamination in the influence zone of IFIN-HH. The activities under this contract are complementary to the current monitoring programme at the site, which focused on nuclear fuel handling and waste disposal areas.

(2) By comparing the radiological characterization results obtained before and after the permanent shut down of the reactor, one can observe that the operation of this facility did not contribute significantly to the environmental contamination. The radioactive release during the operation was less than 1000 Ci per year. The most important part of the inventory released were gaseous effluents with short half-lives.

(3) The zone including reactor area and spent fuel storage site is not highly contaminated. Cs appeared in soil and vegetation as a result of the diffusion when the ventilation in storage was shut down.

(4) The RWTP area is highly contaminated at places, due to the past storage and processing of wastes. The soil and vegetation show different degrees of contamination, depending on the management of the wastes within the plant and outside. Hot spots with Cs, Am and Co contamination were found.

(5) The Magurele Fort and its surroundings showed a level of radioactive contamination requiring a site restoration programme.

Text cont. on page 126.

TABLE I. ANNUAL WIND FREQUENCY DISTRIBUTION AT THE MAGURELE SITE

Direction	Annual average wind frequency (%)
NE	22.3
E	14.6
SW	14.8
W	14.6

TABLE II. LAND USE IN THE MAGURELE DISTRICT

Land use categories	Surface area [km^2]	%
Agricultural (cereals, vineyards, orchards, fruits, pasture-lands)	36.57	84.0
Forest, water surfaces, entertainment facilities, roads	5.34	12.5
Dwellings	1.48	3.5
Total village land	43.39	100.0

TABLE III. CALCULATED RADIOACTIVE INVENTORY OF THE VVR-S RESEARCH REACTOR AS OF 31.12.1999

Activated material	**Activity**	**Mass**
Aluminium	37 Ci	3670 kg
Steel	1622 Ci	84250 kg
Concrete	229 Ci	60250 kg
Total	1900 Ci	152000 kg
Main isotopes ^{60}Co, ^{63}Ni		
Contaminated material		**Mass/Volume**
Primary circuit		47000 kg
Hot cells		3130 kg
Reactor Hall		up to 30 tones of different materials
Contaminated concrete		20-50 m^3
Secondary wastes		**Volume**
Liquids		120 m^3
Ion exchange resins		1-3 m^3

TABLE IV. RADIOACTIVE INVENTORY OF SPENT FUEL FROM THE MAGURELE RESEARCH REACTOR AS OF 31.12.1999.

Fissile materials in spent fuel

Nuclide	**Mass**
^{235}U	10.5 kg
^{238}U	178.0 kg
^{239}Pu	0.251 kg
^{240}Pu	0.0989 kg
^{241}Pu	0.0032 kg

Radioactivity

Fuel Assembly	**Total Activity [Ci]**	**^{90}Sr - ^{90}Y [Ci]**	**^{137}Cs - ^{137m}Ba [Ci]**	**^{85}Kr [Ci]**	**^{3}He [Ci]**
EK-10	$5.20 \cdot 10^4$	$7.14 \cdot 10^3$	$7.67 \cdot 10^3$	447	16
C-36	$5.49 \cdot 10^4$	$8.21 \cdot 10^3$	$8.08 \cdot 10^3$	789	24
Total	**$10.69 \cdot 10^4$**				

TABLE V. MONITORING POINTS AND MATERIALS SAMPLED

Point	Description of place	Sample	Sector
A	1st channel of Reactor	- water - sediment - vegetation - soil	S
B	2nd channel IFA	- water	S
C	Ciorogirla river - upstream	- surface water - sediment	SSW
D	Ciorogirla river - downstream	- surface water	ESE
E	Used domestic water plant	- water - sediment	WSW
F	ICAB plant	- water - sediment	S
G	1st group IFIN-HH	- drinking water	WSW
H	2nd group IFA	- drinking water	
I	Village fountains	- water piping in 1st channel - Reactor (ground water) - water piping in 2nd channel - IFA (ground water)	ESE ESE
J	Surveillance bore holes	ground water in the Reactor area	
K	IFA park	- soil - vegetation - sediment	WSW
L	Helen subcritical assembly	- soil - vegetation	WSW
	Bucharest-Titan (background)	- soil - vegetation	ENE
M	Forest	- soil - vegetation	WSW
	Village (channels area)	- soil - vegetables - cereals - fruits - milk	S
N	HV supply	- soil - vegetation	WNW
O	Pumping station	- soil - vegetation	NW
P	Mechanical workshop	- soil - vegetation	N
R	Lab. No. 8	- air	NW

TABLE VI. MONITORING FREQUENCY

Nuclide	$T_{1/2}$	Sample	Average residence time	Average time for exposure route	Frequency
Tritium	12.3 years	air	minutes	minutes	continuously
		vegetables	3 months	3 months	quarterly
		drinking water	5 days	5 days	weekly
		surface water	1 day	1 day	daily
		milk	5 days	5 days	weekly
Noble gases	2 days	air	minutes	minutes	continuously
^{131}**I**	8 days	air	minutes	minutes	continuously
		milk	5 days	4 days	weekly
^{134}**Cs**	2 years	milk	5 days	5 days	weekly
		air	minutes	minutes	continuously
		surface wastes	2–4 weeks	4 weeks	monthly
		drinkable water	2 months	2 months	bimonthly
		sediment	2 months	2 months	bimonthly
^{90}**Sr**	30 years	milk	5 days	3 days	weekly

TABLE VII. SAMPLING LOCATIONS

Point	Sampling point
P1	Nuclear Medicine Lab
P2	Cyclotron building (left side)
P3	Reactor plateau (center)
P4	Reactor auto-gate (left)
P5	Reactor auto-gate (right)
P6	Spent fuel storage (left)
P7	Spent fuel storage (right)
P8	Reactor - RWTP route (5 m right from plant gate)
P9	Reactor - RWTP route (5 m left from plant gate)
P10	Waste pond (underground)
P11	Surface waste storage
P12	300 m^3 ponds
P13	Heating plant
P14	Reactor filter pond
P15	Electrical power supply (behind RPC)
P16	Railway platform (third label ?)
P17	Railway platform (first label ?)

TABLE VIII. SMART RADIATION MONITOR SRM-200, DETECTORS AND ACCESSORIES

MODEL NO.	TYPE OF MEASUREMENT	USEFUL RANGE
AC-3	Alpha Contamination	Background to 33,000 counts/s
HP-210	Beta-gamma Contamination, 2 inch window	Background to 66,000 counts/s
HP-260	Beta-gamma Contamination	Background to 66,000 counts/s
HP-270	Gamma Exposure or Exposure Rate	Background to 2500 mR/h
HP-290	Gamma Exposure or Exposure Rate	0.005 to 50 R/h
LEG-1	Low Energy Gamma or X Ray 20 to 70 keV	Background to 33,000 counts/s
SPA-3	High Sensitivity Gamma 40 keV to 1 MeV	Background to 25,000 counts/s
SPA-6	Medium Sensitivity Gamma 40 keV to 1 MeV	Background to 25,000 counts/s

TABLE IX. NOMAD-PLUS CHARACTERISTICS

Dimensions			
Crystal Diameter	58.6 mm		
Crystal Length	79.4 mm		
End Cap to Crystal	3 mm		
Absorbing Layers — Aluminum	1.27 mm		
- Inactive Germanium	0.70 mm		
High Voltage Bias			
Recommended Operation Bias, POSITIVE	2300 V		
Performance Specifications (measured at a nominal rate of 1000 counts/s)	**Warranted**	**Measured**	**Amplifier Time Constant**
Resolution (FWHM) at 1.33 MeV, ^{60}Co	2.00 keV	1.73 keV	6 μs
Peak-to-Compton Ratio, ^{60}Co	58	68.8	6 μs
Relative Efficiency at 1.33 MeV, ^{60}Co	40 %	42.5 %	6 μs
Peak Shape (FWTM/FWHM), ^{60}Co	1.98	1.87	6 μs
Peak Shape (FWFM/FWHM), ^{60}Co	2.98	2.54	6 μs
Resolution (FWHM) at 122 keV, ^{57}Co	1100 eV	766 eV	

TABLE X. CALIBRATION OF NOMAD: MINIMUM DETECTABLE ACTIVITY.

