ENVIRONMENTAL RADIOACTIVITY - RADIATION EXPOSURE OF THE POPULATION LIVING NEAR THE SITE

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LIST OF ABBREVIATIONS

Short name	Full name
ÁNTSZ OTH	National Public Health and Medical Officer Service
BNO	International Statistical Classification of Diseases ICD
DBC4	Design Basis Category 4 Conditions (EUR Main policies and objectives, Revision D, 2012.)
ERMAH	Radiological Monitoring and Data Acquisition Network RAMDAN
HAKSER	Joint Environmental Radiation Monitoring System JERMS
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
BDL	Below Detection Level
ISFS	Interim Spent Fuel Storage Facility
KSH	Hungarian Central Statistical Office
MCNP	Monte Carlo N-Particle
MIR	Modernized International Reactor
MVM	MVM Hungarian Electricity Ltd.
NBSz	Nuclear Security Code Government Decree no. (118/2011. (VII. 11.) Korm.
OKSER	National Environmental Radiation Monitoring System NERMS
OSSKI	”Frédéric Joliot-Curie” National Research Institute for Radiology and Radiohygiene
OTH	National Public Health Office
DBC4	Very low frequency design basis accident (NSC Appendix 10 Section 163)
ÜKSER	Plant Environmental Radiation Monitoring System PERMS
VBJ	Final Safety Report FSR
VVER	Water-Water Energetic Reactor (Russian)

20 ENVIRONMENTAL RADIOACTIVITY – RADIATION EXPOSURE OF THE POPULATION NEAR THE SITE

20.1 LEGAL BACKGROUND, LIMIT VALUES

20.1.1 LEGISLATION

European Union law (Decision, Directive)

Council Directive 96/29/EURATOM

Acts of Law

Act LIII of 1995 on the General Rules of Environmental Protection

Act VXVI of 1996 on Nuclear Energy (Atv.)

Act I of 1997 on the promulgation of the Convention on Nuclear Safety concluded in Vienna on the 20th of September in 1994 under the umbrella of the International Atomic Energy Authority

Government Decrees

Government Decree 314/2005. (XII.25.) regarding the procedures of environmental impact assessment and the single procedure of authorization of utilization of the environment

Government Decree 118/2011. (VII. 11.) on the nuclear safety requirements of nuclear facilities and related regulatory activities

Government Decree 275/2002 (XII.21.) Korm. on Monitoring the National Radiation Situation and Radioactive Material Concentrations

Ministerial Decrees

Decree 16/2000. (VI. 8.) EüM issued by the Ministry of Health on the execution of certain provisions of Act CXVI of 1996 on Nuclear Energy

Decree 15/2001. (VI. 6.) KöM issued by the Ministry of Environmental Protection on Radioactive Releases to the Atmosphere and into Waters in the Course of Using Atomic Energy and their Monitoring

Here in particular the following sections must be highlighted:

1.§: This Decree shall apply in the course of using atomic energy to:

- the releases of radioactive materials to the atmosphere and into water,
- the protection of waters and water containing formations against radioactive contamination and heat pollution,
- the monitoring of radioactive contamination of air and water environment, furthermore to any party undertaking the above activities.

3.§ (1) a) The user of atomic energy for special facilities derives the annual release limits from the dose constraint specified by the Office of the Chief Medical Officer of State according to a separate legal regulation.
5.§ (1) At the planning of a special facility the following conditions shall be determined for

the radionuclides or radioactive materials released under normal operation:

- the place of origin,
- the procedure of origin,
- the activities,
- the mode of the release,
- the release pathways,
- the characteristics of released radioactive materials,
- the planned release levels.

9. § (1) b) The liquid release of radionuclides is permissible for nuclear power plants into surface waters only.

9. § (2) a) The liquid release of radionuclides is not permissible into natural lakes and into underground water containing formations.

20.1.2 LIMIT VALUES

20.1.2.1 Limitation of population radiation exposure

Decree 16/2000. (VI. 8.) EüM issued by the Ministry of Health on the execution of certain provisions of Act CXVI of 1996 on Nuclear Energy regulates the limitation of employee and population radiation exposure, and the accident control and rescue intervention levels related to radiation exposure.

Population dose limit

According to Decree 16/2000. (VI. 8.) EüM, Supplement 2, Chapter I. *Dose limits*, action levels for radon concentrations in workplaces, Clause 4.2:

The total external and internal public exposure originating from artificial sources – except for the doses received from medical diagnostic examinations and therapeutical treatment, by voluntarily supporting and comforting patients or during voluntary participation in medical research - **shall not exceed the annual effective dose limit of 1 mSv**.

20.1.2.2 Dose constraint

It is a fundamental radiation protection objective that the population should not be exposed to any unjustified additional radiation dose from a given source (activity), therefore the principle of dose constraint must be applied.

In respect of the population, the annual radiation exposure cannot exceed the 1 mSv dose limit value (Decree 16/2000. (VI. 8.) EüM), thus a dose constraint value must be determined below this threshold for a given source (activity) such that it takes into account both the existing sources and those potentially created in the future.

According to Decree 16/2000. (VI. 8.) EüM, Supplement 2, Chapter II. *Dose constraint*

In order to make sure that the occupational or public exposure originating from a given practice or from a controlled source does not exceed considerably the reasonably achievable lowest level a source related constraint should be applied. Its values - below the dose limits - (the range in case of the occupational exposure of the employees and the upper limit of the annual effective dose in case of the public exposure of a group of the population), related to the given source, field of application and group of population shall be determined by the Office of CMOS, based on the consideration of the radiation hygienic situation.

20.1.2.2.1 Selection of reference group (representative person)

In 2011, SOM SYSTEM Ltd. published a study under the title SOM(R)435/3, Rev.3. 5401 03A00015 SSA providing the foundation for dose constraint. The survey analyzed the five relevant reactor types used in 2011. The calculations considered the particular reactor types and included both normal operating conditions, both probable events, and defined the radiation exposure of the nearby population for liquid discharge and atmospheric emission release paths, applying suitable models and assumptions. The results obtained from detailed analyses showed that the current 90 μSv dose constraint applied to the 4 units of the Paks NPP can be retained for any of the five new reactor types selected.

Based on the calculations, a reference group of the population was identified. This proposed population reference group is a hypothetical adult group with respect to the new nuclear power plant units whose members endure the impact of airborne (atmospheric) emissions near the Csámpa bus stop, and face the effect of liquid discharges in Gerjen.

It must be noted that at present the reference group defined for the Paks site (Paks NPP, ISFS Facility) is that of hypothetical children, where earlier calculations neglected the effects of expected future events. In the current study, the calculations were extended to include these events too for the new units, thus the reference group was defined as comprising adults, being the subjects of higher radiation exposure.

20.1.2.2.2 Dose constraint for the new units planned for the Paks site

According to Resolution no. ÁNTSZ OTH KEF- 14381-4/2012:

The Office of CMOS (H-1097 Budapest IX., Gyáli út 2-6., hereinafter: CMOS) has considered the request of MVM Paks II NPP Development Ltd. (H-7030 Paks, Gagarin u. 1, 3rd floor 302/B, hereinafter: MVM Paks II Zrt.) submitted in respect of the new nuclear power plant units to be constructed on the site of the Paks NPP, and determined for the artificial source of ionizing radiation

in respect of the population a

90 µSv/yr (effective dose)

d o s e c o n s t r a i n t.

The CMOS hereby instructs MVM Paks II Zrt. to send – once the new units have been commissioned – measurement results, related calculations and estimates for CMOS confirming the observation of the prescribed annual dose constraint.

Deadline: March 31 of the year following the given year.

20.1.2.3 Emergency rescue intervention levels related to radiation exposure

In emergency situations (status induced by some extra-ordinary event or radiation exposure conditions sustained prolongedly subsequent to an extra-ordinary event), the intervention levels relevant to radiation exposure are specified in Decree 16/2000. (VI. 8.) EüM, Supplement 2, Annex 1. The levels expressed in terms of absorbed dose and corresponding to justified protection measures are set out in Clause III. 4 of Supplement 2 to said Decree.

20.1.2.3.1 Optimized, general intervention levels for urgent protection measures

It is understood that protective measures must be taken if the avoidable radiation exposure exceeds the intervention level corresponding to the measure.

	Intervention dose level	
Protection measure	**Effective dose, E**	**Committed absorbed dose in thyroid gland, D(τ)**
Sheltering	10 mSv, during a period not exceeding 2 days	
Evacuation	50 mSv, during a period not exceeding 1 week	
Iodine prophylaxis	-	100 mGy

Table 20.1.2-1: Intervention levels for emergency radiation exposures – urgent rescue measures.

The (counter)measures aiming at avoiding or reducing the increase of radiation exposure of the members of the population must be adjusted to the intervention levels (dose) or the action levels (activity concentration).

When deciding the extent and execution of said measures, the basic principle to apply is to bear in mind that it is the sufficient degree of abatement of the adverse health effects caused by radiation what justifies the damages and costs arising during interventions. The method, scale and duration of intervention must be selected to achieve optimum results.

The avoidable doses, set for intervention levels (i.e. the difference between the doses expected without countermeasure and with its execution) are understood for mean values defined for groups selected from the population.

According to Clause III. 4 of Supplement 2 to Decree 16/2000. (VI. 8.) EüM:

For the protection of the life and health of the public it is justified to take actions appropriate to the radiation situation if the projected absorbed whole body or bone marrow dose, expectable within a short period of time (less than 2 days), exceeds 1 Gy, or the absorbed dose to the lens of the eye exceeds 2 Gy, or the dose to the skin or to the gonads exceeds 3 Gy, or the dose to the thyroid exceeds 5 Gy, or the dose to the lung exceeds 6 Gy.

20.1.2.3.2 Optimized, general intervention levels for population resettlement

Nature of resettlement	Intervention levels for resettlement	
	Initiate (effective dose)	Cancel (effective dose)
Temporary	30 mSv / month	10 mSv / month
Permanent	1 Sv / lifetime	

Table 20.1.2-2: Intervention levels for emergency radiation exposure - population resettlement.

20.2 CURRENT ENVIRONMENTAL RADIOACTIVITY OF THE INVESTIGATED 30 KM RADIUS AREA

The control of the environment surrounding the Paks NPP by measuring the radioactivity of environmental samples has been an on-going program since 1978, from setting the baseline (zero level) to continuous operating measurements. The measurements were made by the staff of the Paks NPP, the authorities and several other institutions as well.

20.2.1 PROCESSING THE DATA MEASURED BETWEEN 2001 AND 2011 IN THE 30 KM RADIUS AREA

The measured results of the following environmental elements were used to characterize the environmental radioactivity of the Paks NPP:

- Dose rate of environmental radiation,
- In-situ gamma spectrometry measurements,
- Atmospheric activity concentration,
- Soil and grass sample activity concentrations,
- Surface water activity concentrations,
- Surface catchment basin mud sample activity concentrations,
- Fish sample activity concentrations,
- Groundwater sample activity concentrations,
- Milk sample activity concentrations.

Environmental radiology characteristics were investigated and evaluated within a 30 km radius area around the site, over a period of 11 years, with reference to the topics listed below:

- Properties defining the spreading of radioactive materials on-site and in its vicinity,
- Properties characteristic of the atmospheric, surface and subsurface water-bound migration of radioactive materials,
- Radiological conditions of the environment surrounding the site.

The key inputs forming the basis of evaluation were primarily the PERMS and JERMS YR 2001-2011 Annual Reports [20.2-10], the comprehensive analysis of the annual radiation protection activity reports issued by the Paks NPP [20.2-9], and the other related documents made available, and there were also special test reports (e.g. accumulation measurements) that referred to the given period and concerned the environment around the Paks NPP:

- Ground level air activity concentrations (aerosols, radioiodines, tritium and radiocarbon),
- Soil and grass sample activity concentrations (gamma-radiating isotopes, radiostrontium),
- Danube water and mud sample activity concentrations (gamma-radiating isotopes, radiostrontium, tritium),
- Fish pond fish, water and mud sample activity concentrations (gamma-radiating isotopes, radiostrontium, tritium),
- Groundwater activity concentration (gamma-radiating isotopes, tritium),
- Milk sample activity concentration (gamma-radiating isotopes),
- Gamma radiation dose rate in the environment.

Baseline data

The two most important databases are PERMS and JERMS. The essential measurements when sample radioactivity and radiation levels were determined in relation to the Paks NPP were as follows:

According to PERMS

Data taken from YR 2001-2011 nuclear environmental monitoring reports for airborne (gaseous) emission and liquid discharge (measurement specifics and orientations are shown in parentheses):

Investigation of liquid discharge

Release control	Environmental control	
Control tanks	**Water samples**	**Sludge samples**
Gross-beta (= gb) Isotope composition (gamma spectrometry m. = gs) Tritium (liquid scintillation meas. = ls) Radiostrontium (ls) Radiocarbon (ls) Alpha-emitters (alpha spectrometry m. = as)) Gross-alpha (= ga) X-ray emitters (SiLi detector)	Canal waters (gs, ls, ga) Groundwater (gb, gs, ls) Fish ponds (gb, gs, ls) Diversion ditch (gb, gs, ls) Lime mud basins (gb, gs, ls) Danube water (gs, ls)	Danube sludge (gb, gs) Fish ponds (gb, gs, ls) Diversion ditch, Fadd ditch (gs) Lime mud (gs) Defecated mud (gs)

Investigation of atmospheric emission

Release control	Data collected at sampling stations
Noble gases (gs) Aerosol, radioiodine (gs) Radiostrontium (ls) Tritium (HTO/HT) (ls) Radiocarbon (CO2/CnHm) (ls)	Aerosol, radioiodine (gs) Elemental iodine (gs) Organic iodine (I-telemeter, activated carbon), (gs) Aerosol (large volume), (gb, gs) Elemental iodine (large volume), (gs) Organic iodine (a. c., large volume), (gs) Radiostrontium (ls) Tritium (HTO/HT)(ls) Radiocarbon (C_nH_m, CO_2) (gb) Fall-out (gs)

Periodic environmental monitoring investigation:

Soil sample (gs, as, gb)
Grass sample (gs, gb)
Milk sample (gs)
Fish sample (gs)
Dose (TLD)
On-site measurements (in-situ gamma spectrometry, dose rate)

According to JERMS

Authority measurements between 2001-2011 (measurement specifics and orientations are shown in parentheses):

- Atmospheric aerosol (gb, gs),
- Atmospheric fall-out (gb, gs),
- Surface waters (rivers, natural and artificial lakes, canals), (gb, gs, H-3, Sr-90),
- Drinking water (gb, gs, H-3, Sr-90),
- Sediment (rivers, natural and artificial lakes), (gb, gs, H-3, Sr-90),
- Soils (gb, gs, H-3, Sr-90),
- Plants (gb, gs, H-3, Sr-90),
- Meats (gb, gs, Sr-90),
- Raw milk (gb, gs, Sr-90),
- Gamma dose rate.

When collecting baseline input data, first the JERMS database and YR 2001-2011 [20.2-10] reports were used.