Nuclid	E(keV)	Yield	MDA (s^{-1})	MDA (Bq)
^{241}Am	59.54	0.359	0.435	56.45
^{137}Cs	661.66	0.8521	0.151	8.25
^{60}Co	1173.24	0.999	0.184	8.56
	1332.5	0.999	0.212	9.88
^{152}Eu	121.78	0.284	0.14	23.07
	344.28	0.266	0.129	22.63
	778.9	0.1297	0.132	47.36
	1408.03	0.208	0.155	34.78

TABLE XI. CALIBRATION OF NOMAD: ERRORS

Source type	Nuclide	Source label	Activity [Bq]	Uncertainty [%]	Measured activity [Bq]	σ (%)	ε (%)
point	^{152}Eu	7-713	7026	±3	7038	±1.91	+0.2
	^{152}Eu	7-669	5188	±3	5162	±1.99	-0.5
	^{137}Cs	6-675	57759	±3	60597	±1.91	+4.9
	^{60}Co	7-510	2625	±1.5	2599	±1.91	-1.0
volume	^{152}Eu	7-660	6500	±3	6579	±2	+1.2
	^{152}Eu	7-644	3500	±5	3631	±2	+3.7
	^{137}Cs	8-309	2695	±5	2764	±2	+2.6
	^{60}Co	8-310	1910	±5	1952	±2	+2.2

TABLE XII. SPECIFIC ACTIVITY [Bq/kg] OF SELECTED ISOTOPES IN VEGETATION (TOP) AND SOIL (BOTTOM) SAMPLES TAKEN IN 1996.

Sample	**96veg1**	**96veg2**	**96veg3**	**96veg4**	**96veg5**	**96veg6**	**96veg7**	**96veg8**	**96veg9**
Mass [g]/ Isotope	61.18	54.75	60.85	56.25	52.55	56.89	60.99	61.00	60.88
^{7}Be	227.88	446.08	193.96	202.66	400.54	136.26	127.60	130.52	258.52
^{40}K	310.80	241.54	805.10	599.06	137.58	802.78	1152.30	905.86	320.68
^{134}Cs	26.18	40.58	22.34	25.76	24.00	15.38	13.68	14.76	13.22
^{137}Cs	6.04	10.86	3.96	4.56	3.60	7.32	13.12	6.46	7.44
^{212}Pb	0.00	27.38	0.00	3.62	10.18	0.00	0.00	0.00	0.98
^{214}Pb	28.40	70.46	19.52	16.44	57.50	45.14	32.70	42.04	52.92
^{131}I	5.64	6.20	4.52	7.60	0.00	0.00	0.00	6.50	3.86
^{214}Bi	1.18	1.02	0.00	0.00	0.98	0.84	0.88	1.20	1.28
^{228}Ac	1.18	12.98	59.50	1.32	6.88	0.00	0.00	0.00	2.06
TOTAL	**607.30**	**857.10**	**1108.90**	**861.02**	**641.26**	**1007.72**	**1340.28**	**1107.34**	**660.96**
Sample	**96sol1**	**96sol2**	**96sol3**	**96sol4**	**96sol5**	**96sol6**	**96sol7**	**96sol8**	**96sol9**
Mass [g]/ Isotope	216.13	215.52	196.50	206.40	195.11	195.00	193.05	203.35	193.62
^{40}K	830.78	822.32	930.60	916.98	903.38	862.44	756.56	914.16	815.04
^{134}Cs	7.22	6.04	6.72	7.94	6.76	12.54	9.74	7.86	6.00
^{137}Cs	200.10	150.36	195.04	244.60	169.88	493.36	322.54	214.84	182.96
^{212}Pb	54.16	57.90	67.92	63.78	74.06	60.04	40.17	63.48	56.22
^{214}Pb	53.52	50.40	57.74	59.50	60.54	51.38	51.60	60.36	48.30
^{212}Bi	33.84	29.00	40.54	31.54	36.26	29.56	18.54	38.62	33.66
^{214}Bi	40.02	34.40	39.46	40.34	43.02	35.60	33.14	43.80	30.00
^{226}Ra	167.08	149.74	210.72	186.76	213.98	195.74	166.66	198.44	185.68
^{235}U	122.80	141.60	152.16	111.92	194.46	167.58	88.38	143.10	161.46
^{208}Tl	18.88	17.72	19.64	18.02	20.92	18.88	10.46	20.46	17.04
^{228}Ac	52.46	41.92	50.06	48.14	52.60	44.28	25.34	48.78	40.60
TOTAL	**1580.86**	**1501.42**	**1770.60**	**1729.52**	**1775.86**	**1971.40**	**1523.13**	**1753.90**	**1576.96**

TABLE XIII. SPECIFIC ACTIVITY (Bq/kg) OF SELECTED ISOTOPES IN VEGETATION (TOP) AND SOIL (BOTTOM) SAMPLES TAKEN IN 1997.

Sample	97 veg1	97 veg2	97 veg3	97 veg4	97 veg5	97 veg6	97 veg7	97 veg8	97 veg9	97 veg10	97 veg11	97 veg12	97 veg13
Mass [g] Isotope	84.750	89.300	81.200	53.800	63.370	77.420	67.800	62.550	61.600	89.090	110.280	100.600	62.410
^{7}Be	26.754	24.721	0.000	34.063	30.753	32.625	52.956	0.000	19.824	162.513	179.906	149.605	146.678
^{22}Na	0.000	0.000	0.000	0.000	0.000	2.301	0.000	0.000	0.000	0.000	0.000	2.549	0.000
^{40}Ka	979.00	1246.84	1246.96	611.13	743.72	1118.66	622.08	1859.23	1707.14	727.30	679.15	1033.5	525.55
^{241}Am	0.000	0.000	0.000	14.978	6.714	0.000	0.000	0.000	0.000	0.000	56.118	0.000	23.174
^{60}Co	0.000	0.000	0.000	0.000	0.000	0.000	0.000	14.510	14.120	232.236	184.295	8.118	66.631
^{134}Cs	0.000	0.000	0.000	0.000	0.000	0.000	0.000	9.589	13.116	5.982	0.000	0.000	3.457
^{137}Cs	0.000	0.000	0.000	0.000	0.000	0.000	0.000	603.894	871.847	10.749	4.932	0.000	22.277
^{208}Tl	0.000	0.000	0.000	0.000	3.968	48.838	39.398	92.608	90.957	48.425	53.746	50.785	41.971
^{212}Pb	20.605	21.061	18.982	14.539	14.136	15.257	14.985	145.428	146.419	19.445	46.265	17.003	0.000
^{214}Pb	0.000	0.000	0.000	0.000	14.835	0.000	9.994	39.655	46.404	0.000	0.000	0.000	0.000
^{212}Bi	0.000	0.000	0.000	0.000	0.000	0.000	0.000	64.927	70.710	0.000	0.000	0.000	0.000
^{214}Bi	12.894	0.000	0.000	7.553	20.350	9.912	0.000	34.441	50.492	16.826	7.811	0.000	0.000
^{228}Ac	9.005	0.000	0.000	0.000	0.000	0.000	0.000	110.923	101.523	14.136	35.351	0.000	0.000
TOTAL	**1048.26**	**1292.63**	**1265.94**	**682.26**	**834.47**	**1227.59**	**739.41**	**2975.21**	**3132.55**	**1237.62**	**1247.58**	**1261.56**	**829.73**

Sample	97 sol1	97 sol2	97 sol3	97 sol4	97 sol5	97 sol6	97 sol7	97 sol8	97 sol9	97 sol10	97 sol11	97 sol12	97 sol13
Mass [g]/ Isotope	219.470	215.100	220.020	225.280	224.870	217.000	223.630	213.400	213.050	233.000	236.500	219.220	198.600
^{7}Be	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	7.655	0.000	51.907	0.000	0.000
^{22}Na	0.000	0.000	0.000	0.000	0.000	1.048	0.000	0.000	0.000	0.000	0.000	0.000	1.536
^{40}Ka	779.286	753.360	780.790	787.260	813.004	759.147	710.940	717.957	659.224	748.667	485.716	707.432	575.341
^{241}Am	0.000	0.000	0.000	0.000	0.000	0.000	13.036	0.000	0.000	0.000	1240.35	20.094	146.257
^{60}Co	1.909	0.000	0.000	3.809	3.991	0.000	4.374	5.604	5.454	179.127	5868.23	30.546	836.652
^{65}Zn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	26.227	0.000	0.000
^{134}Cs	2.201	2.802	2.912	2.766	2.629	3.413	3.960	3.704	5.067	3.759	419.697	4.780	29.325
^{137}Cs	158.108	203.978	188.140	177.031	182.872	211.915	278.002	233.198	336.670	242.211	1800.93	203.850	457.192
^{208}Tl	36.789	35.950	39.363	38.725	39.532	38.178	32.943	35.763	35.126	35.946	192.564	38.894	34.109
^{212}Pb	65.503	61.070	68.656	64.578	67.567	59.443	50.203	56.158	56.541	61.621	602.041	68.811	53.871
^{214}Pb	34.451	35.517	18.413	27.557	24.204	16.772	24.304	15.314	17.920	18.659	202.966	41.828	88.213
^{212}Bi	31.608	25.963	34.816	36.442	35.841	29.530	24.541	25.074	27.307	27.958	335.558	44.129	30.100
^{214}Bi	35.016	31.991	22.226	29.936	28.441	22.217	26.505	13.300	19.497	21.256	184.554	34.615	84.526
^{228}Ac	45.564	45.446	51.556	52.139	60.049	48.777	37.800	42.835	39.204	52.732	498.747	52.891	39.673
TOTAL	**1190.44**	**1196.08**	**1206.87**	**1220.24**	**1258.13**	**1190.44**	**1206.61**	**1148.91**	**1209.66**	**1391.94**	**11909.5**	**1247.87**	**2376.79**

TABLE XIV. SPECIFIC ACTIVITY (Bq/kg) FOR SELECTED ISOTOPES IN SOIL SAMPLES TAKEN 1998 IN THE REACTOR AREA.

Sample	**98sol1**	**98sol2**	**98sol3**	**98sol4**	**98sol5**	**98sol6**	**98sol7**	**98sol8**	**98sol9**
Mass [g]	195.15	186.30	175.40	193.95	182.50	185.70	178.10	193.85	168.80
Isotope									
^{40}K	701.97	585.88	697.15	607.89	2512.33	683.25	503.77	631.73	666.41
^{51}Cr	0.00	0.00	0.00	0.00	0.00	12.39	0.00	0.00	0.00
^{54}Mn	0.00	0.00	0.00	0.00	2.58	0.00	0.00	0.00	0.00
^{60}Co	0.00	1.87	2.26	4.44	61.67	0.00	7.20	3.27	18.85
^{65}Zn	0.00	0.00	0.00	0.00	4.93	0.00	0.00	0.00	0.00
^{69}Zn	0.00	1.22	1.90	1.27	0.00	0.00	0.00	0.00	0.00
^{134}Cs	0.00	2.23	4.22	2.76	5.08	3.74	5.43	1.73	4.94
^{137}Cs	129.39	152.82	287.27	193.16	187.63	267.98	379.89	108.88	370.95
^{208}Tl	19.09	16.77	19.13	12.32	45.69	17.07	12.10	14.07	16.94
^{212}Pb	60.68	55.89	64.26	38.04	121.82	54.02	36.59	44.24	52.32
^{214}Pb	40.46	41.06	44.47	35.71	127.23	45.93	33.82	33.94	31.65
^{212}Bi	29.54	30.53	44.13	21.53	93.68	34.87	18.65	25.50	22.17
^{214}Bi	37.96	37.82	38.71	31.57	132.29	44.32	29.10	31.01	25.68
^{224}Ra	79.12	53.43	63.24	0.00	104.48	63.28	38.88	34.00	65.59
^{226}Ra	64.90	80.83	93.59	97.67	204.83	47.88	45.87	58.66	94.37
^{228}Ac	54.02	46.61	55.92	32.26	131.15	46.14	32.06	39.88	43.05
^{235}U	0.00	0.00	0.00	0.00	2.21	0.00	0.00	0.00	0.00
TOTAL	**1217.14**	**1106.95**	**1416.26**	**1078.65**	**3737.59**	**1320.88**	**1143.37**	**1026.91**	**1412.92**

TABLE XV. SPECIFIC ACTIVITY (Bq/kg) FOR SELECTED ISOTOPES IN SOIL SAMPLES TAKEN IN 1998.