Measurement	Number of attempts, above detection level	Number of attempts, below detection level	Number of measurements, total
Atmospheric aerosol			
Gross-beta	2010	892	2902
^{7}Be	453	3	456
^{134}Cs	0	348	348
^{137}Cs	28	426	454
^{131}I	6	422	428
^{210}Pb	430	4	434
Atmospheric fallout (dryout)			
Gross-beta	958	0	958
^{7}Be	648	23	671
^{137}Cs	16	707	723
^{40}K	45	1	46
Surface waters (rivers, natural and artificial lakes, canals)			
Gross-beta	1731	1	1732
^{228}Ac	10	0	10
^{214}Bi	56	0	56
^{60}Co	0	3	3
^{134}Cs	2	3	5
^{137}Cs	104	316	420
^{40}K	470	9	479
^{212}Pb	9	2	11
^{214}Pb	82	35	117
^{226}Ra	10	0	10
^{234}Th	9	0	9
^{208}Tl	14	74	88
^{235}U	382	29	411
^{3}H	615	340	955
^{90}Sr	271	140	411
Drinking water (wells, deep)			
Gross-beta	536	2	538
^{134}Cs	0	178	178
^{137}Cs	21	275	296
^{40}K	24	0	24
^{3}H	133	90	223
^{90}Sr	73	107	180

Measurement	Number of attempts, above detection level	Number of attempts, below detection level	Number of measurements, total
Sediment (rivers, natural and artificial lakes)			
Gross-beta	872	0	872
^{228}Ac	239	0	239
^{7}Be	85	0	85
^{214}Bi	240	0	240
^{60}Co	5	5	10
^{134}Cs	30	566	596
^{137}Cs	974	122	1096
^{40}K	1044	2	1046
^{212}Pb	237	0	237
^{214}Pb	319	4	323
^{226}Ra	224	0	224
^{234}Th	224	0	224
^{208}Tl	324	0	324
^{235}U	344	26	370
^{90}Sr	328	275	603
Soils (irrigated and non-irrigated arable land, garden, field and roadside)			
Gross-beta	469	0	469
^{134}Cs	38	544	582
^{137}Cs	665	62	727
^{40}K	727	3	730
^{90}Sr	268	20	288
Grass			
Gross-beta	200	0	200
^{134}Cs	21	61	82
^{137}Cs	79	131	210
^{40}K	214	0	214
^{3}H	117	1	118
^{90}Sr	180	14	194
Leafy vegetables (garden indicator plant, raw garden food, fruit)			
Gross-beta	349	0	349
^{134}Cs	10	136	146
^{137}Cs	120	238	358
^{40}K	362	2	364
^{3}H	5	0	5
^{90}Sr	151	38	189
Meat types (pork, beef, mutton, poultry, game)			
Gross-beta	34	0	34
^{134}Cs	12	21	33
^{137}Cs	33	15	48
^{40}K	52	0	52
^{90}Sr	1	0	1
Raw milk			
Gross-beta	736	0	736
^{134}Cs	47	471	518
^{137}Cs	147	654	801
^{131}I	0	139	139
^{40}K	761	4	765
^{90}Sr	259	170	429
Dose rate			
-	408	0	408

Table 20.2.1-1: Baseline data – Evaluation of JERMS database measurements between 2001-2011. [20.2-10]

The environmental measurement results available for the period between 2001-2011 were split into groups according to location areas. Based on preliminary investigations, the nuclear power plant surroundings were described by 3 distances and 4 directions as indicated hereunder:

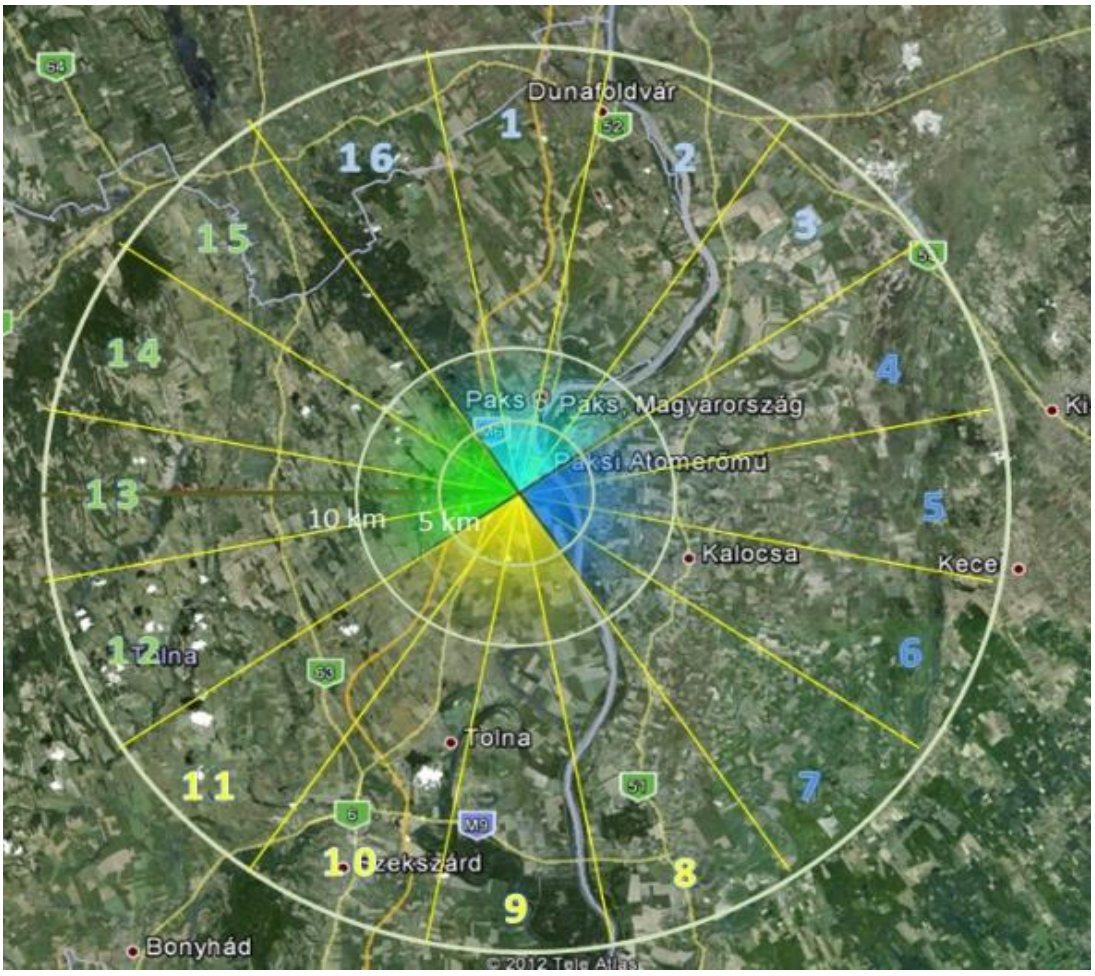
Distance:

- Less than 5 km,
- Between 5-10 km,
- Larger than 10 km (but at most 30 km).

Direction:

- Northern part: Sectors 16,1-3,
- Eastern part: Sectors 4-7,
- Southern part: Sectors 8-11,
- Western part: Sectors 12-15.

In JERMS, the northwest semicircle corresponded to the northern (light blue) and western (green) parts, while the southeast semicircle corresponded to the southern (yellow) and eastern (dark blue) parts, respectively.



Paksi Atomerőmű – Paks, Nuclear Power Plant

Figure 20.2.1-1: Sector group split for the 30 km area surrounding the nuclear power plant.

In JERMS, measurement data are available for several sectors out of the 16 related to various distances; these sector / distance data were combined to obtain, wherever possible, a statistically meaningful item number (*n* being at least 10-20) for each area and each measurement type.

For the locations so established, the statistical data of particular features are provided (mean, item number, standard deviation, minimum, maximum).

For Danube water and mud samples, the following split was used:

Danube reach upstream from Paks:

- *Larger than 10 river km (at most 35 km),*
- *Smaller than 10 river km.*

Danube reach downstream from Paks:

- *Smaller than 10 river km,*
- *Between 10-20 river km,*
- *Between 20-50 river km,*
- *Larger than 50 river km (at most 100 km).*

The statistical parameters of the data were given for the cells obtained using this mesh for the entire period (2001-2011).

In addition to the above, to better describe the time evolution of environmental radioactivity statistical parameters were given for the entire area too in a yearly breakdown, and also for the entire period.

Any further breakdown in terms of spatial and/or time coordinates seems to be pointless, unless later investigations justify its necessity, as even with the above resolution it often happens that groups with little or no data are created.

The first attempt was to try and adhere to the preliminary plans, and accordingly to take only data with an error less than 20% into account, but for several samples and radionuclides this produced empty or statistically less easily interpreted groups, therefore the statistics relevant to the whole database (for data with arbitrary error or below detection limit (BDL)) were also included in separate tables. In both cases, the rule applied was to include means (averages) and deviations (variances, standard errors) for at least 10 values in each group only, whereas for a single value the maximum, while for two values the minimum and the maximum were stated, that is, if there was only 1 measured value in a given row – a specific sample type measured in a given way at a given place or during a given period -, then it was entered in the maximum column, if there were 2-9, then their minimum (maximum) was entered in the minimum (maximum) column, and the average and deviation columns were left blank – these latter were only filled in for at least 10 measurements. Regarding the statistics of the entire database, BDL data were included to calculate averages and (root) deviations, using the value published in JERMS (BDL or measured value below BDL).

From all JERMS measurement data, the ones deemed truly out of range and as such difficult to interpret from the professional angle were neglected or eliminated (giving a total of 64 values). The investigations showed that for 89 measurements BDL values were – incorrectly - not defined at all. Again from the whole set of measurement data regarding the total period and area, investigated directions with only 1-2 measurements including BDL were also discarded. Wherever possible, the baseline values recorded prior to power plant construction were also included. Data were disclosed in a format similar to that familiar from JERMS reports (average, min-max; pcs (BDL), item numbers mean the number of (weekly, monthly, etc.) datum items available and not (necessarily) the number of measurements.

Data found in the PERMS database were processed in a similar way.

The data published in the Paks reports [20.2-9] or obtained from other sources (PERMS, ISFS, Isotoptech Zrt.) were also collected and summarized.

As a supplement to Paks NPP emissions found in operating reports, airborne emissions and liquid discharges from the ISFS Facility were also recapitulated by nuclide in annual breakdown.

20.2.1.1 Properties determining the migration of radioactive materials on-site and in its vicinity

The movement and binding of radioactive materials in elements of the environment are a result of complex processes, so e.g. the absorption of radioisotopes by plants is influenced by a number of factors, of which the most important are:

- The soil structure, soil cohesion degree and mechanical composition,
- The liquid content and re-supply of soil,
- The chemical composition, organic matter content and nutrition balance of soil,
- The agrotechnical and agrochemical procedures used,
- The type of vegetation,
- The rooting depth of plants, the ratio of plant parts above and below ground surface,
- The length of the vegetation period, the climatic and meteorological conditions.

The effect exerted by one element of the environment upon another, that is, the interactions between them can be described most simply using the IAEA coordinated BIOMASS (BIOsphere Modelling and ASSessment) recommendations and the so-called interaction matrices. Knowing these interactions also allows the description of the movement of radioactive materials escaped into the environment.

Natural habitats and growth locations – being the most general system division – in the nuclear power plant area comprise the following constituent elements:

- forest,
- cultivated area,
- grassland,
- river and
- lake.

Table 20.2.1-2 shows natural habitats and growth areas and their main interactions through which radioactive contaminations may propagate and move from one location to another. The diagonal of the interaction matrix contains the main environmental elements, while the adjacent cells show the interactions between them. Interactions between the diagonal elements are understood to be effective clockwise.

	1	2	3	4
1	Forest	Wind (aerosol, vapor) Ground- and surface water (downflow) Soil (mixing) Ash use (manuring) Use of animal dung (manuring) Organic decomposition products Use of wood products	Wind (aerosol, vapor) Ground- and surface water (downflow) Soil (mixing) Ash sedimentation (incineration) Organic decomposition products Animal fodder	Wind (aerosol, vapor) Ground- and surface water (downflow) Soil (mixing) Ash sedimentation (incineration)
2	Wind (aerosol, vapor) Ash sedimentation (incineration)	Cultivated area	Wind (aerosol, vapor) Ground- and surface water (downflow) Soil (mixing) Ash sedimentation (incineration) Organic decomposition products Animal feed	Wind (aerosol, vapor) Ground- and surface water (downflow) Soil (mixing) Ash sedimentation (incineration) Organic decomposition products
3	Wind (aerosol, vapor) Ash sedimentation (incineration) Farm animals, animal dung	Wind (aerosol, vapor) Ash sedimentation (incineration) Use of animal dung	Grassland	Wind (aerosol, vapor) Ground- and surface water (downflow) Soil (mixing) Ash sedimentation (incineration) Organic decomposition products
4	Wind (aerosol, vapor, spray) Water (animal trough) Flood	Wind (aerosol, vapor, spray) Groundwater (inflow) Sediment (excavation) Water (animals drinking) Irrigation Flood	Wind (aerosol, vapor, spray) Groundwater (inflow) Sediment (excavation) Water (animals drinking) Irrigation Flood	River, lake

Table 20.2.1-2: The main interactions between natural habitats and growth areas.

Another typical interaction matrix includes the human community among the interactions, hence the main elements in Table 20.2.1-3 are: water, arable land, food and fodder, domestic animals, agricultural produce, human community.

	1	2	3	4	5	6
1	Water extraction from contaminated aquifer	Irrigation, sediment transfer	Irrigation Leaf contamination	Water, sediment ingestion	X	Water, sediment ingestion
2	X	Arable land	Root absorption Contamination with soil (resuspension)	Consumption (with contaminated feed)	Soil transfer to plant produces	Soil ingestion External irradiation
3	X	Plant residues	Food, feed	Feed ingestion	Collection, harvest	X
4	X	Manuring	X	Domestic animals	Slaughter, milking, collecting eggs	X
5	X	Mulching, composting	X	Consumption of stored feed	Storage, processing and distribution of agricultural produces	Agricultural produce ingestion
6	X	X	X	X	X	Human community

Note:
X – there is no significant interaction among the elements.

Table 20.2.1-3: The main interactions observed for cultivated areas.

The interaction matrix of the woodland area found in the vicinity of the nuclear power plant (^{137}Cs movement) is shown in Table 20.2.1-4.

The interactions between environmental elements can be determined by measurements upon very rare occasions only, therefore to display them a compartment model was used and transfer factors between compartments were applied, and the latter were obtained by measuring the radioactivity of individual environmental elements or in some other experimental way mostly. The core of the compartment system is that these are certain parts (the so-called compartments) that can be clearly separated in terms of morphology or even functionally in the environment (atmosphere, soil, human body, etc.) in which the distribution of the radioactive material under scrutiny can be regarded as homogeneous.

	1	2	3	4	5	6	7	8	9	10	11
1	Atmosphere	Wet fallout	Wet fallout	X	X	Wet fallout	X	X	Wet fallout	Wet fallout	Inhalation
2	X	Tree leaves	Erosion	Translocation	Translocation	Falling leaves, erosion	X	X	Erosion, migration	Erosion, migration	Ingestion
3	X	X	Tree outer parts	Translocation		Erosion, migration	X	X	Erosion, migration	Erosion, migration	Ingestion
4	X	Translocation	Translocation	Forest	Translocation	X	Pollination	Pollination	Mycorrhizae transfer	X	Ingestion
5	X	X	X	Translocation	Dry forest	X	X	X	X	X	X
6	Resuspension	X	Rain splashing	Uptake through root	X	Waste	Decomposition	Seepage into soil, biotas	Nutrient uptake	Rain splashing, uptake through root	Ingestion
7	X	X	X	Uptake through root	X	X	Organic soil	Seepthrough, advection, soil biota	Nutrient uptake	Uptake through root	X
8	X	X	X	Uptake through root	X	X	Capillary rise, soil biota, diffusion	Mineral in soil	Nutrient uptake	Uptake through root	X
9	X	X	X	Uptake through root (mycorrhizae)	X	Pollination	Pollination	Pollination	Mushrooms, funghi	Uptake through root (mycorrhizae)	Ingestion
10	Exhalation	X	X	X	X	Dead leaves, erosion, catchment	Pollination	Pollination	Mycorrhizae transfer	Undergrowth	Ingestion
11	X	X	X	X	X	Pollination	X	X	X	X	Wildlife

Table 20.2.1-4: The ^{137}Cs interaction matrix for a forest ecosystem.

20.2.1.2 Radiological conditions of the atmospheric, surface and subsurface water environments around the Paks NPP

To analyze the radioactivity of environmental elements in the surroundings of the Paks NPP, first the JERMS [20.2-10] and PERMS databases, plus the data supplied by Isotoptech Zrt. were used, supplemented with those radionuclides that were generated artificially, in order to determine their potential NPP origin. During the evaluation process, only those data were considered that were above detection level (ADL) with error not exceeding 20 %. The data were obtained during measurements between 2001-2011, and the initial step was to analyze the JERMS data relevant to particular environmental elements. To complete the analyses, averages and deviations were provided whenever more than 10 data items were measured, moreover minimum–maximum values were specified, and the number of meaningful measurements was also indicated along with the sectoral occurrences mentioned in the preceding section.