Sample	298sol1	298sol2	298sol3	298sol4	298sol5	298sol6	298sol7	298sol8	298sol9
Mass (g)/ Isotope	177.10	183.50	181.30	202.80	194.15	186.05	186.90	177.20	190.60
^{40}K	665.95	708.72	708.00	732.89	762.55	479.46	691.65	608.41	629.80
^{241}Am	0.00	0.00	16.79	0.00	0.00	0.00	0.00	0.00	0.00
^{60}Co	0.00	0.00	0.00	0.00	4.02	0.00	0.00	3.99	0.00
^{69}Zn	0.00	0.00	0.00	0.00	0.00	14.24	0.00	0.00	0.00
^{134}Cs	2.22	0.00	0.00	0.00	0.00	0.00	2.57	0.00	0.00
^{137}Cs	252.06	184.51	195.76	104.64	131.47	262.82	281.42	211.35	62.42
^{208}Tl	17.23	19.49	18.38	17.91	18.12	10.11	16.75	13.69	18.41
^{212}Pb	59.57	65.72	63.61	63.13	66.68	40.00	57.46	47.61	55.83
^{214}Pb	12.73	23.99	7.17	16.10	16.14	0.00	13.34	9.42	9.14
^{212}Bi	32.43	40.80	43.73	33.57	35.25	21.24	33.00	25.96	36.41
^{214}Bi	15.36	21.54	9.28	13.41	13.66	0.00	12.28	6.17	8.47
^{224}Ra	63.62	63.32	51.16	60.01	66.35	0.00	66.61	58.02	57.38
^{226}Ra	95.08	65.81	86.12	111.66	90.60	0.00	114.55	36.66	54.53
^{228}Ac	50.06	57.49	54.92	49.02	54.03	35.38	49.98	43.22	47.34
^{235}U	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.61	0.00
TOTAL	**1266.31**	**1251.39**	**1254.91**	**1202.34**	**1258.86**	**863.25**	**1339.61**	**1067.13**	**979.73**

Sample	298sol10	298sol11	298sol12	298sol13	298sol14	298sol15	298sol16	298sol17	298sol18
Mass (g)/ Isotope	174.85	182.80	200.75	189.55	184.90	189.00	224.68	218.45	208.80
^{7}Be	0.00	0.00	0.00	0.00	0.00	11.69	18.86	0.00	13.18
^{40}K	612.24	605.69	638.31	692.53	684.59	396.82	279.17	294.47	421.09
^{241}Am	0.00	135.96	0.00	0.00	0.00	0.00	23.09	0.00	613.84
^{60}Co	1023.05	1551.75	5.12	17.21	38.98	0.00	826.73	141.73	579.93
^{65}Zn	0.00	10.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00
^{69}Zn	0.00	0.00	0.00	0.00	0.76	1.61	0.00	0.00	0.00
^{134}Cs	81.65	34.41	3.07	3.70	1.51	5.81	127.80	15.62	89.53
^{137}Cs	497.37	239.38	247.07	201.32	107.58	610.74	1086.66	1079.97	895.45
^{208}Tl	13.83	22.35	15.08	18.24	17.60	7.99	5.97	4.32	7.76
^{212}Pb	49.80	82.80	57.29	61.32	59.61	22.24	21.72	17.70	23.89
^{214}Pb	143.63	28.36	10.46	152.29	29.38	0.00	11.97	0.00	0.00
^{207}Bi	0.00	0.00	0.00	0.00	0.00	0.00	2.42	0.00	0.00
^{212}Bi	35.09	48.13	35.10	39.51	32.55	13.26	18.77	9.83	26.42
^{214}Bi	129.04	26.11	9.82	130.69	28.19	0.00	12.09	0.00	0.00
^{224}Ra	0.00	78.34	65.81	0.00	59.62	0.00	0.00	0.00	0.00
^{226}Ra	291.84	240.26	87.28	248.59	126.44	81.58	430.15	112.53	0.00
^{228}Ac	47.92	64.01	48.64	53.61	49.23	21.13	12.29	19.02	20.80
^{110m}Ag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.87
^{235}U	0.00	0.00	0.00	0.00	0.00	0.00	19.73	3.89	0.00
TOTAL	**2925.45**	**3167.94**	**1223.05**	**1619.03**	**1236.07**	**1161.18**	**2878.55**	**1699.09**	**2687.59**

TABLE XVI. SPECIFIC ACTIVITY (Bq/kg) FOR SELECTED ISOTOPES IN VEGETATION SAMPLES TAKEN IN 1998.

Sample	**98veg1**	**98veg2**	**98veg3**	**98veg4**	**98veg5**	**98veg6**	**98veg7**	**98veg8**	**98veg9**
Mass (g)/ Isotope	67.02	75.30	73.70	59.05	48.77	62.78	61.08	61.22	68.62
^{7}Be	123.98	117.18	142.23	392.92	356.88	219.59	110.40	162.11	196.08
^{40}K	628.11	410.31	482.25	664.84	443.53	590.68	532.91	675.30	624.88
^{60}Co	0.00	0.00	0.00	0.00	0.00	4.87	0.00	2.28	0.00
^{69}Zn	2.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
^{131}J	111.07	138.79	14.98	3.55	7.71	20.75	19.72	25.53	14.05
^{137}Cs	0.00	0.00	0.00	0.00	0.00	8.68	0.00	13.01	0.00
^{224}Ra	0.00	0.00	88.53	0.00	0.00	0.00	0.00	0.00	0.00
^{228}Ac	0.00	0.00	14.22	0.00	0.00	0.00	0.00	0.00	0.00
^{235}U	6.37	7.26	15.76	0.00	0.00	6.52	0.00	0.00	0.00
TOTAL	**871.58**	**673.54**	**757.96**	**1061.32**	**808.12**	**851.10**	**663.03**	**878.24**	**835.01**
Sample	98veg10	98veg11	98veg12	98veg13	98veg14	98veg15	98veg16	98veg17	
Mass (g)/ Isotope	66.97	84.50	81.15	64.50	61.12	63.82	62.45	56.45	
^{7}Be	78.38	79.92	65.37	118.33	110.08	165.83	127.93	144.76	
^{40}K	550.34	659.91	831.69	675.27	1889.89	795.93	806.58	1435.77	
^{51}Cr	0.00	0.00	0.00	0.00	0.00	0.00	31.40	0.00	
^{60}Co	38.20	88.25	0.00	6.73	46.01	0.00	14.65	0.00	
^{69}Zn	0.00	0.00	0.00	0.00	2.12	0.00	0.00	0.00	
^{131}J	113.47	65.64	40.57	52.32	47.11	18.69	8.68	11.85	
^{134}CS	0.00	0.00	0.00	3.16	0.00	0.00	0.00	0.00	
^{137}Cs	31.91	0.00	0.00	3.43	22.33	12.52	40.90	38.08	
^{214}Pb	0.00	0.00	0.00	21.97	113.40	0.00	0.00	0.00	
^{214}Bi	0.00	0.00	0.00	22.80	114.09	0.00	0.00	0.00	
^{226}Ra	0.00	0.00	0.00	0.00	192.06	0.00	0.00	0.00	
^{228}Ac	0.00	16.88	0.00	0.00	0.00	0.00	19.65	0.00	
TOTAL	**812.30**	**910.59**	**937.64**	**904.00**	**2537.08**	**992.97**	**1049.79**	**1630.46**	

TABLE XVII. SPECIFIC ACTIVITY (Bq/kg) FOR SELECTED ISOTOPES IN SOIL SAMPLES TAKEN IN 1999.