For at least 10 samples their average, for less than 10 samples the arithmetic average of the minimum and maximum values was taken as reference level. For radionuclides with short half-lives compared to the length of the data collection period over-arching several years no reference level was specified. The latter include the following: ^{134}Cs ($T_{1/2}$=2.06 yrs), ^{131}I ($T_{1/2}$=8 days), ^{58}Co ($T_{1/2}$=71 days), ^{60}Co ($T_{1/2}$=5 yrs) and finally ^{54}Mn ($T_{1/2}$=312 days).

Global contaminants like ^{134}Cs, ^{137}Cs or ^{90}Sr originate with high probability from nuclear experiments or the Chernobyl catastrophe, and it is also difficult to separate tritium (^{3}H) and radiocarbon (^{14}C) to tell whether their origin is cosmogeneous, or they are global contaminants, or they were generated by the operation of the Paks NPP.

20.2.1.2.1 Measurement results of environmental elements – JERMS data

Measurements of ***aerosol*** activity concentration only supplied appreciable data for the *spatial distribution* of ^{134}Cs, ^{137}Cs and ^{131}I (for >10 km). ^{131}I was observed 11 times at distances larger than 10 km, which may indicate a hospital use origin, while the YR 2011 data may refer to emissions from the Institute of Isotopes Co. Ltd. (or Fukushima).

Nuclide	Year	Average [Bq/m³]	Min [Bq/m³]	Max [Bq/m³]	Deviation	Number	Reference level [Bq/m³]
^{134}Cs	2001-2011	-	8,4E-06	4,0E-05	-	5	**-**
^{137}Cs	2001-2011	-	9,0E-06	5,0E-05	-	5	**2,95E-05**
^{131}I	2001-2011	8,4E-4	1,0E-05	3,1E-3	1,1E-3	11	**-**

Table 20.2.1-5: Cumulative data of activity concentration.

Regarding the *temporal distribution* of ***fallout***[1] activity values again there is only 1-1 meaningful datum each, altogether 3 items, which do not deviate from the nation-wide average (mo=month):

Nuclide	Year	Average [Bq/(m²•mo)]	Min [Bq/(m²•mo)]	Max [Bq/(m²•mo)]	Deviation	Number	Reference level [Bq/(m²•mo)]
^{137}Cs	2003	-	-	0,39	-	1	
^{137}Cs	2005	-	-	0,26	-	1	
^{137}Cs	2008	-	-	0,44	-	1	
^{137}Cs	2001-2011	-	0,26	0,44	-	3	**0,35**

Table 20.2.1-6: Time distribution of fallout activity.

The timewise constant radioactivity of ***soil*** samples also shows that mostly global origin nuclear materials are found in the proximity of the nuclear power plant, and it is also apparent that the mean values fall short of the national average:

Nuclide	Year	Average [Bq/kg]	Min [Bq/kg]	Max [Bq/kg]	Deviation	Number	Country average [Bq/kg]	Reference level [Bq/kg]
^{134}Cs	2001-2011	-	0,26	2,6	-	5	-	**-**
^{137}Cs	2001-2011	9,7	0,5	52	6,0	516	17	**9,7**
^{90}Sr	2001-2011	1,8	0,18	56	4,6	183	2,3	**1,8**

Table 20.2.1-7: Cumulative data of soil activity concentration.

[1] The fallout of radioactive isotopes in the atmosphere may take via dryout but can also be caused by humidity during cloud formation, or yet again due to the washout effect of falling precipitation (rain, snow). These processes are collectively termed fallout.

Turning to the *spatial distribution* of ***soil*** activity concentrations, for the most part global origin radioactive materials occur near the Paks NPP (in Bq/kg units):

Nuclide	Sector	Average [Bq/kg]	Min [Bq/kg]	Max [Bq/kg]	Deviation	Number
		< 5 km				
^{134}Cs	12-15	-	-	0,26	-	1
	16-03	-	1,4	2,6	-	2
^{137}Cs	04-07	8,6	2,1	24	4,8	30
	12-15	9,7	0,69	24	5,8	69
	16-03	13	2,9	52	6,7	93
^{90}Sr	04-07	3,1	0,64	15	3,9	19
	12-15	1,1	0,18	17	2,8	35
	16-03	0,39	0,18	0,89	0,24	10
		5-10 km				
^{137}Cs	04-07	8,9	0,64	23	4,9	19
	16-03	6,6	0,55	21	3,9	40
^{90}Sr	04-07	-	1,3	4,5	-	8
	16-03	1,7	0,73	5,1	1,2	14
		> 10 km				
^{134}Cs	04-07	-	1,3	1,6	-	2
^{137}Cs	04-07	11	1,1	50	7,3	130
	08-11	7,1	2,1	19	3,0	75
	12-15	-	-	6,5	-	1
	16-03	7,7	3,5	21	2,8	59
^{90}Sr	04-07	2,8	0,21	56	8,2	47
	08-11	1,8	0,19	8,8	2,1	21
	16-03	0,63	0,21	1,5	0,33	29

Table 20.2.1-8: Spatial distribution of soil activity concentration.

Moving on to the *spatial distribution* of ***grass*** and animal ***feed*** activity concentration, similar properties were found like for soil radioactivity, with the exception of the occurrence of tritium:

Nuclide	Sector	Average [Bq/kg]	Min [Bq/kg]	Max [Bq/kg]	Deviation	Number
		< 5 km				
^{137}Cs	04-07	-	0,080	0,30	-	8
	16-03	0,49	0,027	1,4	0,31	20
^{3}H	04-07	2,5	0,34	11	1,9	76
^{90}Sr	04-07	0,57	0,12	3,4	0,59	63
	16-03	2,5	0,34	6,9	1,5	47
		5-10 km				
^{137}Cs	04-07	0,40	0,090	0,94	0,23	23
	16-03	0,37	0,095	0,71	0,20	15
^{3}H	04-07	2,3	0,070	6,5	2,0	11
	16-03	2,1	0,94	6,0	1,4	12
^{90}Sr	04-07	3,0	0,16	89	8,7	148
	16-03	0,96	0,12	5,9	1,2	55
		> 10 km				
^{137}Cs	04-07	1,6	0,11	27	5,7	22
	16-03	0,54	0,058	5,6	1,3	21
^{3}H	04-07	2,0	0,66	10	1,5	52
	08-11	-	2,9	6,2	-	2
	16-03	-	1,3	5,8	-	7
^{90}Sr	04-07	1,1	0,11	5,0	1,1	144
	08-11	-	0,15	0,33	-	3
	16-03	0,63	0,085	2,3	0,60	59

Table 20.2.1-9: Spatial distribution of grass and feed activity concentrations.

The *temporal distribution* of ***grass*** and ***feed*** annual activity concentrations indicated the uniform absorption of ^{90}Sr during the entire investigation period:

Nuclide	Year	Average [Bq/kg]	Min [Bq/kg]	Max [Bq/kg]	Deviation	Number	Reference level [Bq/kg]
^{137}Cs	2001-2011	0,66	0,027	27	2,6	109	**0,66**
^{3}H	2001-2011	2,3	0,070	11	1,8	160	**2,3**
^{90}Sr	2001-2011	1,7	0,085	89	4,8	519	**1,7**

Table 20.2.1-10: Cumulative data of grass and fodder activity concentrations.

The *distribution by river km* of the ***water*** sample activity concentrations obtained for the ***Danube section upstream from Paks*** also shows that radioactive materials are present in the river even upstream from the liquid discharge point of the Paks NPP (in Bq/dm^3 units):

Nuclide	Average [Bq/dm³]	Min [Bq/ dm³]	Max [Bq/ dm³]	Deviation	Number
	< 10 km				
^{137}Cs	0,0012	0,0003	0,0029	0,00069	18
^{3}H	2,7	1,2	4,4	0,9	33
^{90}Sr	0,0051	0,0019	0,03	0,0071	15
	> 10 km				
^{137}Cs	-	0,0017	0,0045	-	5
^{3}H	2	0,09	7,2	1,1	105
^{90}Sr	0,0031	0,00033	0,0069	0,0015	14

Table 20.2.1-11: Distribution by distance of water sample activity concentration in the Danube upstream from Paks.

The typical three radioactive materials of global origin (^{137}Cs, ^{90}Sr, ^{3}H) could be detected continuously in *time* too.

Nuclide	Year	Average [Bq/dm³]	Min [Bq/dm³]	Max [Bq/dm³]	Deviation	Number	Reference level [Bq/dm³]
^{137}Cs	2001-2011	0,0015	0,00030	0,0045	0,0010	27	**0,0015**
^{3}H	2001-2011	2,1	0,99	7,2	0,93	157	**2,1**
^{90}Sr	2001-2011	0,0041	0,00033	0,030	0,0052	29	**0,0041**

Table 20.2.1-12: Cumulative data of water sample activity concentration in the Danube upstream from Paks.

The ***water*** samples taken from the ***Danube section downstream from the Paks NPP*** showed nearly identical activity concentrations as upstream from the discharge point, in fact sometimes the value measured upstream from the discharge point was higher than its Paks downstream counterpart:

Nuclide	Average [Bq/dm³]	Min [Bq/dm³]	Max [Bq/dm³]	Deviation	Number
	< 10 km				
^{137}Cs	0,0013	0,00047	0,0024	0,00059	12
^{3}H	2,8	1,2	8,3	1,2	61
^{90}Sr	0,0020	0,00045	0,0031	0,00074	11
	10 - 20 km				
^{137}Cs	-	-	-	-	-
^{3}H	2,5	0,96	12	1,5	98
^{90}Sr	0,0035	0,0022	0,0066	0,0013	18
	20 - 50 km				
^{137}Cs	-	0,0016	0,0093	-	4
^{3}H	2,9	1,7	4,8	0,78	62
^{90}Sr	-	0,0023	0,0040	-	6
	> 50 km				
^{137}Cs	0,0020	0,00020	0,032	0,0046	48
^{3}H	2,6	1,5	4,9	0,61	106
^{90}Sr	0,0020	0,0010	0,0045	0,00071	52

Table 20.2.1-13: Distribution by distance of water sample activity concentration in the Danube downstream from Paks.

Nuclide	Year	Average [Bq/dm^3]	Min [Bq/dm^3]	Max [Bq/dm^3]	Deviation	Number	Reference level [Bq/dm^3]
^{137}Cs	2001-2011	0,0021	0,00020	0,032	0,0041	64	**0,0021**
^{3}H	2001-2011	2,6	0,96	12	1,1	327	**2,6**
^{90}Sr	2001-2011	0,0024	0,00045	0,0066	0,0011	87	**0,0024**

Table 20.2.1-14: Cumulative data of water sample activity concentration in the Danube downstream from Paks.

In the ***Danube section upstream from the Paks NPP***, ***sediments*** show uniform ^{137}Cs distribution in *time*.

Nuclide	Average [Bq/kg]	Min [Bq/kg]	Max [Bq/kg]	Deviation	Number
	< 10 km				
^{137}Cs	29	2,8	83	15	161
^{90}Sr	-	0,18	4,4	-	7
	> 10 km				
^{134}Cs	-	1,7	2,2	-	4
^{137}Cs	25	0,50	87	23	115
^{90}Sr	-	0,17	5,4	-	8

Table 20.2.1-15: Distribution by distance of sediment activity concentration in the Danube upstream from Paks.

Nuclide	Year	Average [Bq/kg]	Min [Bq/kg]	Max [Bq/kg]	Deviation	Number	Reference level [Bq/kg]
^{134}Cs	2001-2011	-	1,7	2,2	-	4	**-**
^{137}Cs	2001-2011	27	0,50	87	19	276	**27**
^{90}Sr	2001-2011	2,4	0,17	5,4	2,4	15	**2,4**

Table 20.2.1-16: Cumulative date of sediment activity concentration in the Danube upstream from Paks.

In sediments in the ***Danube section downstream from the discharge point*** the ^{137}Cs and ^{90}Sr radionuclides are present uniformly in time, with values not significantly higher than those upstream of the nuclear power plant:

Nuclide	Average [Bq/kg]	Min [Bq/kg]	Max [Bq/kg]	Deviation	Number
	< 10 km				
^{134}Cs	-	1,6	2,7	-	7
^{137}Cs	34	3,0	91	19	106
^{90}Sr	-	2,7	3,8	-	3
	10 - 20 km				
^{137}Cs	9,0	0,65	55	11	78
^{90}Sr	-	0,20	0,45	-	3
	20 - 50 km				
^{134}Cs	2,1	1,7	2,6	0,27	11
^{137}Cs	44	14	67	14	54
Ss-90	-	2,4	4,7	-	5
	> 50 km				
^{134}Cs	-	1,9	2,3	-	3
^{137}Cs	30	0,35	81	14	322
^{90}Sr	4,4	1,3	12	2,2	25

Table 20.2.1-17: Distribution by distance of sediment activity concentration in the Danube downstream from Paks.

Nuclide	Year	Average [Bq/kg]	Min [Bq/kg]	Max [Bq/kg]	Deviation	Number	Reference level [Bq/kg]
^{134}Cs	2001-2011	2,1	1,6	2,7	0,30	21	**2,1**
^{137}Cs	2001-2011	29	0,35	91	17	560	**29**
^{90}Sr	2001-2011	3,8	0,20	12	2,2	36	**3,8**

Table 20.2.1-18: Cumulative data of sediment activity concentration in the Danube downstream from Paks.

The activity concentrations measured in ***aquatic animals*** in the ***Danube section downstream from Paks*** exceeded detection levels only very few times and far away (>50 km), while the *time distribution* varies but also due to low measurable detection levels, and does not deviate considerably from the national average:

Nuclide	Year	Average [Bq/kg]	Min [Bq/kg]	Max [Bq/kg]	Deviation	Number	National average [Bq/kg]	Reference level [Bq/kg]
^{137}Cs	2001-2011	0,31	0,10	0,80	0,15	57	0,42	**0,31**
^{90}Sr	2001-2011	0,54	0,20	1,0	0,27	11	0,48	**0,54**

Table 20.2.1-19: Cumulative data of aquatic animal activity concentration in the Danube downstream from Paks.

The *spatial distribution* of ***stagnant water*** sample activity concentration does not depart from other domestic still water activity concentration values. Time variation of stagnant water detectable samples is mostly observed for ^{90}Sr, while the ^{3}H value stays below the national average (^{3}H: 4,3 Bq/dm^3, based on JERMS and NERMS data).

Nuclide	Year	Average [Bq/ dm^3]	Min [Bq/ dm^3]	Max [Bq/ dm^3]	Deviation	Number	Reference level [Bq/ dm^3]
^{137}Cs	2001-2011	-	0,0059	0,0059	-	2	**0,0059**
^{3}H	2001-2011	-	0,83	2,4	-	7	**1,62**
^{90}Sr	2001-2011	0,0041	0,0018	0,010	0,0021	16	**0,0041**

Table 20.2.1-20: Cumulative data of stagnant water water sample activity concentration.

The *temporal distribution* of ***stagnant water sediment*** activity concentration can be best measured for ^{137}Cs.

Nuclide	Year	Average [Bq/kg]	Min [Bq/kg]	Max [Bq/kg]	Deviation	Number	Reference level [Bq/kg]
^{137}Cs	2001-2011	5,4	1,2	25	3,7	115	**5,4**
^{90}Sr	2001-2011	0,44	0,18	0,75	0,20	10	**0,44**

Table 20.2.1-21: Cumulative data of stagnant water sediment activity concentration.

There is only 1-1 meaningful datum each concerning the spatial distribution of ***stagnant water aquatic animal*** activity concentration, it these the average activity concentration of ^{137}Cs was 0.22 Bq/kg. This value does not exceed the national average (0.42 Bq/kg).

Regarding the *spatial distribution* of activity concentrations measured in ***cow milk***, meaningful data were available for the ^{137}Cs and ^{90}Sr radionuclides only. The time distribution of cow milk activity concentration was uniform (even), falling into the order of magnitude of the national average.

Nuclide	Sector	Average [Bq/dm^3]	Min [Bq/dm^{3}l]	Max [Bq/dm^{3}l]	Deviation	Number
		< 5 km				
^{137}Cs	16-03	-	0,021	0,073	-	6
^{90}Sr	16-03	-	0,044	0,083	-	7
		5-10 km				
^{137}Cs	04-07	-	0,023	0,060	-	4
^{90}Sr	04-07	0,089	0,024	0,93	0,16	33
		> 10 km				
^{137}Cs	04-07	-	0,020	0,040	-	5
	08-11	-	-	0,050	-	1
	16-03	0,041	0,027	0,068	0,011	21
^{90}Sr	04-07	-	0,063	0,48	-	2
	16-03	-	0,040	0,23	-	5

Table 20.2.1-22: Spatial distribution of cow milk activity concentration.

Nuclide	Year	Average [Bq/ dm^3]	Min [Bq/ dm^3]	Max [Bq/ dm^3]	Deviation	Number	National average [Bq/ dm^3]	Reference level [Bq/dm^3]
^{137}Cs	2001-2011	0,040	0,020	0,073	0,014	37	0,055	**0,040**
^{90}Sr	2001-2011	0,092	0,024	0,93	0,15	47	0,066	**0,092**

Table 20.2.1-23: Cumulative data of cow milk activity concentration.

The ***spatial distribution*** of ***dose rate (measured with TLD)*** shows that in the proximity of the Paks NPP the values tend to fall into the lower range of the values measured in the country.

Sector	Average [nSv/h]	Min [nSv/h]	Max [nSv/h]	Deviation	Number
	< 5 km				
12-15	67	54	99	7,4	34
16-03	72	61	160	17	35
	5-10 km				
04-07	80	66	110	7,4	68
08-11	78	67	110	8,5	34
12-15	82	72	110	6,5	34
	> 10 km				
04-07	78	59	130	12	69
08-11	83	73	120	8,2	34
12-15	76	62	120	9,5	67
16-03	83	60	230	28	33

Table 20.2.1-24: Spatial distribution of dose rate.

The temporal distribution (time evolution) of dose rate is shown below:

Year	Average [nSv/h]	Min [nSv/h]	Max [nSv/h]	Deviation	Number	Reference level [nSv/h]
2001	79	66	95	7,8	47	
2002	80	63	96	8,7	48	
2003	77	61	95	9	47	
2004	76	54	92	7,9	44	
2005	74	57	96	7,5	48	
2006	74	60	87	7,4	45	
2007	92	65	230*	28	45	
2008	75	58	91	7,9	48	
2009	71	59	110	9,7	36	
2010	-	-	-	-	-	
2011	-	-	-	-	-	
2001-2011	78	54	230	13	408	**78**

Table 20.2.1-25: Time distribution of dose rate.

*In the quarter when these measurement data were obtained the results of the nationwide TLD measuring network also indicated random nature, unrealistic, exceedingly high measurement values. The root cause of the discrepancy is most likely some measurement error.

20.2.1.2.1 Measured values of environmental elements – PERMS data

The PERMS measurements were essentially performed close to the Type ”A” measuring stations (A1-A9) and the control measurement station (B24), plus the site and its immediate surrounding.

The location of the measuring stations around the Paks NPP is indicated in the figure below.

Paksi Atomerőmű – Paks, Nuclear Power Plant

Figure 20.2.1-2: Type ”A” measuring stations (A1 – A9) within a radius of 5 km around the Paks NPP.

Type ”A” stations are located closer to the Paks NPP, where the radionuclides emitted by the nuclear power plant can be detected with higher probability. Here again only artificial radionuclides were considered as a basis.

Based on operational measurements, air sample data show that only a few radionuclides generally characteristic of the nuclear power plant (^{54}Mn, ^{58}Co, ^{60}Co) could be detected in the study period between 2001-2011. It is apparent that the ^{137}Cs, ^{14}C and ^{3}H activity concentration values of Type ”A” stations and those of the Type ”B” control station are similar to each other. Based on fallout, soil and grass sample measurements, only the ^{60}Co radionuclide was typical of the Paks NPP, the ^{137}Cs and ^{90}Sr nuclides were at the same time radioactive isotopes of global origin. The ^{131}I radionuclide of air and fallout samples may originate from the Fukushima NPP accident and the emissions of the Institute of Isotopes. In the sludge and soil samples taken on-site and its immediate surroundings the occurrence of nuclear power plant (^{54}Mn, ^{58}Co, ^{60}Co, ^{110m}Ag, ^{106}Ru, ^{144}Ce) radionuclides is a result of confluences and thus accumulation, but the results make evident their origin as nuclear power plant emission.

Apart from these places of accumulation, nuclear power plant radionuclides cannot be detected with certainty in other environmental elements. Dose rate values also fall into the bottom region of the measured domestic range.

Air sample measurements (the top row shows the average value, while those below give the min-max values and the number of meaningful measurements (above detection level)):

Nuclide / Station	A1	A2	A3	A4	A5	A6	A7	A8	A9	B24	Reference level
^{54}Mn [µBq/m^3]			6,5 1	14,7 6,3 - 23; 2							**-**
^{137}Cs [µBq/m^3]	7,3 5,5 - 9,1; 2	10,1 4,1 - 23; 3	2,8 2,5 - 3; 2	3,5 2 - 5; 2	5,0 1,7 - 10; 4	7,6 1,7 - 14; 3	4,1 2,5 - 9; 9	4,5 1 - 7,7; 8	3,1 1,1 - 5; 9	6,7 2,6 - 10; 4	**29,5**
^{60}Co [µBq/m^3]		9,5 1	20,0 1	43,0 7 - 64; 3		3,4 1	9,3 2,7 - 23; 4	3,7 1,6 - 5,7; 2	3,2 1,1 - 4,3; 3		**-**
^{58}Co [µBq/m^3]							19,2 4,4 - 34; 2				**-**
^{14}C (CO_2) [mBq/m^3]	43,1 41,3 - 45,3; 128		42,9 42,1- 44,6; 23	43,6 41,7 - 51; 125	42,2 41,6 - 42,7; 12	43,1 41,7 - 45,5; 127	42,2 41,7 - 43,2; 12	43,3 41,6-45,2; 127	42,7 40,8- 45,2; 24	43,0 41,5 - 44,68; 126	**42,9**
^{14}C (CO_2 + C_nH_m) [mBq/m^3]	43,7 42 - 45,49; 124		46,2 42,3 - 53,7; 129	44,6 42,3 - 55,3; 128	43,7 42,8 - 44,5; 12	43,5 42,8 - 45,1; 23	44,0 42,5 - 47,6; 12	44,0 42 - 46,7; 128	43,4 42,5 - 45; 24	42,9 41,8 - 44,2; 120	**44,0**
^{3}H (HT+HTO) [mBq/m^3]*	12,9 4,06 - 37,8; 48"			21,6 3 - 57; 48"		14,3 0,47 - 46; 48"		18,3 4 - 55; 48"		10,7 1 - 43; 48"	**24,1**
^{90}Sr [µBq/m^3]										8,9 1,3 - 27; 74	**8,9**
^{131}I [µBq/m^3]	236,3 8,2 - 701; 6	255,7 7,2 - 820; 6	278,5 10,7 - 711; 5	301,3 10,7 - 801; 5	278,7 11,6 - 684; 5	336,5 10,5 - 785; 5	279,5 13,5 - 789; 5	280,4 16 - 711; 5	276,6 13,9 - 688; 5	368,3 14,4 - 1013; 5	**-**

*Data obtained between 2005-2008.

Table 20.2.1-26: Measurement results for air samples.

Fallout sample measurements:

Nuclide / Station	A1	A2	A3	A4	A5	A6	A7	A8	A9	B24	Reference level
^{137}Cs [Bq/m^2]	0,3 0,07 - 0,8; 8	0,3 0,09 - 1,24; 9	0,7 0,1 - 1,4; 3		0,3 0,3 - 0,4; 4	0,2 0,1 - 0,4; 5	0,2 0,1 - 0,3; 3		0,2 0,1 - 0,3; 5	0,3 0,2 - 0,4; 2	**0,35**
^{60}Co [Bq/m^2]	0,2 0,1 - 0,3; 2	0,3 0,1 - 0,45; 5		0,3 1	0,4 0,1 - 1,9; 4		0,3 1		0,25 0,2 - 0,3; 2		-
^{131}I [Bq/m^2]	3,5 1,93 - 5,03; 2	2,7 2,31 - 3,02; 2	2,4 1,6 - 3,27; 2	2,9 2,94 - 2,94; 1	2,2 1,33 - 3,06; 2	2,2 1,27 - 3,14; 2	3,7 3,68 - 3,68; 1	3,6 3,6 - 3,6; 1	3,6 3,61 - 3,61; 1	1,7 1,69 - 1,69; 1	-

Table 20.2.1-27: Fallout activity near the nuclear power plant.

Soil sample measurements:

Nuclide / station	A1	A2	A3	A4	A5	A6	A7	A8	A9	B24	Reference level
^{90}Sr [Bq/kg]	2,8 1,2 - 9,3; 22	1,6 0,72 - 3,2; 22	1,3 0,24 - 2,4; 21	2,1 0,54 - 6,1; 22	1,6 0,53 - 3,1; 22	2,9 1,2 - 8,1; 22	2,2 0,54 - 4,7; 22	1,6 0,39 - 3,6; 20	1,6 0,57 - 3,3; 22	1,7 0,9 - 2,6; 22	**1,8**
^{137}Cs [Bq/kg]	1,6 0,36 – 4,4; 6	3,1 0,23 – 8,4; 8	1,3 0,2 – 3,29; 10	0,7 0,4 – 0,9; 4	1,6 0,52 – 2,6; 5	2,1 0,6 – 7,5; 6	2,6 0,77 – 10; 7	1,1 0,8 – 1,4; 3	0,7 0,3 – 1,11; 6	3,3 0,7 – 13; 5	**9,7**

Table 20.2.1-28: Soil sample activity concentration near the nuclear power plant.

Grass sample measurements:

Nuclide / Station	A1	A2	A3	A4	A5	A6	A7	A8	A9	B24	Reference level
^{90}Sr [Bq/kg]	0,6 0,2 - 1,7; 16	0,5 0,16 - 0,7; 15	0,6 0,27 - 1,1; 14	0,4 0,17 - 0,92; 20	0,6 0,2 - 1,8; 19	0,7 0,18 - 2,2; 19	0,8 0,2 - 2,7; 20	0,5 0,2 - 0,81; 17	0,5 0,16 - 0,83; 20	0,9 0,45 - 2,6; 17	**1,7**
^{137}Cs [Bq/kg]	13,7 1,6 - 23; 21	8,4 0,71 - 29; 21	5,0 1,25 - 15; 21	7,0 0,3 - 12,2; 21	7,6 3,9 - 15; 21	12,1 1,38 - 38; 21	6,6 0,38 - 21; 21	5,6 0,2 - 11; 21	4,5 1,42 - 12; 21	8,6 0,88 - 15; 21	**0,66**

Table 20.2.1-29: Grass sample activity concentration near the nuclear power plant.

Environmental equivalent dose rate measured with TLD:

Station	***Dose rate [nSv/h]***	***Years***
A1	*65,5* *46 - 82; 130*	*2001-2011*
A2	*66,6* *57 - 78; 128*	*2001-2011*
A3	*73,3* *60 - 88; 130*	*2001-2011*
A4	*77,0* *64 - 100; 128*	*2001-2011*
A5	*73,8* *49 - 92; 130*	*2001-2011*
A6	*68,7* *54 - 82; 129*	*2001-2011*
A7	*63,8* *51 - 75; 130*	*2001-2011*
A8	*82,2* *65 - 110; 130*	*2001-2011*
A9	*66,4* *52 - 85; 130*	*2001-2011*
B24	*82,1* *63 - 104; 128*	*2001-2011*
C10	*80,7* *34 - 101; 130*	*2001-2011*
C11	*71,1* *57 - 87; 129*	*2001-2011*
C12	*77,2* *61 - 95; 130*	*2001-2011*
C13	*79,2* *59 - 99; 130*	*2001-2011*
C14	*67,7* *54 - 89; 130*	*2001-2011*
C15	*80,0* *64 - 100; 130*	*2001-2011*
C16	*81,1* *62 - 103; 130*	*2001-2011*
C17	*85,3* *65 - 105; 130*	*2001-2011*
C18	*85,9* *60 - 116; 130*	*2001-2011*
C19	*70,4* *47 - 98; 128*	*2001-2011*
C20	*84,7* *51 - 107; 130*	*2001-2011*
C21	*69,8* *58 - 118; 130*	*2001-2011*
C22	*88,3* *73 - 112; 129*	*2001-2011*
C23	*80,5* *61 - 98; 130*	*2001-2011*
L25	*72,7* *60 - 134; 129*	*2001-2011*
Average	*75,8*	*2001-2011*
Reference level based on JERMS	***78***	***2001-2011***

Table 20.2.1-30: Environmental equivalent dose rate measured with TLD.

According to JERMS data, the reference level of environmental dose rate is 78 nSv/h.

20.2.1.2.2 Radiological conditions of the subsurface aquatic environment – Groundwater measurement results

On the site of the Paks NPP and in its neighborhood, sampling wells were constructed at several locations, in order to allow the measurement of ^{3}H and other radioactive isotope activities in groundwater. In samples taken at places within The relationship of the age and sex standardized cancer diseases (2007-2009) and cardiovascular diseases (2009) and the regression analysis of the distance to the power plant corrected by the socio-economic status of the settlements smoothed by empirical Bayesian estimationthe site perimeter tritium could be detected showing large fluctuations. The maximum values varied between 2 and 8 020 Bq/ dm^3, the minimum values between 1 and 136 Bq/ dm^3, whereas the averages changed between 2 and 2 326 Bq/dm^3 as a function of season, water level and flow velocity.

The location of each sampling well is indicated in Figure 20.2.1-3, which also makes it clear that outside the site only data from 4 sampling wells can be discussed, the rest are to be found within the operating area of the Paks NPP.

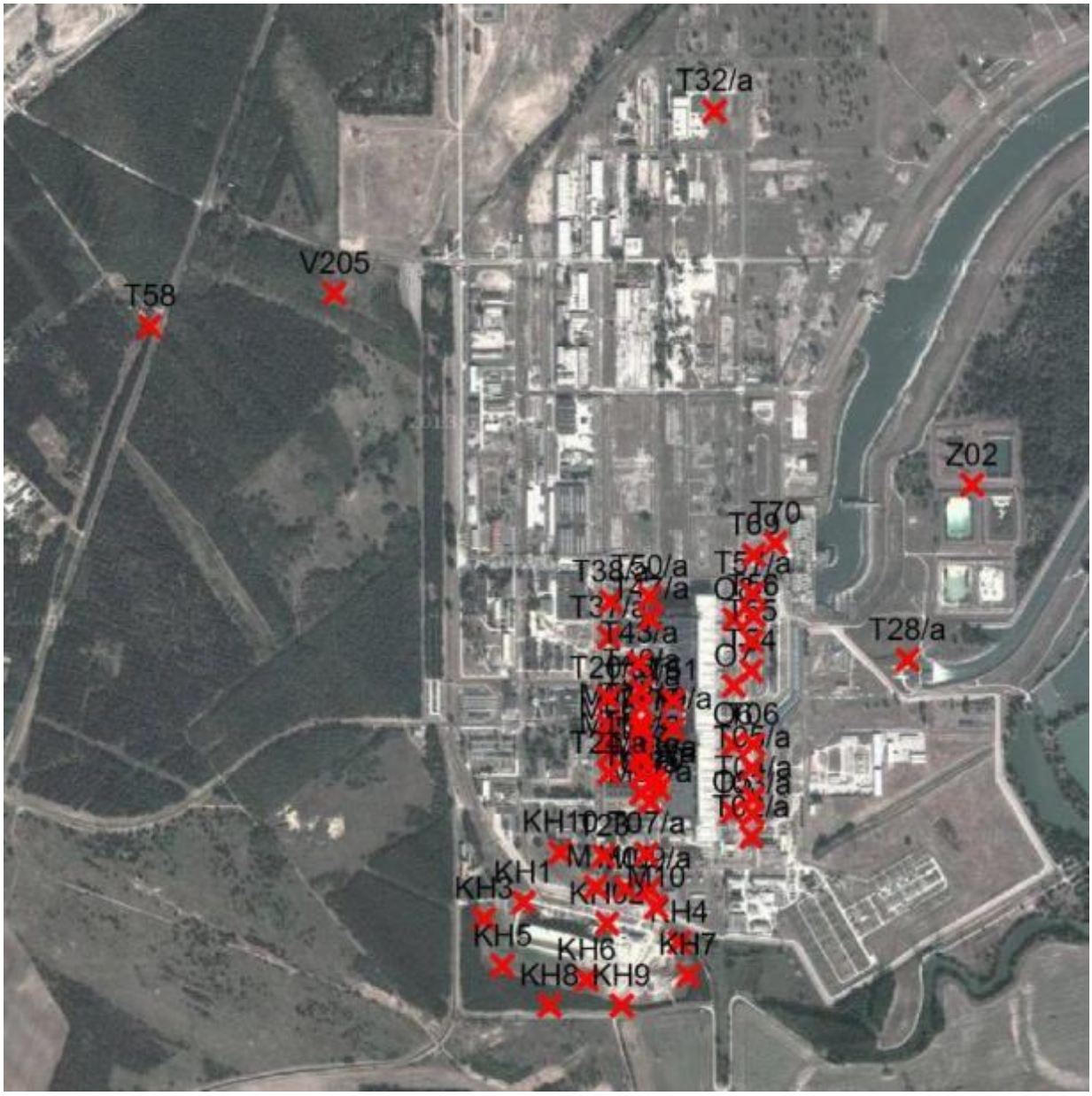


Figure 20.2.1-3: Location and marking of tritium sampling wells.