Sample	99sol1	99sol2	99sol3	99sol4	99sol5	99sol6	99sol7	99sol8	99sol9
Mass [g]/ Isotope	166.50	171.90	161.98	206.35	188.23	180.40	173.20	178.50	154.00
^{7}Be	49.50	45.97	25.09	0.00	0.00	0.00	46.42	11.27	0.00
^{40}K	692.07	685.95	693.27	778.74	848.89	582.89	694.05	688.65	637.78
^{134}Cs	0.00	0.00	0.00	0.00	0.00	3.22	0.00	0.00	0.00
^{137}Cs	162.11	186.85	234.11	195.58	196.67	357.70	210.95	79.60	234.42
^{208}Tl	18.18	18.17	18.65	21.29	21.94	13.05	18.22	19.03	15.35
^{212}Pb	63.29	69.81	67.28	69.71	73.75	46.66	63.02	62.49	51.84
^{214}Pb	20.67	23.98	43.13	32.13	53.27	32.81	55.32	46.76	35.04
^{212}Bi	35.71	34.40	36.99	40.08	46.17	25.54	33.76	34.50	34.25
^{214}Bi	14.58	19.08	41.74	29.63	51.10	27.81	50.86	40.34	29.89
^{224}Ra	109.14	68.56	80.88	78.47	82.70	67.81	49.86	77.11	65.33
^{226}Ra	96.92	76.62	127.25	120.07	148.04	59.24	107.80	161.02	124.89
^{228}Ac	50.88	55.54	54.56	61.17	64.13	37.11	48.35	50.96	38.30
TOTAL	**1313.05**	**1284.95**	**1422.94**	**1426.88**	**1586.66**	**1253.85**	**1378.62**	**1271.72**	**1267.09**

Sample	99sol10	99sol11	99sol12	99sol13	99sol14	99sol15	99sol16	99sol17	
Mass [g]/ Isotope	173.60	186.00	130.85	160.80	151.60	153.90	199.30	170.70	
^{40}K	596.60	369.90	706.80	424.10	300.01	419.02	380.82	343.12	
^{60}Co	92.87	22668.20	45.53	1390.32	337.66	3.84	0.00	0.00	
^{241}Am	0.00	1841.30	41.81	3576.96	50.97	0.00	0.00	0.00	
^{134}Cs	0.00	148.26	0.00	31.48	7.66	0.00	0.00	3.19	
^{137}Cs	280.06	2645.97	171.49	1435.37	725.17	325.46	56.74	439.75	
^{208}Tl	16.27	65.07	20.59	43.47	5.78	10.32	7.75	6.04	
^{212}Pb	54.55	238.20	64.64	149.11	23.59	34.14	20.16	23.66	
^{214}Pb	46.70	265.75	61.23	377.02	20.25	21.40	18.94	23.18	
^{212}Bi	36.05	141.29	38.93	86.65	0.00	22.29	0.00	12.59	
^{214}Bi	40.82	232.74	51.81	327.32	16.39	22.01	17.10	23.01	
^{224}Ra	56.75	278.23	56.82	108.92	49.40	0.00	0.00	36.33	
^{226}Ra	89.75	0.00	129.47	822.29	0.00	55.95	0.00	39.54	
^{228}Ac	45.26	174.61	55.70	128.51	20.56	31.07	19.54	17.74	
^{235}U	0.00	210.15	0.00	0.00	2.84	0.00	0.00	0.00	
TOTAL	**1355.69**	**29279.67**	**1444.82**	**8901.53**	**1560.27**	**945.50**	**521.05**	**968.16**	

TABLE XVIII. RESULTS OF DOSE AND β-, AND γ-CONTAMINATION MEASUREMENTS ON THE ASPHALT SURFACING ALONG THE WASTE AND SPENT FUEL TRANSPORT ROUTES

Point No.	HP 210L β+γ [cnt/min]	HP 270 γ [mR/min]	Contamination [Bq/cm^2]	Dose rate [mR/h]	[mSv/h]
1	66.70	$1.62\cdot10^{-4}$	0.1859	0.0097	$8.52\cdot10^{-5}$
2	28.60	$2.92\cdot10^{-4}$	0.0797	0.0175	$1.54\cdot10^{-4}$
3	24.10	$2.92\cdot10^{-4}$	0.0672	0.0175	$1.54\cdot10^{-4}$
4	31.10	$9.75\cdot10^{-5}$	0.0867	0.0059	$5.13\cdot10^{-5}$
5	31.10	$2.76\cdot10^{-4}$	0.0867	0.0166	$1.45\cdot10^{-4}$
6	25.10	$2.27\cdot10^{-4}$	0.0700	0.0136	$1.19\cdot10^{-4}$
7	43.60	$2.44\cdot10^{-4}$	0.1215	0.0146	$1.28\cdot10^{-4}$
8	25.10	$2.27\cdot10^{-4}$	0.0700	0.0136	$1.19\cdot10^{-4}$
9	25.60	$2.44\cdot10^{-4}$	0.0714	0.0146	$1.28\cdot10^{-4}$
10	31.60	$2.76\cdot10^{-4}$	0.0881	0.0166	$1.45\cdot10^{-4}$
11	28.10	$8.12\cdot10^{-5}$	0.0783	0.0049	$4.27\cdot10^{-5}$
12	28.10	$2.76\cdot10^{-4}$	0.0783	0.0166	$1.45\cdot10^{-4}$
13	28.60	$4.87\cdot10^{-5}$	0.0797	0.0029	$2.56\cdot10^{-5}$
14	28.10	$3.25\cdot10^{-5}$	0.0783	0.0020	$1.71\cdot10^{-5}$
15	23.60	$1.79\cdot10^{-4}$	0.0658	0.0107	$9.42\cdot10^{-5}$
16	26.60	$2.27\cdot10^{-4}$	0.0741	0.0136	$1.19\cdot10^{-4}$
17	54.60	$1.95\cdot10^{-4}$	0.1522	0.0117	$1.03\cdot10^{-4}$
18	25.10	$2.44\cdot10^{-4}$	0.0700	0.0146	$1.28\cdot10^{-4}$
19	28.60	$2.60\cdot10^{-4}$	0.0797	0.0156	$1.37\cdot10^{-4}$
20	24.60	$1.95\cdot10^{-4}$	0.0686	0.0117	$1.03\cdot10^{-4}$
21	57.60	$1.14\cdot10^{-4}$	0.1606	0.0068	$6.00\cdot10^{-5}$
22	25.60	$1.95\cdot10^{-4}$	0.0714	0.0117	$1.03\cdot10^{-4}$
23	23.60	$1.79\cdot10^{-4}$	0.0658	0.0107	$9.42\cdot10^{-5}$
24	19.50	$1.79\cdot10^{-4}$	0.0544	0.0107	$9.42\cdot10^{-5}$
25	26.10	$2.92\cdot10^{-4}$	0.0728	0.0175	$1.54\cdot10^{-4}$
26	31.60	$3.41\cdot10^{-4}$	0.0881	0.0205	$1.79\cdot10^{-4}$
27	29.60	$1.79\cdot10^{-4}$	0.0825	0.0107	$9.42\cdot10^{-5}$
28	45.60	$4.06\cdot10^{-4}$	0.1271	0.0244	$2.14\cdot10^{-4}$
29	48.10	$2.92\cdot10^{-4}$	0.1341	0.0175	$1.54\cdot10^{-4}$
30	52.60	$2.27\cdot10^{-4}$	0.1466	0.0136	$1.19\cdot10^{-4}$
31	27.10	$2.27\cdot10^{-4}$	0.0755	0.0136	$1.19\cdot10^{-4}$
32	29.10	$1.95\cdot10^{-4}$	0.0811	0.0117	$1.03\cdot10^{-4}$
33	43.60	$1.14\cdot10^{-4}$	0.1215	0.0068	$6.00\cdot10^{-5}$
34	17.50	$2.27\cdot10^{-4}$	0.0488	0.0136	$1.19\cdot10^{-4}$
35	27.60	$2.44\cdot10^{-4}$	0.0769	0.0146	$1.28\cdot10^{-4}$
36	29.60	$2.44\cdot10^{-4}$	0.0825	0.0146	$1.28\cdot10^{-4}$
37	31.60	$1.79\cdot10^{-4}$	0.0881	0.0107	$9.42\cdot10^{-5}$
38	22.10	$3.25\cdot10^{-4}$	0.0616	0.0195	$1.71\cdot10^{-4}$
39	27.10	$2.44\cdot10^{-4}$	0.0755	0.0146	$1.28\cdot10^{-4}$
40	27.10	$2.76\cdot10^{-4}$	0.0755	0.0166	$1.45\cdot10^{-4}$
41	32.60	$3.57\cdot10^{-4}$	0.0909	0.0214	$1.88\cdot10^{-4}$
42	26.10	$3.09\cdot10^{-4}$	0.0728	0.0185	$1.63\cdot10^{-4}$
43	22.60	$3.57\cdot10^{-4}$	0.0630	0.0214	$1.88\cdot10^{-4}$
44	39.60	$2.92\cdot10^{-4}$	0.1104	0.0175	$1.54\cdot10^{-4}$
45	32.60	$1.79\cdot10^{-4}$	0.0909	0.0107	$9.42\cdot10^{-5}$
46	32.10	$2.60\cdot10^{-4}$	0.0895	0.0156	$1.37\cdot10^{-4}$
47	25.60	$1.30\cdot10^{-4}$	0.0714	0.0078	$6.84\cdot10^{-5}$
48	35.60	$2.76\cdot10^{-4}$	0.0992	0.0166	$1.45\cdot10^{-4}$

TABLE XIX. RESULTS OF DOSE AND γ-CONTAMINATION MEASUREMENTS ON THE GREEN VERGE ALONG THE WASTE AND SPENT FUEL TRANSPORT ROUTES

Point No.	HP 270 γ [mR/min]	Dose rate [mR/h]	[mSv/h]
49	$1.95 \cdot 10^{-4}$	0.0117	$1.03 \cdot 10^{-4}$
50	$2.76 \cdot 10^{-4}$	0.0166	$1.45 \cdot 10^{-4}$
51	$3.76 \cdot 10^{-4}$	0.0226	$1.98 \cdot 10^{-4}$
52	$1.79 \cdot 10^{-4}$	0.0107	$9.42 \cdot 10^{-5}$
53	$3.09 \cdot 10^{-4}$	0.0185	$1.63 \cdot 10^{-4}$
54	$1.95 \cdot 10^{-4}$	0.0117	$1.03 \cdot 10^{-4}$
55	$2.11 \cdot 10^{-4}$	0.0127	$1.11 \cdot 10^{-4}$
56	$1.79 \cdot 10^{-4}$	0.0107	$9.42 \cdot 10^{-5}$
57	$2.27 \cdot 10^{-4}$	0.0136	$1.19 \cdot 10^{-4}$
58	$2.92 \cdot 10^{-4}$	0.0175	$1.54 \cdot 10^{-4}$
59	$2.44 \cdot 10^{-4}$	0.0146	$1.28 \cdot 10^{-4}$
60	$3.41 \cdot 10^{-4}$	0.0205	$1.79 \cdot 10^{-4}$
61	$2.76 \cdot 10^{-4}$	0.0166	$1.45 \cdot 10^{-4}$
62	$2.44 \cdot 10^{-4}$	0.0146	$1.28 \cdot 10^{-4}$
63	$2.76 \cdot 10^{-4}$	0.0166	$1.45 \cdot 10^{-4}$
64	$3.09 \cdot 10^{-4}$	0.0185	$1.63 \cdot 10^{-4}$
65	$3.90 \cdot 10^{-4}$	0.0234	$2.^{-5} \cdot 10^{-4}$
66	$2.92 \cdot 10^{-4}$	0.0175	$1.54 \cdot 10^{-4}$
67	$3.09 \cdot 10^{-4}$	0.0185	$1.63 \cdot 10^{-4}$
68	$4.06 \cdot 10^{-4}$	0.0244	$2.14 \cdot 10^{-4}$
69	$2.76 \cdot 10^{-4}$	0.0166	$1.45 \cdot 10^{-4}$
70	$3.25 \cdot 10^{-4}$	0.0195	$1.71 \cdot 10^{-4}$
71	$1.79 \cdot 10^{-4}$	0.0107	$9.42 \cdot 10^{-5}$
72	$2.92 \cdot 10^{-4}$	0.0175	$1.54 \cdot 10^{-4}$
73	$3.25 \cdot 10^{-4}$	0.0195	$1.71 \cdot 10^{-4}$
74	$2.11 \cdot 10^{-4}$	0.0127	$1.11 \cdot 10^{-4}$
75	$5.85 \cdot 10^{-4}$	0.0351	$3.08 \cdot 10^{-4}$
76	$3.25 \cdot 10^{-4}$	0.0195	$1.71 \cdot 10^{-4}$
77	$2.11 \cdot 10^{-4}$	0.0127	$1.11 \cdot 10^{-4}$
78	$2.11 \cdot 10^{-4}$	0.0127	$1.11 \cdot 10^{-4}$
79	$3.74 \cdot 10^{-4}$	0.0224	$1.97 \cdot 10^{-4}$
P4	$2.11 \cdot 10^{-4}$	0.0127	$1.11 \cdot 10^{-4}$
P5	$1.46 \cdot 10^{-4}$	0.0088	$7.68 \cdot 10^{-5}$

TABLE XX. SPECIFIC ACTIVITY (Bq/kg) FOR SELECTED ISOTOPES IN SOIL SAMPLES TAKEN IN 1998 OUTSIDE OF THE MAGURELE FORT.

Sample	**98fortp1**	**98fortp2**	**98fortp3**	**98fortp4**	**98fortp5**	**98fortp6**	**98fortp7**	**98fortp8**	**98fortp9**
Depth [cm]	P1 (0-2)	P1 (2-4)	P1 (4-6)	P1 (6-8)	P2 (0-4)	P2 (4-8)	P3 (0-3)	P3 (3-6)	P3 (6-9)
Mass [g]	178.85	208.00	210.55	221.55	199.05	210.35	168.45	213.05	216.20
Isotope									
^{40}K	550.99	600.00	628.97	574.68	602.76	434.43	398.36	480.17	401.98
^{60}Co	2687.62	8527.88	7160.29	4086.62	4036.22	385.21	1355.24	662.38	477.06
^{65}Zn	11.11	17.92	25.89	9.59	0.00	0.00	0.00	0.00	0.00
^{69}Zn	2.83	0.00	0.00	0.00	0.00	1.68	0.00	0.00	0.00
^{137}Cs	186.03	203.06	86.39	62.51	124.06	50.25	2404.27	1098.15	583.16
^{208}Tl	9.55	12.21	11.67	10.83	13.87	7.26	17.84	13.74	12.86
^{212}Tl	43.69	51.56	46.07	43.39	54.94	28.29	58.99	47.25	44.36
^{214}Pb	11.21	36.13	30.97	41.45	47.28	42.77	57.86	48.73	40.88
^{212}Bi	0.00	0.00	0.00	19.35	0	13.74	37.82	28.58	26.53
^{214}Bi	8.82	22.91	21.06	36.73	53.22	34.44	50.85	49.97	35.86
^{224}Ra	79.45	97.16	81.40	61.35	0.00	0.00	0.00	0.00	0.00
^{226}Ra	0.00	0.00	104.78	53.22	0.00	0.00	89.16	77.41	49.52
^{228}Ac	29.82	46.39	41.63	38.11	0.00	23.23	50.91	41.28	40.77
^{235}U	3.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	**3624.71**	**9615.22**	**8239.12**	**5037.83**	**4932.35**	**1021.30**	**4521.31**	**2547.66**	**1712.98**

TABLE XXI. SPECIFIC ACTIVITY (Bq/kg) FOR SELECTED ISOTOPES IN SOIL SAMPLES TAKEN IN 1998 AT THE MAGURELE FORT.