The characteristics of the values obtained at the four measuring points are presented in Table 20.2.1-31. From these values one may conclude that the mean of the values measured in groundwater is very close to the average tritium concentrations found in natural groundwater. No significant tritium concentration increase can be demonstrated outside the site.

Well mark	Minimum [Bq/dm^3]	Maximum [Bq/dm^3]	Average [Bq/dm^3]	Reference level [Bq/dm^3]
T32/a	1	13	2,95	**2,95**
Z02	1	96	4,36	**4,36**
T58	1,4	6,4	2,92	**2,92**
V205	1,4	4,5	1,94	**1,94**

Table 20.2.1-31: Mesurement results observed in samples taken from tritium monitoring wells.

The measurements and modeling studies of Isotoptech Zrt. furnished the following general purpose conclusions:

- Tritium flow is mainly directed N – NE in the close neighborhood of the main building of the Paks NPP.
- The exposure propagation direction is perturbed by high Danube water levels. High levels turn the flow direction towards N – NW and exposure propagation stops, while its area widens westward, too.
- Near the now repaired waste water pipe – manifesting a breakdown earlier – significant concentration gradient was built up.
- In the power plant area, scattered local hubs were formed. The results of well data do not prove that an extended region characterized by significant tritium concentration indeed stretches underneath the central power plant building.
- The presence of local hubs beneath the main building block cannot be excluded, however, any major effect exerted by these on more sparsely placed wells further away from the building can be ruled out.
- Apart from tritium, only a small amount of ^{14}C was detectable, no other artificial origin radionuclides were observed in groundwater wells.
- Measurement results suggest that tritium activity concentrations are gradually reducing.

20.2.2 YR 2012 STUDY OF RADIOISOTOPE OCCURRENCE IN THE 30 KM RADIUS AREA

To determine the current status (radioisotope concentrations) of the 30 km radius surrounding area, 5 test locations were selected to perform the following measurements:

- in-situ gamma spectrometry measurement (50 tests),
- gamma dose rate measurement (50 tests),
- soil activity concentration measurement (performed on 50 pcs samples taken from 0-5 cm deep topsoil layer to determine gamma-emitting isotopes and ^{90}Sr),
- grass, sedge and tree bark activity concentration measurement (performed on 50 pcs of samples to determine gamma-emitting isotopes and ^{90}Sr).

20.2.2.1 Lifetime extension test locations

The tests were performed within the framework of the Paks NPP lifetime extension environmental rationale project, at the following potential accumulation points identified on a morphological basis:

Test location I (sector 8 – 4.9 km): Found in an E-W directed, 200-300 m wide, 1 km long, 1.5 m deep meander[2] bending in arc. Ca. 70% of the meander surface is subject to agricultural cultivation, the actual canal bank is lined with patches of willow arbor.

Test location II / sector 7 – 4.1 km): Placed in a NE-SW directed, 150-200 m wide, 500-600 m long, 1.5 m deep no outlet (closed drainage) meander. The measuring point is located directly on the meander axis. Area subject to agricultural exploitation.

[2] *The meander represents a controlled, flood-free riverbed type.*

Test location III (sector 7 – 2.7 km): Found in a flat, low-lying flood zone level, on a one-time belt shoal. The surface lying at 91.8 m asl altitude, covered with meadow black soil (chernozem) is subject to argicultural exploitation.

Test location IV (sector 7 – 1.4 km): Located right next to the nuclear power plant (near Lake Kondor). The measuring point is characteristic from the geo-ecological perspective, being in a N-S sloping, 50-100 m wide no outlet meander, representing the meander type influenced by periodic, seasonal groundwater effects. Its close-to-natural vegetation consists of meadow and mountain communities, its neighbourhood is subject to argicultural exploitation.

Test location V (sector 3 – 3.2 km): Found in a municipal environment, in the direct neighbourhood of the community of Dunaszentbenedek (termed "Dunaszentbenedek pasture"). Along the rows of houses, on the 92 m asl altitude high flood zone surface intense pastureland farming is practised. The manured pasture itself is characterized by close-to-natural grassland (phyto)communities. The monotony of the surface is broken by 5 m deep, 2-5 m wide silted one-time meanders articulating the high flood zone surface.

The measuring points associated with the test locations were selected by applying the criteria below:

- The selected measuring point and its immediate surroundings should be in an unperturbed area, if possible
- The vegetation found at the selected measuring point should by characteristic of the investigation area
- The 5 measuring points together should cover the entire investigation area
- The selected points should coincide with potential accumulation points

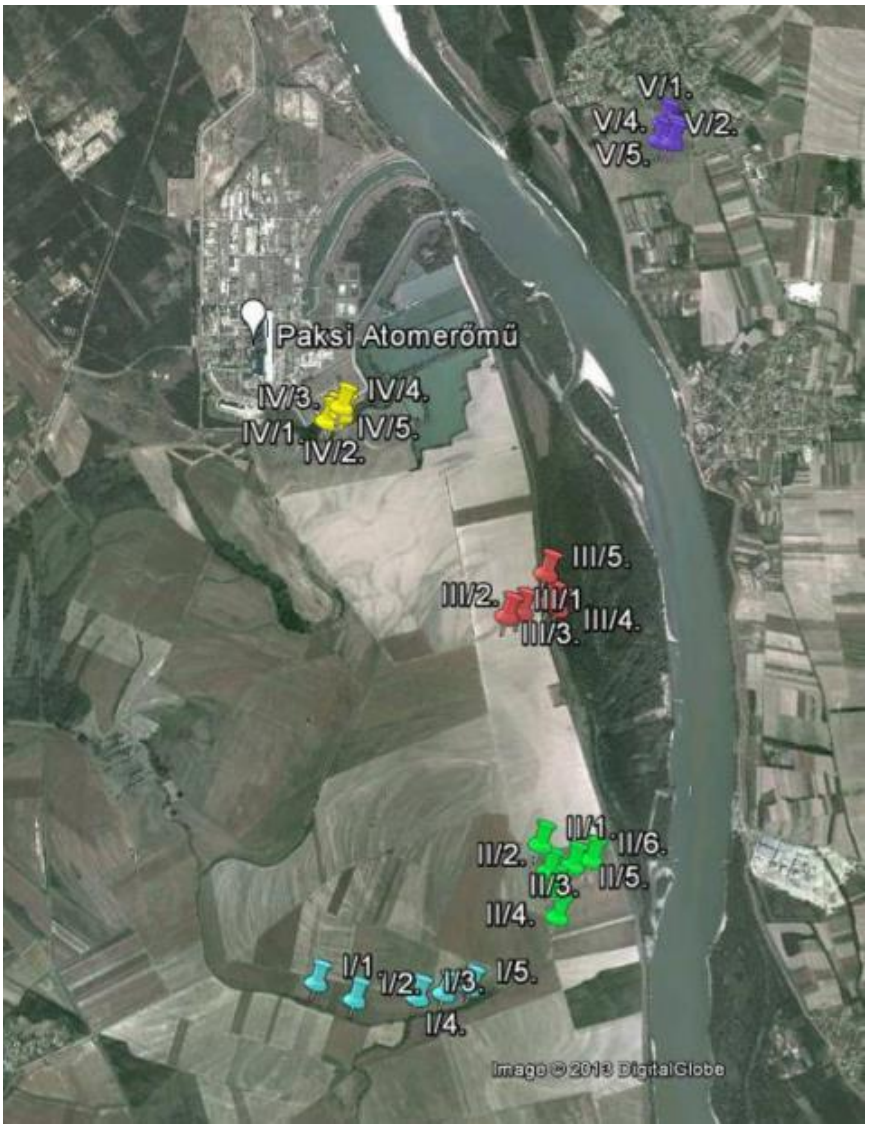


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Figure 20.2.2-1: Satellite image of the sampling locations defined in the program.

Using the selected measuring locations, soil and plant samples were taken in two stages of the vegetation cycle (spring-summer and late summer-autumn) in order to determine their radionuclide concentration.

Taking the defined 5 test locations and using 5-5 sampling points, for each locally typical plant cover (grass, sedge, agricultural plant, tree bark, etc.) samples plus subsoil samples from under the vegetation were obtained.

Once the samples were processed, gamma spectrometry measurements were used to determine natural and artificial gamma-emitting isotopes, the gross-beta and potassium concentrations applied during environmental monitoring and suitable for monitoring, and the activity concentration of ^{90}Sr in the samples subsequent to digestion.

Laboratory measurement:

- Soil activity concentration measurement (50 pcs of samples measured for gamma-emitting isotopes and ^{90}Sr),
- Grass, sedge and tree bark activity concentration measurement (50 pcs of samples measured for gamma-emitting isotopes and ^{90}Sr).

20.2.2.2 Test results

In Table 20.2.2-1 and Table 20.2.2-2 below, the average values and the single standard deviations calculated from them using the laboratory radioactivity measurements of plant and soil samples taken at selected sampling points around the Paks NPP are presented by nuclide and test orientation for each test location. Further, the tables show the minimum and maximum values measured for samples at each test location. Where no deviation value is indicated, there the given radionuclide was detectable in at most two samples.

Plant Bq/kg dry mass	**Average ± deviation (min. – max.)**				
	Location I	**Location II**	**Location III**	**Location IV**	**Location V**
Spring					
Gross-beta	943 ± 24 % (663 – 1236)	540 ± 22 % (409 – 693)	651 ± 13 % (556 – 785)	757 ± 21 % (641 – 1023)	637 ± 9 % (538 – 684)
^{90}Sr	0,65 ± 50 % (0,41 – 1,19)	0,95 ± 41% (0,75 - 1,44)	0,86 ± 20 % (0,67 – 1,10)	1,47 ± 79 % (0,11 – 3,25)	0,79 ± 56 % (0,10 - 1,18)
^{137}Cs	0,12 (0,12 – 0,12)	0,23 (0,23 – 0,23)	0,33 ± 47 % (0,15 – 0,42)	BDL* (0,26 – 0,46)	0,49 ± 31 % (0,31 – 0,63)
^{40}K	1040 ± 20 % (818 – 1298)	654 ± 63 % (498 – 888)	755 ± 21 % (576 – 1015)	903 ± 20 % (698 – 1149)	760 ± 8 % (691 – 858)
^{7}Be	99 ± 41 % (44 -145)	184 ± 87 % (103 -352)	159 ± 59 % (43 - 267)	166 ± 14 % (129 – 196)	179 ± 29 % (139 – 262)
Autumn					
Gross-beta	488 ± 13 % (436 – 596)	593 ± 74 % (344 – 946)	786 ± 28 % (521 – 1073)	492 ± 52 % (226 – 912)	659 ± 52 % (375 – 1227)
^{90}Sr	0,85± 20 % (0,56 – 0,97)	1,27 ± 50 % (0,46 – 2,00)	0,72 ± 39 % (0,42 – 1,09)	1,60 ± 17 % (1,37 – 1,96)	1,47 ± 45 % (1,06 – 2,65)
^{137}Cs	0,26 ± 6 % (0,25 – 0,28)	0,57 (0,56 – 0,57)	0,97 (0,57 – 1,37)	0,33 (0,28 – 0,38)	0,79 (0,45 – 1,13)
^{40}K	513 ± 22 % (433 – 702)	840 ± 71 % (529 – 1304)	789 ± 41 % (517 – 1260)	558 ± 47 % (281 – 983)	800 ± 56 % (400 – 1439)
^{7}Be	284 ± 16 % (230 – 341)	300 ± 59 % (255 – 382)	230 ± 39 % (99 – 329)	187 ± 32 % (113 – 263)	292 ± 24 % (217 – 386)

Table 20.2.2-1: Averages calculated from laboratory measurement results of plant radioactivity by test location.

Soil Bq/kg dry mass	Average ± deviation (min- max.)				
	Location I	**Location II**	**Location III**	**Location IV**	**Location V**
Spring					
Gross-beta	631 ± 15 % (498 – 716)	671 ± 7 % (611 – 712)	582 ± 11 % (507 – 644)	474 ± 10 % (410 – 529)	588 ± 5 % (557 – 630)
^{90}Sr	1,10 ± 32 % (0,51 - 1,37)	0,40 ± 77% (0,09 – 0,68)	0,37 ± 40 % (0,12 – 0,50)	0,75 ± 57 % (0,41 – 1,47)	0,97 ± 25 % (0,54 – 1,13)
^{137}Cs	14 ± 41 % (4,7 – 18,6)	11 ± 44 % (7,4 – 17,7)	7 ± 44 % (5,0 – 12,5)	8 ± 59 % (3,5 – 15,5)	18 ± 36 % (7,1 – 22,7)
^{40}K	497 ± 6 % (448 – 515)	540 ± 6 % (499 – 577)	462 ± 6 % (434 – 505)	397 ± 6 % (367 – 429)	472 ± 6 % (437 – 507)
^{7}Be	5,1 (5,1 – 5,1)	6,3 (4,8 – 7,7)	4,7 (4,7 – 4,7)	2,4 (2,4 – 2,4)	BDL* (7,5 – 16,7)
^{232}Th series	28 ± 9 % (24 – 32)	31 ± 5 % (29 – 34)	27± 13 % (21 – 33)	20 ± 13 % (16 – 23)	26 ± 9 % (22 – 30)
^{238}U series	26 ± 6 % (23 – 28)	32 ± 8 % (29 – 36)	28 ± 12 % (22 – 30)	21 ± 12 % (17 – 24)	28 ± 9 % (24 – 34)
Autumn					
Total beta	694 ± 10 % (601 – 788)	682 ± 5 % (651 - 724)	653 ± 13 % (544 – 751)	481 ± 13 % (416 – 573)	635 ± 8 % (587 – 701)
^{90}Sr	0,38± 55 % (0,11 – 0,67)	0,62 ± 35% (0,40 – 0,87)	0,39 ± 39 % (0,15 – 0,56)	0,48 ± 14 % (0,39 – 0,55)	0,85 ± 47 % (0,50 – 1,54)
^{137}Cs	15 ± 44 % (3,3 – 18,4)	11 ± 38 % (7,3 – 15,1)	8 ± 35 % (5,3 – 13,2)	8 ± 68 % (3,3 – 16,8)	15 ± 61 % (3,6 – 26,9)
^{40}K	550 ± 5 % (518 – 583)	550 ± 3 % (535 – 571)	479 ± 8 % (443 – 534)	396 ± 7 % (362 – 429)	457 ± 8 % (414 – 510)
^{7}Be	2,3 (2,3 – 2,3)	7,3 (7,3 – 7,3)	6,5 (3,9 –9,1)	BDL* (4,3 – 10,8)	10,3 (10,3 – 10,3)
^{232}Th series	32 ± 5 % (29 – 34)	31 ± 6 % (28 – 34)	28 ± 12 % (23 – 34)	20 ± 22 % (15 – 28)	25 ± 10 % (21 – 28)
^{238}U series	35 ± 6 % (32 – 38)	35 ± 5 % (32 – 37)	28 ± 11 % (24 – 33)	23 ± 26 % (16 – 35)	27 ± 10 % (22 – 29)

Note:
* 'BDL' indicates where the values obtained for samples at every measuring point were below detection level.