Sample	**98foso1**	**98foso2**	**98foso3**	**98foso4**	**98foso5**	**98foso6**	**98foso7**	**98foso8**
Depth [cm]	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16
Mass [g]/ Isotope	157.40	173.25	189.50	191.15	218.75	220.50	210.72	225.00
^{7}Be	22.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00
^{40}K	678.65	639.94	657.36	738.90	705.97	723.90	669.70	670.27
^{60}Co	2061.82	3109.78	1920.42	1028.88	366.20	139.13	95.71	67.88
^{134}Cs	4.74	6.90	0.00	0.00	0.00	0.00	0.00	0.00
^{137}Cs	361.84	275.88	109.16	57.20	28.80	18.15	16.51	17.03
^{208}Tl	14.59	15.72	17.72	17.66	15.18	14.43	14.36	12.82
^{212}Pb	52.79	57.26	57.46	57.52	49.43	47.08	47.11	45.60
^{214}Pb	32.15	32.05	30.68	36.40	30.56	29.42	22.26	35.55
^{212}Bi	28.26	31.12	42.26	31.56	24.59	30.07	28.47	29.74
^{214}Bi	30.69	31.70	25.33	36.12	29.90	31.88	21.45	31.72
^{224}Ra	61.64	65.25	63.44	75.55	57.94	49.50	50.92	34.43
^{226}Ra	63.78	48.61	0.00	104.10	89.38	77.51	78.05	82.73
^{228}Ac	45.86	47.38	52.05	48.69	42.18	41.77	40.44	38.23
TOTAL	**3459.76**	**4361.59**	**2975.88**	**2232.57**	**1440.13**	**1202.85**	**1084.98**	**1066.00**
Sample	**98foso9**	**98foso10**	**98foso11**	**98foso12**	**98foso13**	**98foso14**	**98foso15**	
Depth [cm]	16-18 cm	18-20 cm	20-22 cm	22-25 cm	25-28 cm	28-31 cm	31-35 cm	
Mass [g]/ Isotope	207.45	204.30	191.00	228.60	231.85	214.70	172.35	
^{40}K	664.88	572.10	483.79	500.48	524.00	571.77	607.72	
^{60}Co	65.10	92.92	91.07	28.93	16.34	27.25	74.64	
^{137}Cs	16.92	44.65	36.98	12.11	4.82	2.68	5.54	
^{208}Tl	11.69	10.00	8.57	8.11	7.75	9.17	10.61	
^{212}Pb	39.30	37.56	29.39	23.46	25.44	31.10	45.15	
^{214}Pb	33.71	22.31	19.62	11.80	13.32	22.16	29.93	
^{212}Bi	25.73	23.96	16.70	14.55	12.86	16.20	21.76	
^{214}Bi	29.98	20.10	22.13	14.01	13.50	20.55	27.51	
^{224}Ra	41.88	37.73	29.55	0.00	0.00	0.00	64.11	
^{226}RA	40.06	70.60	0.00	0.00	0.00	0.00	66.71	
^{228}Ac	38.22	31.74	23.67	22.12	23.73	26.84	35.89	
TOTAL	**1007.48**	**963.67**	**761.47**	**635.57**	**641.78**	**727.73**	**989.57**	

TABLE XXII. RESULTS OF DOSE AND β-. AND γ-CONTAMINATION MEASUREMENTS AT THE MAGURELE FORT.

Point No.		HP 210L β+γ (cnt/min)	HP 270 γ (mR/min)	Contamination (Bq/cm^2)	Dose rate (mR/h)	(mSv/h)
-4	A	29.10	$4.10 \cdot 10^{-4}$	0.0811	0.0246	$2.16 \cdot 10^{-4}$
	B	711.00	$7.55 \cdot 10^{-3}$	1.9819	0.4530	$3.97 \cdot 10^{-3}$
	C	252.00	$2.57 \cdot 10^{-3}$	0.7024	0.1542	$1.35 \cdot 10^{-3}$
	D	78.20	$1.80 \cdot 10^{-3}$	0.2180	0.1080	$9.47 \cdot 10^{-4}$
-3	A	38.60	$3.41 \cdot 10^{-4}$	0.1076	0.0205	$1.79 \cdot 10^{-4}$
	B	185.00	$1.66 \cdot 10^{-3}$	0.5157	0.0996	$8.73 \cdot 10^{-4}$
	C	219.00	$1.79 \cdot 10^{-3}$	0.6105	0.1074	$9.42 \cdot 10^{-4}$
	D	33.10	$3.90 \cdot 10^{-4}$	0.0923	0.0234	$2.05 \cdot 10^{-4}$
-2	A	35.10	$6.01 \cdot 10^{-4}$	0.0978	0.0361	$3.16 \cdot 10^{-4}$
	B	42.60	$6.82 \cdot 10^{-4}$	0.1187	0.0409	$3.59 \cdot 10^{-4}$
	C	42.10	$6.17 \cdot 10^{-4}$	0.1174	0.0370	$3.25 \cdot 10^{-4}$
	D	35.60	$5.20 \cdot 10^{-4}$	0.0992	0.0312	$2.74 \cdot 10^{-4}$
-1	A	37.10	$3.41 \cdot 10^{-3}$	0.1034	0.2046	$1.79 \cdot 10^{-3}$
	B	72.70	$6.50 \cdot 10^{-4}$	0.2026	0.0390	$3.42 \cdot 10^{-4}$
	C	48.60	$6.66 \cdot 10^{-4}$	0.1355	0.0400	$3.50 \cdot 10^{-4}$
	D	36.60	0.0	0.1020	0.0000	0.0
0	A	38.10	$5.85 \cdot 10^{-4}$	0.1062	0.0351	$3.08 \cdot 10^{-4}$
	B	270.00	$3.14 \cdot 10^{-3}$	0.7526	0.1884	$1.65 \cdot 10^{-3}$
	C	417.00	$6.04 \cdot 10^{-3}$	1.1624	0.3624	$3.18 \cdot 10^{-3}$
	D	46.60	$7.64 \cdot 10^{-4}$	0.1299	0.0458	$4.02 \cdot 10^{-4}$
1	A	31.60	$5.20 \cdot 10^{-4}$	0.0881	0.0312	$2.74 \cdot 10^{-4}$
	B	79.20	$1.93 \cdot 10^{-3}$	0.2208	0.1158	$1.02 \cdot 10^{-3}$
	C	1810.00	$9.16 \cdot 10^{-3}$	5.0453	0.5496	$4.82 \cdot 10^{-3}$
	D	37.60	$9.10 \cdot 10^{-4}$	0.1048	0.0546	$4.79 \cdot 10^{-4}$
2	A	31.60	$4.06 \cdot 10^{-4}$	0.0881	0.0244	$2.14 \cdot 10^{-4}$
	B	87.20	$1.27 \cdot 10^{-3}$	0.2431	0.0762	$6.68 \cdot 10^{-4}$
	C	56.60	$9.26 \cdot 10^{-4}$	0.1578	0.0556	$4.87 \cdot 10^{-4}$
	D	27.60	$4.06 \cdot 10^{-4}$	0.0769	0.0244	$2.14 \cdot 10^{-4}$
3	A	35.10	$3.41 \cdot 10^{-4}$	0.0978	0.0205	$1.79 \cdot 10^{-4}$
	B	39.10	$5.20 \cdot 10^{-4}$	0.1090	0.0312	$2.74 \cdot 10^{-4}$
	C	33.60	$5.69 \cdot 10^{-4}$	0.0937	0.0341	$2.99 \cdot 10^{-4}$
	D	28.10	$4.55 \cdot 10^{-4}$	0.0783	0.0273	$2.39 \cdot 10^{-4}$
4	A	43.60	$4.55 \cdot 10^{-4}$	0.1215	0.0273	$2.39 \cdot 10^{-4}$
	B	130.00	$1.82 \cdot 10^{-3}$	0.3624	0.1092	$9.58 \cdot 10^{-4}$
	C	41.60	$1.30 \cdot 10^{-3}$	0.1160	0.0780	$6.84 \cdot 10^{-4}$
	D	58.10	$8.29 \cdot 10^{-4}$	0.1620	0.0497	$4.36 \cdot 10^{-4}$

TABLE XXIII. RESULTS FROM *IN SITU* MEASUREMENTS AT MAGURELE FORT.

Point 1	Φ_γ [$s^{-1}cm^{-2}$]			
Relaxation factor	^{137}Cs (661.62 keV)	^{60}Co (1173.23 keV)	^{60}Co (1332.51 keV)	^{40}K (1460.75 keV)
$6.25 \cdot 10^{-2}$	1.5595	39.6257	38.6556	1.0018
$2.06 \cdot 10^{-1}$	0.7617	20.1946	19.6043	0.5556
$3.12 \cdot 10^{-1}$	0.6145	16.6602	16.2193	0.4189
$6.25 \cdot 10^{-1}$	0.4324	12.1438	12.0179	0.3138
$6.25 \cdot 10^{0}$	0.2636	7.5346	7.4594	0.1948

Point 2	Φ_γ [$s^{-1}cm^{-2}$]			
Relaxation factor	^{137}Cs (661.62 keV)	^{60}Co (1173.23 keV)	^{60}Co (1332.51 keV)	^{40}K (1460.75 keV)
$6.25 \cdot 10^{-2}$	2.1196	0.5609	0.5582	1.1694
$2.06 \cdot 10^{-1}$	1.0353	0.2858	0.2831	0.5901
$3.12 \cdot 10^{-1}$	0.8352	0.2358	0.2342	0.4889
$6.25 \cdot 10^{-1}$	0.5877	0.1719	0.1735	0.3663
$6.25 \cdot 10^{0}$	0.3583	0.1066	0.1077	0.2274

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Characterization of Radioactively Contaminated Sites for Remediation Purposes, IAEA-TECDOC-1017, IAEA, Vienna, (1998).

[2] IAEA INT/9/018 Report – WAMAP Mission in Romania, Vienna, Austria (1990).

[3] COMMISISION OF THE EUROPEAN COMMUNITIES, Detailed Regional Study of Management Schemes for the Back-End of the Nuclear Fuel Cycle, Radioactive Waste Management and Decommissioning of Obsolete Nuclear Installations, unpublished Report on Project No. ZZ.92.17/01.01/B006 (Romania), Brussels (1994).

[4] Law no. 137/1995 (Law of environment protection), Romania (1995).

[5] Law no.111*/1996 (Law for safe deployment of nuclear installations), Romania (1996).

[6] PARLIAMENT OF ROMANIA, CHAMBERS OF DEPUTIES, Environment Legislation, Official Monitor, Sept., Bucharest (1996).

[7] FRUJINOIU, C., Environmental surveillance concept for nuclear units in IFIN-HH, Bucharest, Romania, Report RAPSEN/14-96, Bucharest (1996).

[8] GARLEA, I. et al., Decommissioning plan for VVR-S research reactor, counterpart report, performed under TAP IAEA ROM/9/017, Bucharest (1998).

[9] GARLEA, C., GARLEA, I., KELERMAN, C., GRANCEA, I., "VVR-S Bucharest spent fuel", Rom. J. of Physics, 44 3-4 (1999) 209-215, Bucharest.

[10] COMMISISION OF THE EUROPEAN COMMUNITIES, Recommendations for Future Safe Strategies – Technical Annex for Romania – PHARE, Project PH 4.01/94, Report TSAF/WL/249/PH2 (ROM), Brussels (1997).

[11] GARLEA, C., et al., Progress Report IAEA 8735/R0, December (1996).

[12] GARLEA, C., et al., Progress Report IAEA 8735/R1, June (1998).

[13] GARLEA, C., "Site characterization of radioactivity in the influence area of IFIN-HH Bucharest – Magurele", A Summary Report on the Second Research Co-Ordination Meeting on Site Characterization Techniques Used in Environmental Restoration, 3-7 November 1997, Madrid (CIEMAT), IAEA, Vienna (1997).

[14] GARLEA, C., GARLEA, I., KELERMAN, C., Preliminary characterization of IFIN-HH Magurele Nuclear Site, Report Bucharest University, UBPub-EPPG/Phys 43, March, Bucharest (1999).

[15] HELFER, I.K., MILLER, K., "Calibration factors for Ge detectors used for field spectrometry", Health Physics, 55 1 (1988) 15-29.

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Summary Report of the First Research Co-Ordination Meeting on Site Characterization Techniques used in Environmental Restoration, 22-26 April 1996, Vienna (1996).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, A Summary Report on the Second Research Co-Ordination Meeting on Site Characterization Techniques Used in Environmental Restoration, 3-7 November 1997, Madrid (CIEMAT), IAEA, Vienna (1997).

[18] GARLEA, I., GARLEA, C., KELERMAN, C., Environmental radioactivity characterization in the area influenced by IFIN-HH, R.I. IFIN-HH A.42.1, Bucharest (1997).

[19] GARLEA, I., GARLEA, C., KELERMAN, C., The characterization of environmental radioactivity by α, β, γ, measurements on the IFIN-HH site, R.I. IFIN-HH A.133.1, Bucharest (1998)

[20] MARGINEANU, R., STANESCU, S.P., In situ gamma spectrometry measurements of the surrounding area of a decommissioned repository, Insitute of Atomic Physics (IAP) Report No. RB-44-1993, Bucharest, (1993).
[21] GARLEA, I., GARLEA, C., KELERMAN, C., Information of the public regarding nuclear facility decommissioning, R.I. IFIN-HH A.133.2, Bucharest (1998).