Table 20.2.2-2: Averages calculated from laboratory measurement results of soil radioactivity by test location.

The reference level was determined for the long half-life radionuclides of the 5 measuring locations and the two seasons (see Table 20.2.2-3). It should be noted that the reference levels quoted here differ from those obtained from the PERMS and JERMS databases, as the present levels were derived from a smaller set of results.

Nuclide	Reference level (Bq/kg)	
	Soil	**Plant**
^{90}Sr	**0,63**	**0,93**
^{137}Cs	**11,5**	**0,45**
^{40}K	**480,0**	**761,2**
^{232}Th series	**26,8**	**-**
^{238}U series	**28,3**	**-**

Table 20.2.2-3: Soil and plant reference level values of the test locations.

^{238}U series and ^{232}Th series

Soil and sludge samples

In the soil samples taken in the 30 km radius area around the Paks NPP, the activity concentration of the elements of the natural ^{238}U series (^{214}Pb and ^{214}B) and those of the ^{232}Th series (^{228}Ac and ^{208}Tl) were typically between 25-35 Bq/kg, with an average of 29 Bq/kg. The only values that departed appreciably from this were measured at test location IV near Lake Kondor (merely 20-22 Bq/kg). Considering all tested samples, the minimum – maximum values were in between 16-34 Bq/kg.

The reference values published in the UNSCEAR Report [20.2-13] for soils in Hungary are: averages (and minimum - maximum ranges) for ^{238}U series elements: 29 Bq/kg (12-66 Bq/kg); ^{232}Th series elements: 28 Bq/kg (12-45 Bq/kg). The measured results showed a good fit to the default values.

^{40}K

Soil and sludge samples

In the soil samples taken in the 30 km radius area around the Paks NPP, the lowest activity concentration of the ^{40}K radioisotope was observed at test location IV, being 397 Bq/kg on the average. The same indicator in the samples taken from the rest of the test locations showed an average of 501 Bq/kg. Considering all tested samples, the minimum – maximum values were in between 362-583 Bq/kg.

The reference values published in the UNSCEAR Report [20.2-13] for the specific ^{40}K activity of soils in Hungary are: average (and minimum - maximum range): 370 Bq/kg (79 – 570 Bq/kg).

Plant samples

In the plant samples taken in the 30 km radius area around the Paks NPP, the concentration of ^{40}K was measured between 281 and 1439 Bq/kg. The ^{40}K concentration of plants manifested a seasonal change, because the samples collected in springtime showed (apart from a few exceptions) higher measured dry mass projected ^{40}K activity concentration than samples taken in autumn. The average values calculated for plants examined in spring (autumn) were 822 Bq/kg (700 Bq/kg), respectively. For the sake of comparison, the ^{40}K content of grass samples taken from the OSSKI courtyard between 2009 and 2012 gave an average of 820 Bq/kg. Looking at the individual values, it was obvious that these were scattered within a wide range: notably between 223-1182 Bq/kg, which led to the corollary that the K uptake of plants is influenced by a number of factors.

^{7}Be

Soil samples

The ^{7}Be activity concentration of soils was, with the exception of one or two samples, invariably below detection level, that is, < 6-10 Bq/kg.

Plant samples

In contrast, the ^{7}Be activity concentration of plants was readily measurable. The average of ^{7}Be activity concentration derived for all plant samples taken within a 30 km radius area around the Paks NPP was 208 Bq/kg, the measured values ranged between 43 – 386 Bq/kg. The specific activity of ^{7}Be again showed seasonal variations. Concentrations were double in plant samples taken in autumn on the average with respect to their spring counterparts. To be specific, the average values measured for spring and autumn samples were 158 Bq/kg and 259 Bq/kg, respectively. This can presumably be explained (among others) by the observation that autumn sampling coincided with a rainy period while spring sampling was done in dry weather.

Gross-beta activity concentration

It can be stated in general that the gross-beta activity concentration measured in soil and plant samples originated for the majority of them in 80 – 95 % from their ^{40}K content, thus the two values showed good correlation.

Soil and mud samples

The average gross-beta activity concentration of soil samples taken within a 30 km radius area around the Paks NPP was 612 Bq/kg. The measured values varied within the 410 – 788 Bq/kg range.

Plant samples

The average gross-beta activity concentration of plant samples taken within a 30 km radius area around the Paks NPP was 706 Bq/kg in springtime, and 604 Bq/kg in autumn. The measured values varied within a broader range, between 226 – 1236 Bq/kg. It is also clear that the seasonal variations described for the case of the ^{40}K isotope naturally appeared through these values, too.

^{137}Cs and ^{90}Sr

Soil and sludge samples

In the soil samples taken in the 30 km radius area around the Paks NPP, the highest ^{90}Sr and ^{137}Cs activity concentrations (1.0 Bq/kg and 15 Bq/kg, respectively on the average) were measured at test locations I and V, whereas the lowest ones were obtained for test location III (0.4 Bq/kg and 7 Bq/kg on the average). It is to be noted that the measuring points of test locations I and V happened to be located within one meander each, therefore the status of the areas concerned corresponded best to what is deemed natural. The measuring points of test locations II and III were placed in cultivated agricultural areas, and the soil concentration values measured there were usually below those measured for the other test locations. The measuring points selected here were wedged in cultivated agricultural areas. In contrast, measuring points III/4 and III/5 were defined next to the flood protection bank, where the soil activity concentration of ^{137}Cs approached that of the areas left in their original natural state. It is worth pointing out that only areas conserved in their natural status, in particular meanders, can behave as accumulation places, as all the other areas are constantly perturbed.

Based on the outcome of soil measurements, it can be concluded that the meanders found at test locations I and V may have played the role of accumulation points. This is also supported by the fact that the results of measurements at the same location but outside the meander produced lower results (see point V/2).

Similarly, measuring point IV/1 – in the ditch stretching along the prolongation of the Lake Kondor bed, right next to a causeway - showed features typical for accumulation points. Here effects of surface downwash may also have played a role. The activity concentrations of ^{90}Sr and ^{137}Cs measured in soil (1.0 and 16.1 Bq/kg on the average) were higher here that at the rest of the measuring points of test location IV. The concentration values obtained for the latter points did not deviate markedly from the measurement results of cultivated areas.

In general, it can be stated that no seasonal variation can be expected in the measurement results of spring and autumn soil samples, unless fallout caused by some radiology event or some other outside artificial intervention takes place (e.g. the soil is disturbed by ploughing).

However, in mud samples - in contrast to soil results – the measured values of both ^{90}Sr and ^{137}Cs isotope concentrations turned out to be lower. In mud samples, the average ^{90}Sr activity concentration was 0.30 Bq/kg within a 0.06 – 0.62 Bq/kg minimum - maximum range, whereas the average ^{137}Cs activity concentration was 5.9 Bq/kg with a 0.7-15.8 Bq/kg deviation range. For the sake of comparison, the average of ^{90}Sr activity concentrations measured in Lake Balaton mud was 0.92 Bq/kg (within a 0.16 – 3.24 Bq/kg minimum - maximum range), while that of the ^{137}Cs isotope was 45 Bq/kg on the average, the values falling into the 4 – 123 Bq/kg range. In Lake Velence mud, the average ^{90}Sr activity concentration was 4.39 Bq/kg (within 0.41 – 22.7 Bq/kg minimum-maximum range), and average ^{137}Cs concentration was 31 Bq/kg (with all values within the 3 – 73 Bq/kg range).

Plant samples

Considering the plant samples taken in the 30 km radius area around the Paks NPP, the highest ^{137}Cs concentrations (0.6 Bq/kg average) were again measured in samples from test location V, but the lowest values (0.2 Bq/kg) were obtained for samples collected from test location I. The concentration of ^{90}Sr was highest in samples taken from test location IV (1.5 Bq/kg). The average activity concentration calculated from the results of all plant samples gives 0.44 Bq/kg for ^{137}Cs, and 1.06 Bq/kg for ^{90}Sr.

The ^{137}Cs and ^{90}Sr activity concentrations of plant samples also showed an observable seasonal variation. The ^{137}Cs concentration of plant samples taken in autumn (0.58 Bq/kg on the average) was higher in almost all samples than in the ones collected in spring (0.30 Bq/kg on the average), while in terms of ^{90}Sr concentration the same was also true for the majority of samples (autumn average 1.18 Bq/kg, spring average 0.94 Bq/kg).

20.2.3 SUMMARY

According to the JERMS database, and the Nuclear Environmental Control chapters of the Annual Radiation Protection reports published by the Paks NPP, during the period between 2001-2011 mainly the ^{3}H, ^{14}C, ^{90}Sr and ^{137}Cs artificial radionuclides could be detected in the different environmental samples (elements) originating from the area surrounding (0-30 km) the nuclear power plant. It can be assumed that the ^{90}Sr and ^{137}Cs radionuclides are not contributed by the nuclear power plant, but rather originate from the Chernobyl accident and atmospheric nuclear explosions. This view is also supported by evaluation analyses, which argue that the appearances and activity concentrations of the ^{90}Sr and ^{137}Cs radionuclides in particular environmental elements bear similarities with national measurement data issued by the RAMDAN laboratory and the NERMS system, therefore these obviously cannot be attributed to the Paks NPP.

The occurrence of tritium (^{3}H) and radiocarbon (^{14}C) can essentially traced back to global origin, too. Unfortunately, the available pertinent national coverage measurement database is of limited scope only, but a certain part of the values appearing around the nuclear power plant can be assigned to it for sure. Their occurrence on-site in subsurface waters is undoubtedly due to the nuclear power plant, but the extent of exposure is restricted to the site boundaries.

The environmental monitoring measurements revealed that the radionuclides typical of the nuclear power plant were appreciable in the detectable range only a few times in air, fallout, mud and soil samples; in fact, mostly ^{54}Mn, ^{60}Co, ^{58}Co and ^{110m}Ag radionuclides were observed. No alpha spectrometry measurements were performed on environmental samples.

The appearance of radioiodine nuclides was detected in cases when there was an operational failure in the nuclear power plant, when the impact of the Fukushima accident reached Hungary or the emissions of the Institute of isotopes were measured. At points further away from the power plant, the occurrence of radioiodine could be assigned to escape due to medical applications, too.

In addition to processing the data measured between 2001-2011, in 2012 in-situ gamma spectroscopy and gamma dose rate measurements were made in the vicinity of the nuclear power plant at 5 different test locations, plus soil and plant samples were taken to perform laboratory measurements. These measurements again only confirmed the ^{90}Sr and ^{137}Cs radionuclides in the different environmental samples. The presence of the ^{60}Co radionuclide in soil could be ascertained only once at one specific place (near the Paks NPP). In the same spirit, the measurements performed at these locations (defined as accumulation points due to morphological and wind direction considerations) in the 1990's could also detect radionuclides – namely ^{110m}Ag - in a couple of cases only.

Analyses were performed in order to find out what expected environmental activity levels will be observed in the individual environmental elements subject to the maximum measured emission values, and whether or not these can be determined at all with the detection levels of the measuring instruments currently in use. In the final analysis, it was concluded that only a very limited number of radionuclides (tritium, radiocarbon) could be detected in the power plant area from airborne emissions. Regarding water discharges, again probably only radiocesium could be detected in fish samples among the isotopes involved in the investigation.

Based on the above arguments, it can be concluded that it is impossible to attempt to assess the environmental effects of normal nuclear power plant releases, including the behavior of radionuclides in the environment, by measurements, or to describe their movements and migration through particular environmental elements. Environmental gamma dose rates also supports the statement that no places with elevated values can be found in the nuclear power plant area.

20.3 HEALTH STATUS OF THE POPULATION LIVING IN THE STUDIED 30 KM RADIUS AREA

By examining the health status of people living in the vicinity of the site should the incidence of diseases potentially related to ionizing radiation be evaluated among the population living within 30 km radius of the site. The analysis should answer the question whether additional risks can be linked to the Paks Nuclear Power Plant based on the pattern of certain diseases.

We carry out the assessment and determination of the health status of people living in the vicinity of the site:

- cause-specific mortality (for 10 years),
- mortality established based on hospital care because of cancer (for 3 years),
- incidence of developmental disorders (for 3 years),

- incidence based on non-cancer diseases with genetically component needing medical care (for 5 years)
- mortality established based on hospital care because of cardiovascular diseases (for 1 year),

The main task of the study was not to measure the induced effect, but the demonstration that the health of people living near the nuclear power plant is not at risk. The expositions suitable to induce time limited and acute physiological effects can be excluded (the health evaluation status should also not focuses on the exploration of such effects), thus no specific study end point exists (there is no possibility to organize a study taking into account the dose, the timing and the persons exposed). The development of tumors, of cardiovascular diseases is a long process. The time till the clinical appearance shows a significant individual variability (even in case of an exposure with the same timing and dose no onset of focused appearance of the induced effects is expected), thus by the designation of the endpoints it should not be focused on the short by significant doses but on the effects of the low doses. Therefore the test period should be determined in the way to have a large enough number of cases to be able to detect the possible potential risks by statistics (the endpoints have been selected accordingly). The case numbers of the morbidity detected based on the mortality, the hospital patient flow are significantly different. It is advisable to define a longer time period to the lower case number of mortality (in case of non-cancer diseases due to the higher incidence a shorter study period give ensured enough data for the statistics). The theoretical progress of the study was therefore to demonstrate in a first step the security (there is no health loss which could be linked to the vicinity of the power plant). If at this endpoint there is any suspicion regarding the additional risks, it will be needed to conduct an appropriate target study (which will require a significant financial resources and significant public cooperation) according to the environmental health practice.

The study was carried out in two phases. The first phase is to be carried out based on the available databases in a manner to ensure an appropriate benchmark (base line) for the further studies. The general practitioners were involved in the second phase of the study. It should be clarified at this state how the data based on the processing of these databases cohere, how they can be corrected based on the lifestyle factors, the family history and other confounding factors.

20.3.1 STUDY PHASE 1, DATABASE PROCESSING

20.3.1.1 Delimitation of study areas

For this study, the impact area can be designed in different ways. In principle, dose maps can be created using the time series concerning the nature of emission and the factors influencing the conditions of expansion; the exact impact area can be determined based on these maps.

Since health risks associated with the environmental impact has not been observed, the theoretical impact area can be defined by circles around Paks Nuclear Power Plant; the radius of these circles should be determined to comply with the widespread expectations.

At the start of the test a circle with a radius from 30 km around Paks Power Plant was considered as the impact area.

With the designation of test area we designed a potentially exposed population. Therefore the population within the 10 km radius (as potentially primary affected), in the 10-20 km zone (as potentially secondary affected) and the 20-30 km zone (as a control population able to reflect as the best the local conditions) are considered separately for the evaluation.

20.3.1.2 Study metholodology

The regulations do not specifically apply to the epidemiological related assessments. The standards do not fix processing methods. Regarding the methodology we considered the result published in the international literature as normative.

For the evaluations we considered as the primary reference the publication (Lawson A, Biggeri A, Böhning D, Lessafre E, Viel J-F, Bertollini R: Disease Mapping and Risk Assessment in Public Health, Wiley, 1999) resuming the results of the Biomed 2 project supported by the European Union and the European Office of the WHO.

Carrying out the task it was a decisive criterion that the potential changes in the health status, life quality of the affected population can be traced by epidemiological surveys and analyses.

The criteria were fulfilled according to Decree 23/2002. (V.9.) issued by the Ministry of Health on biomedical research on human beings.

Only indicators relating to diseases or disease groups form the basis of the report, which have an separate ICD (International Classification of Diseases) code, and which does not arise in the practice of reporting anomalies suggestive of differences in statistical data analysis for the reference population (namely, for which the international benchmarks do not point to a disproportionately large deviation to the Hungarian reference data; and for which in the reference population the regional differences and temporal trends do not indicate an incompatible disproportion of the nature of the disease).

20.3.1.3 Review of baseline input data

Diagnosis of the cause of death

For many years now the Central Statistical Office (CSO) in Hungary has collected the death test certificates on which the doctor declaring death records demographic data and the diagnosis of the cause of death.

The cause of death diagnosis - compared to conventional diagnosis - is not a statement of a disease, but a description of the process leading to death in accordance with the relevant rules. We consider the starting point in the disease process as an indicator during health monitoring, as assessments of the potential impacts of potential risk factors associated with the development of the disease are the fundamental objectives of the project.

The annual numbers of death cases observed in the settlements for 2001-2010 were made available by CSO in aggregated form.

Social status

Within the study area, the socio-economic status differences between the citizens of the settlements are significant. Since this status influences through the formation many elements of lifestyle the likelihood of diseases, these effects should be controlled through the study as confounding factor, the first step regarding this is the collection of the belonging data.

For the aggregated data analysis the source of the most reliable area-specific socio-economic status indicators is the database of the National Census which was last conducted in 2011; this database provides information on a wide range of the socio-economic situations. Thus during the program we will analyze the incidence of the diseases for which development an exposure for several years is needed, the status indicators from the census from year 2011 are suitable to meet the aims of the study.

Practically it is true for all diseases that in the maintaining of the pattern playing a role in the development of the disease the socio-economic status as a key role. Therefore, without the control of this factor the results of analyzes cannot be well understood.

The method which can be applied to this task is the Carstair-score. This score, which is tested in many ways and is commonly used in international practice, is based on the qualification, the unemployment, the income and the overcrowded housing situation and can be produced by using national census data for the studied settlements. We use elements of it's to correct the local risk.

- Educational index
- Level of comfort
- The number of dwelling per capita
- Rate of active employees
- Standardized indicators of the socio-economic status
- Adjusted local risks metrics

Population Register

The settlements population register was done by variable institutions over the past 10 year, but always ensuring legal continuity. The structure of the database resulting from the legal predecessors (BM Central Data Processing, Registration and Electoral Office, Management Development Department, Service Department), the method of collecting the data and the solution to made the data available were kept by the current institution in charge, Administration and Electronic Public Services Central Office (KEKKHs). During the program, knowledge about the indicators defined for each year and the calculation of the mid-year resident population demographic data is required, which can be produced using the data of the Administration and Electronic Public Services Central Office (KEKKHs).

In the demographic database for the settlements the population-related data are by age precision (for the 31th of December of each year), separated for men and women and for the years in the time period from 2001 to 2010. The data for the settlements within the impact area are compared to the expected case numbers calculated based on the total population of the country and are evaluated by means of standardization.

Developmental disorders

In Hungary the developmental disorders, almost unique in the world, are registered in a special register covering the entire country by a reporting system required by law. The quality of the register is indicated by the fact, that is it member of EUROCAT, which is the European Surveillance of Congenital Anomalies The data collection for the register is continuous for decades. The developmental disorders are recorded together with detailed classification and following the precise definition of the birth place, the date of birth and the domicile of the children. This is why the settlement specific risk indicators can be evaluated due to the reliable Hungarian register.

Outpatient and inpatient care

Every Hungarian service provider has to prepare an itemized performance accounting report about outpatient and inpatient care. The content of the reports is prescribed by law and their quality is guaranteed by the National Health Insurance Fund of Hungary (OEP). If the accounting report submitted does not meet the requirement it can then be returned to the supplier for correction and the payments will not be effected until the report does not meet the standards in form and content.

As the National Health Service is basically funding the healing under contracts with the National Health Insurance Fund, and the National Health Insurance Fund is the only fund, the special care database covers the entire patient database.

Access is provided to the data for the purpose of epidemiological investigations.

The unique identification is not possible, but as the system allows to set the connection between the events of a patient care, we obtained useful data for the program regarding important diseases.

Definition of the impact area

During the study we processed aggregated data according the settlements inside the impact area and data of the settlements grouped by their post code (Figure 20.3.1-1 and Figure 20.3.1-2). The population register is done at settlement level. The cause of death diagnosis and incidence of developmental disorders are also a data registered at settlement level, but the patient flow data are registered on base of the poste codes of the patients domicile's As there is not possible to map unambiguously the post codes and the settlement's name, we formed the most possible closed settlement groups at the processing of the performance accounting records.

Figure 20.3.1-1: Location of study area (a) within Hungary.

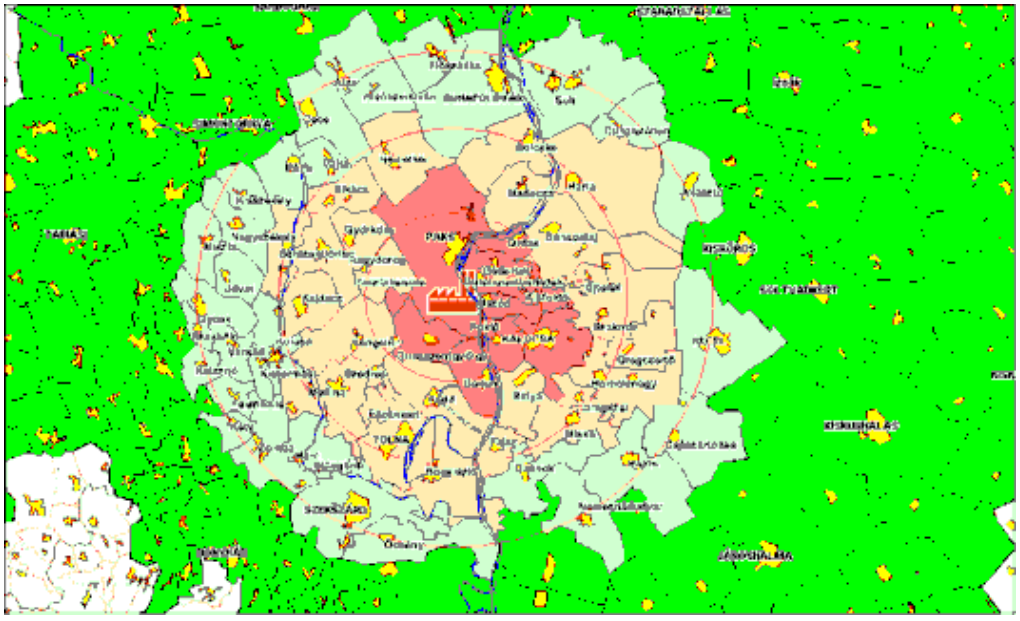


Figure 20.3.1-2: Municipalities located within the zones of the impact area.

The population within the 10 km radius (as potentially first affected), in the 10-20 km zone (as potentially affected second) and the 20-30 km zone (as control population able to reflect as the best the local conditions) are considered separately for the evaluation. The location of the settlements within the zones and the distance between the settlements and the power plant served as the base of the spatial arrangement of the of the risk conditions.

Data processing

During assessment of the relationship between mortality and morbidity we examined the relationship between the expected and reported cases. The first step of this analysis is the production of the standardized ratio by sex, age and the year of the examination:

- Indirect standardization
- Distance trend
- Evaluation of the impact of the socio-economic status

The aim of the indirect standardization is to obtain an incidence data which is expressing the morbidity / mortality risk in a population in the manner to be able to judge if it is high or low compared to the reference value regardless to the interference of the demographic composition.

In case of the distance trend analysis if the nuclear power plant sites already would act as a point of source of some health effects, then going away from it the frequency should decrease. We did not take into account the direction

dependence resulting from the nuclear power plant's emissions, because it would be difficult to achieve this in the affected area and the creation of a suitable information base for this would be circumstantial, so we analyzed the data in a circularly symmetric way.

The effects of the socio-economic status is important is important because, without the control of this factor the results of analyzes cannot be well understood.

20.3.1.4 Assessment of mortality risk near the nuclear power plant

The mortality data were processed according to the individual causes of death. For each cause of death the risk of death observed in Paks was evaluated and a statistical analysis of the deviation of the observed number of cases from the expected values was done.

Statistical evaluations were made of the observed from the mortality risk and its statistical results obtained from testing the reference level deviation in the settlements of the 30 km zone.

- Death caused by malignant diseases of the lip, oral cavity and pharynx
- Death caused by esophageal cancer
- Death caused by gastric cancer
- Death caused by colon cancer
- Death caused by rectum, sigmoid colon and anal cancer
- Death caused by other gastrointestinal cancer
- Death caused by trachea, bronchus and lung cancer
- Death caused by breast cancer
- Death caused by cervical and uterine cancer
- Death caused by brain cancer
- Death caused by Hodgkin's lymphoma
- Death caused by non-Hodgkin's lymphoma and leukemia
- Death caused by tumors
- Death caused by hypertension
- Death caused by ischemic heart disease
- Death caused by cerebrovascular diseases
- Morbidity caused by circulatory system diseases
- Death caused by diseases of the respiratory system
- Death caused by alcoholic liver disease
- Death caused by diseases of the gastrointestinal system
- Death caused by suicide and self-harm
- Death caused by external causes of morbidity and mortality
- Total mortality

By testing the cumulative risk of death and its deviation from the reference level (county) in each zones from 10 km and the local risks corrected by the socio-economic status and the assessment of the relationship between distance measured from the power plant the role of the power plant (Table 20.3.1-1 and Table 20.3.1-2) as the potential point source was tested.

c	Malignant tumor of the lip, oral cavity and pharyngis	Malignant tumor of the esophagus	Malignant tumor of the gastric cancer	Malignant tumor of the colon cancer	Malignant tumor of the rectum, sigmoid colon and anus	Other malignant tumor of the digestive organs	Malignant tumor of the trachea, bronchus and lung	Malignant tumor of the breast	Malignant tumor of the cervix and uterus	Malignant tumor of the brain	Hodgkin's lymphoma	Leukemia and non-Hodgkin's lymphoma
<10km	0,957	0,895	1,036	1,159	1,041	0,998	0,946	0,842	0,716	0,772	1,232	0,898
<20km	1,021	1,053	1,109	1,054	0,926	1,138	1,032	0,836	0,917	0,921	0,643	0,904
<30km	0,943	1,067	0,886	1,005	1,025	0,964	0,945	0,943	1,066	1,203	1,29	0,949
<10km	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
<20km	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
<30km	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

c	Tumors	Hypertension	Ischemic heart disease	Cerebrovascular diseases	Circulatory system diseases	Diseases of the respiratory system	Alcoholic liver disease	Diseases of the gastrointestinal system	Suicide and self-harm	External causes of morbidity and mortality	Total mortality
<10km	0,979	1,171	0,897	0,903	0,934	0,853	0,915	0,93	0,972	0,969	0,949
<20km	1,031	0,986	0,975	1,035	0,974	0,906	0,917	0,966	0,911	0,994	0,988
<30km	0,979	1,163	0,999	1,061	1,013	0,828	0,956	0,961	0,933	1,064	1,001
<10km	ns	high	low	low	low	low	ns	ns	ns	ns	low
<20km	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
<30km	ns	high	ns	high	ns	low	ns	ns	ns	ns	ns

ns: do not differ significantly from the reference level
low/high: differs significantly from the reference level

Table 20.3.1-1: Significance of cause-specific mortality risks standardized by aggregated age and sex data and their difference compared to the reference level within each zone (2001-2010).

	Malignant tumor of the lip, oral cavity and pharyngis	Malignant tumor of the esophagus	Malignant tumor of the gastric cancer	Malignant tumor of the colon cancer	Malignant tumor of the rectum, sigmoid colon and anus	Other malignant tumor of the digestive organs	Malignant tumor of the trachea, bronchus and lung	Malignant tumor of the breast	Malignant tumor of the cervix and uterus	Malignant tumor of the brain	Hodgkin's lymphoma	Leukemia and non-Hodgkin's lymphoma
Regression coefficient	0,0011	0,0003	0	-0,0001	-0,0002	-0,0001	0	0,0005	0	-0,0002	0,0005	0,0001
p	0,293	0,086	0,993	0,052	0,431	0,477	0,903	0,048	0,942	0,697	0,931	0,313

	Tumors	Hypertension	Ischemic heart disease	Cerebrovascular diseases	Circulatory system diseases	Diseases of the respiratory system	Alcoholic liver disease	Diseases of the gastrointestinal system	Suicide and self-harm	External causes of morbidity and mortality	Total mortality
Regression coefficient	0	-0,002	0,0004	0,0002	0,0008	0,003	0,0015	0,0011	0,0011	0,0004	0,0008
p	0,931	0,165	0,505	0,598	0,089	0,003	0,002	0,001	0,026	0,236	0,023

Table 20.3.1-2: The relationship of the age and sex standardized cause specific mortality risk and the regression analysis of the distance to the power plant corrected by the socio-economic status of the settlements smoothed by empirical Bayesian estimation (2001-2010).

20.3.1.5 Assessment of the registered incidence of developmental disorders near the nuclear power plant

The developmental disorders registered by the National Registry of Congenital Disorders (Veleszületett Rendellenességek Országos Nyilvántartása, VRONY) are processed according to the disorders groups. For each group the risk observed in Paks was evaluated and a statistical analysis of the deviation of the observed number of cases from the expected values was done.

Statistical mapped illustrations were made of the observed risks and their statistical results obtained from testing the reference level deviation in the settlements of the 30 km zone.

By testing the cumulative risk of incidence and its deviation from the reference level in each zone from 10 km and the local risks corrected by the socio-economic status and the assessment of the relationship between distances measured from the power plant the role of the power plant as the potential point source was tested.

- *Incidence of developmental disorders of the urogenital system*
- *Incidence of developmental disorders of the head and neck region*
- *Incidence of developmental disorders of the cardiovascular system*
- *Incidence of developmental disorders of the respiratory system*
- *Incidence of cleft lip and palate*
- *Incidence of developmental disorders of the gastrointestinal system*
- *Incidence of developmental disorders of the genitals*
- *Incidence of developmental disorders of the urinary, musculoskeletal system)*
- *Incidence of developmental disorders of the integumentary system*
- *Incidence of chromosomal abnormalities*
- *Incidence of developmental disorders*

By testing the cumulative risk of incidence and its deviation from the reference level (national) in each zones from 10 km (Table 20.3.1-3) and the local risks corrected by the socio-economic status and the assessment of the relationship (Table 20.3.1-4) between distance measured from the power plant the role of the power plant as the potential point source was tested.

zone	Q0 (Developmental disorders of the nervous system)	Q1 (Developmental disorders of the head and neck region)	Q2 (Developmental disorders of the cardiovascular system)	Q30-34 (Developmental disorders of the respiratory system)	Q35-37 (lip and cleft palate)	Q38-45 (Developmental disorders of the gastrointestinal system)	Q5 (Developmental disorders of the urogenital system)	Q6-7 (Developmental disorders of the musculoskeletal system)	Q8 (Developmental disorders of the integumentary system)	Q9 (Chromosomal abnormalities)	All
<10	0,56	0,3	1,34	1,32	1,79	2,61	0,82	1,41	1,55	1,18	1,34
<20	1,36	0,49	1,36	1,59	0,72	1,49	1,4	1,41	1,23	1,12	1,32
<30	1,26	0,82	1,94	2,66	0,6	2,49	1,32	1,14	1,46	1,78	1,55
<10	ns	ns	ns	ns	ns	high	ns	high	ns	ns	high
<20	ns	ns	high	ns	ns	ns	ns	high	ns	ns	high
<30	ns	ns	high	high	ns	high	ns	ns	ns	high	high

ns: do not differ significantly from the reference level
low/high: differs significantly from the reference level

Table 20.3.1-3: Significance cause-specific of the developmental disorder risks standardized by aggregated age and sex data and their difference compared to reference level within each zone (2004-2009).

	Q0 (Developmental disorders of the nervous system)	Q1 (Developmental disorders of the head and neck region)	Q2 (Developmental disorders of the cardiovascular system)	Q30-34 (Developmental disorders of the respiratory system)	Q35-37 (lip and cleft palate)	Q38-45 (Developmental disorders of the gastrointestinal system)	Q5 (Developmental disorders of the urogenital system)	Q6-7 (Developmental disorders of the musculoskeletal system)	Q8 (Developmental disorders of the integumentary system)	Q9 (Chromosomal abnormalities)	All
Regression coefficient	0,0238	0,0086	0,0218	0,0383	-0,046	-0,003	0,0012	0,0046	0,0095	0,0602	0,0115
p	0,322	0,678	0,027	0,737	0,143	0,551	0,858	0,593	0,057	0,034	0,03

Table 20.3.1-4: The relationship of the cause specific development disorder risk and the regression analysis of the distance to the power plant corrected by the socio-economic status of the settlements smoothed by empirical Bayesian estimation (2004-2009).

20.3.1.6 Analysis of the risk of the incidence of diseases

The incidence calculated based on the reports of the health care institutions were processed according to the disorders groups. For each disorder group the risk of morbidity observed in Paks was evaluated and a statistical analysis of the deviation of the observed number of cases from the expected values was done. Statistical mapped illustrations were made of the observed risks of morbidity and their statistical results obtained from testing the reference level deviation in the settlements of the 30 km zone.

By testing the cumulative relative risk and its deviation from the reference level in each zone from 10 km and the local risks corrected by the socio-economic status and the assessment of the relationship between distance measured from the power plant the role of the power plant as the potential point source was tested.

Assessment of the risk of incidence observed during the care of tumoral and cardiovascular diseases in the district of the power plant

- Morbidity caused by malignant tumor of the lip, oral cavity and pharynx
- Morbidity caused by esophageal cancer
- Morbidity caused by stomach cancer
- Morbidity caused by colon cancer
- Morbidity caused by rectum, sigmoid colon and anal cancer
- Morbidity caused by other gastrointestinal cancer
- Morbidity caused by trachea, bronchus and lung cancer
- Morbidity caused by breast cancer
- Morbidity caused by cervical and uterine cancer
- Morbidity caused by malignant tumor of the brain
- Morbidity caused by Hodgkin's lymphoma
- Morbidity caused by non-Hodgkin's lymphoma and leukemia
- Morbidity caused by tumors
- Morbidity caused by hypertension
- Morbidity caused by ischemic heart disease
- Morbidity caused by cerebrovascular diseases
- Morbidity caused by circulatory system diseases

By testing the cumulative relative risk and its deviation from the reference level in each zones from 10 km (Table 20.3.1-5) and the local risks corrected by the socio-economic status and the assessment of the relationship between distance measured from the power plant (Table 20.3.1-6) the role of the power plant as the potential point source was tested.

zone	Malignant tumor of the lip, oral cavity and pharyngis	Malignant tumor of the esophagus	Malignant tumor of the gastric cancer	Malignant tumor of the colon cancer	Malignant tumor of the rectum, sigmoid colon and anus	Other malignant tumor of the digestive organs	Malignant tumor of the trachea, bronchus and lung	Malignant tumor of the breast	Malignant tumor of the cervix and uterus
<10km	0,85	0,98	0,82	1,2	1,19	0,97	0,88	0,93	0,95
<20km	1,12	0,76	0,91	1,07	1,07	1,03	0,85	0,91	1,04
<30km	0,86	0,59	0,86	1,07	1,02	1	0,87	1,06	1,15
<10	ns	ns	ns	high	ns	ns	ns	ns	ns
<20	ns	ns	ns	ns	ns	ns	low	ns	ns
<30	ns	low	ns	ns	ns	ns	low	ns	ns

zone	Malignant tumor of the brain	Hodgkin's lymphoma	Leukemia and non-Hodgkin's lymphoma	Tumors	Hypertension	Ischemic heart disease	Cerebrovascular diseases	Circulatory system diseases
<10km	0.65	0.6	0.76	0,95	2,76	1,58	2,87	2,27
<20km	1,07	1,27	0,85	0,94	1,83	1,04	1,36	1,29
<30km	1,17	0,99	0,9	0,96	1,19	0,95	1,22	1,08
<10	ns	ns	low	ns	high	high	high	high
<20	ns	ns	ns	low	high	ns	high	high
<30	ns	ns	ns	ns	high	ns	high	high

ns: do not differ significantly from the reference level
low/high: differs significantly from the reference level

Table 20.3.1-5: Significance of cancers diseases (2007-2009) and of cardiovascular diseases (2009) standardized by aggregated age and sex data and their difference compared to reference level within each zone.

	Malignant tumor of the lip, oral cavity and pharyngs	Malignant tumor of the esophagus	Malignant tumor of the gastric cancer	Malignant tumor of the colon cancer	Malignant tumor of the rectum, sigmoid colon and anus	Other malignant tumor of the digestive organs	Malignant tumor of the trachea, bronchus and lung	Malignant tumor of the breast	Malignant tumor of the cervix and uterus
Regression coefficient	0,0004	0,0024	0,0005	-0,0002	-0,0002	0,0001	0,0005	0	-0,0001
p	0,2886	0,0265	0,15	0,0403	0,2377	0,5492	0,1284	0,8817	0,8482

	Malignant tumor of the brain	Hodgkin's lymphoma	Leukemia and non-Hodgkin's lymphoma	Tumors	Hypertension	Ischemic heart disease	Cerebrovascular diseases	Circulatory system diseases
Regression coefficient	-0,0004	0,0001	0,0001	0	-0,0077	-0,0018	-0,0084	-0,0061
p	0,3988	0,955	0,1685	0,964	0	0,2373	0	0

Table 20.3.1-6: The relationship of the age and sex standardized cancer diseases (2007-2009) and cardiovascular diseases (2009) and the regression analysis of the distance to the power plant corrected by the socio-economic status of the settlements smoothed by empirical Bayesian estimation.

Assessment of the risk of incidence observed during the care of childhood cancers in the district of the power plant

- Morbidity caused by childhood cancers
- Morbidity caused by childhood lymphoid leukemia
- Morbidity caused by childhood acute lymphoid leukemia
- Morbidity caused by childhood myeloid leukemia
- Morbidity caused by childhood acute myeloid leukemia
- Morbidity caused by childhood brain cancers
- Morbidity caused by childhood renal cancers
- Morbidity caused by childhood Hodgkin's lymphoma
- Morbidity caused by childhood non-Hodgkin's lymphoma
- Morbidity caused by childhood tumor of the peripheral nervous system
- Morbidity caused by childhood limb sarcoma
- Morbidity caused by childhood sarcoma at non-limb

By testing the cumulative relative risk and its deviation from the reference level in each zone from 10 km (Table 20.3.1-7) and the local risks corrected by the socio-economic status and the assessment of the relationship between distance measured from the power plant (Table 20.3.1-8) the role of the power plant as the potential point source was tested.

zone	childhood cancers	lymphoid leukemia	acute lymphoid leukemia	myeloid leukemia	acute myeloid leukemia	brain tumor	renal tumor	Hodgkin's lymphoma	Non-Hodgkin's lymphoma	tumor of the peripheral nervous system	limb sarcoma	other sarcoma
<10	1,29	0,88	0,9	0,56	0,61	0,8	0	0	0	0	1,29	1,22
<20	0,99	0,79	0,82	1,7	1,39	0,61	0,52	1,26	0,8	0,95	0,99	1,87
<30	1,33	1,08	0,9	1,88	2,05	1,45	1,14	1,52	1,56	0.71	0	0,34
<10	high	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
<20	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
<30	high	ns	ns	ns	ns	ns	ns	ns	ns	ns	nc	ns

ns: do not differ significantly from the reference level
low/high: differs significantly from the reference level
nc: not calculable (no case observed in the zone)

Table 20.3.1-7: Significance of childhood cancers diseases standardized by aggregated age and sex data and their difference compared to reference level within each zone (2005-2009).

	Childhood cancers	Lymphoid leukemia	Acute lymphoid leukemia	Myeloid leukemia	Acute myeloid leukemia	Brain tumor	Renal tumor	Hodgkin's lymphoma	Non-Hodgkin's lymphoma	Tumor of the peripheral nervous system	Limb sarcoma	Other sarcoma
Regression coefficient	-0,021	-0,012	-0,011	-0,027	-0,03	-0,001	0,002	-0,01	-0,003	-0,013	-0,001	-0,015
p	0,152	0,404	0,464	0,029	0,025	0,933	0,796	0,408	0,863	0,359	0,892	0,094

Table 20.3.1-8: The relationship of the age and sex standardized childhood cancer diseases and the regression analysis of the distance to the power plant corrected by the socio-economic status of the settlements smoothed by empirical Bayesian estimation. (2005-2009)

Assessment of the risk of incidence observed during the care developmental disorders and the diseases of the central nervous system in the district of the power plant

- Morbidity caused by developmental disorders of the nervous system
- Morbidity caused by developmental disorders of the head and neck region
- Morbidity caused by developmental disorders of the cardiovascular system
- Morbidity caused by developmental disorders of the respiratory system
- Morbidity caused by lip and cleft palate
- Morbidity caused by developmental disorders of the digestive tract
- Morbidity caused by developmental disorders of the genitals
- Morbidity caused by developmental disorders of the urinary system
- Morbidity caused by hip dislocation
- Morbidity caused by other developmental disorders of the musculoskeletal system
- Morbidity caused by developmental disorders of the integumentary system
- Morbidity caused by chromosomal abnormalities
- Morbidity caused by Down syndrome
- Morbidity caused by abnormalities of the sex chromosome
- Morbidity caused by Huntington's disease
- Morbidity caused by heritable ataxias
- Morbidity caused by spinal muscular atrophy
- Morbidity caused by muscular atrophy due to central nervous system anomaly
- Morbidity caused by myasthenia gravis

By testing the cumulative relative risk and its deviation from the reference level in each zones from 10 km (Table 20.3.1-9) and the local risks corrected by the socio-economic status and the assessment of the relationship between distance measured from the power plant (Table 20.3.1-10) the role of the power plant as the potential point source was tested.

zone	Q0 (Developmental disorders of the nervous system)	Q1 (Developmental disorders of the head and neck region)	Q2 (Developmental disorders of the cardiovascular system)	Q30-34 (Developmental disorders of the respiratory system)	Q35-37 (lip and cleft palate)	Q38-45 (Developmental disorders of the gastrointestinal system)	Q5 (Developmental disorders of the urogenital system)	Q60-64 (Developmental disorders of the urinary system)	Q65 (Hip dislocation)	Q85-99 (other developmental disorders of the musculoskeletal system)
<10	0,87	1,34	0,78	1,14	0,69	1,46	0,85	1,11	1,03	2,4
<20	0,74	1,46	0,88	1,03	1	0,8	0,83	1,28	1,06	2,57
<30	1,41	1,97	1,17	1,17	1,49	0,95	1,23	1,58	1,46	3,18
<10	ns	high	low	ns	ns	high	ns	ns	ns	high
<20	low	high	low	ns	ns	low	low	high	ns	high
<30	high	high	high	ns	high	ns	high	high	high	high

zone	(Developmental disorders of the integumentary	Q9 (Chromosomal abnormalities)	Q90 (Down syndrome)	Q91-99 (Abnormalities of the sex chromosome)	G10 (Huntington's disease)	G11 (Heritable ataxias)	G12 (Spinal muscular atrophy)	G13 (Atrophy due to central nervous system anomaly)	G70 (Myasthenia gravis)
<10	0,88	0,81	0.76	0,97	1,15	0,62	1,33	0,46	0,86
<20	0,66	0,77	0,97	0.76	0,23	0,37	0,74	0,18	0,74
<30	1,01	1,39	1,62	1,96	0,35	1,67	1,14	0,86	1,02
<10	ns	ns	ns	ns	ns	ns	ns	ns	ns
<20	low	ns	ns	ns	ns	ns	ns	low	ns
<30	ns	high	high	high	ns	high	ns	ns	ns

ns: do not differ significantly from the reference level
low/high: differs significantly from the reference level

Table 20.3.1-9: Significance of developmental abnormalities and the diseases of the central nervous system standardized by aggregated age and sex data and their difference compared to reference level within each zone. (2005-2009)

	Q0 (Developmental disorders of the nervous system)	Q1 (Developmental disorders of the head and neck region)	Q2 (Developmental disorders of the cardiovascular system)	Q30-34 (Developmental disorders of the respiratory system)	Q35-37 (lip and cleft palate)	Q38-45 (Developmental disorders of the gastrointestinal system)	Q5 (Developmental disorders of the urogenital system)	Q60-64 (Developmental disorders of the urinary system)	Q65 (Hip dislocation)	Q66-79 (other developmental disorders of the musculoskeletal system)
Regression coefficient	-0,016	-0,03	-0,023	-0,019	-0,007	-0,005	-0,028	-0,026	-0,047	-0,112
p	0,168	0,014	0,191	0,157	0,672	0,623	0,088	0,034	0,082	0,001

	Q8 (Developmental disorders of the integumentary system)	Q9 (Chromosomal abnormalities)	Q90 (Down syndrome)	Q96,97,98 (Abnormalities of the sex chromosome)	G10 (Huntington's disease)	G11 (Heritable ataxias)	G12 (Spinal muscular atrophy)	G13 (Atrophy due to central nervous system anomaly)	G70 (Myasthenia gravis)
Regression coefficient	-0,038	-0,011	-0,011	-0,018	0	-0,007	0,001	-0,034	-0,013
p	0,002	0,38	0,509	0,047	0,984	0,49	0,934	0,077	0,164

Table 20.3.1-10: The relationship of the age and sex standardized developmental disorders and diseases of the central nervous system and the regression analysis of the distance to the power plant corrected by the socio-economic status of the settlements smoothed by empirical Bayesian estimation. (2005-2009)

20.3.1.7 Conclusions of Phase 1

In summary, the pathography of the population living in the impact area was favorable in comparison to the reference value or showed the same health status as the reference population.

The theoretical possibility of enhancing the statistical indicators of the risks associated to the power plant arose at the following endpoints (the study results for some pathography):

- Death caused by colon cancer
- Death caused by hypertension
- Incidence of developmental disorders of the gastrointestinal system
- Morbidity caused by colon cancer
- Morbidity caused by hypertension diseases
- Morbidity caused by ischemic heart disease
- Morbidity caused by cerebrovascular diseases
- Morbidity caused by circulatory system diseases
- Morbidity caused by other developmental disorders of the musculoskeletal system
- Morbidity caused by spinal muscular atrophy

The morbidity caused by the diseases of the vascular system – hypertension, ischemic heart disease and cerebrovascular diseases – show essentially the same risk profile and are summarizing the cases of this disease group, and therefore cannot be considered as an independently evaluable risk raising factor.

The risk surpluses registered by the special medical care of the cardiovascular diseases can be explained by the fact, that for the people living near to Paks the special medical care services can take over a major part, thus the residents living farther are cared by the general practitioners. In principle, the less favorable cardiovascular risk factor (smoking, obesity, sedentary lifestyle) of those living in the vicinity of the power plant could also be an explanation for the increase of the local risk. But as the local risks are decreasing while the distance to Paks is rising, the explanation is more based on the difference between the way of medical care.

The ionizing radiation's role as an etiologic factor for cardiovascular disease is still not clearly defined, the increase of the local risk is maybe not to be explained with the surplus of ionizing radiation.

Among the 82 indicators examined 8 summarizing indicators (total of cancers, total of cardiovascular diseases, total of gastrointestinal diseases, different violent deaths) are included. Among the 74 detailed indicators 6 were handling the chronic cardiovascular diseases, which are not including to their etiological factors the ionizing radiation. Considering this facts, the statistical assessment was done for 68 indicators. The number of statistical artifact at such an analysis for this case number was 68 × 0.05 = 3.4. Based on this (assuming an equal number of tests producing apparently significant positive and negative differences) 1.7 is the number of statistically significant differences expected, containing also a distribution risk explained by chance.

The mortality caused by malignant colon cancer (high risk in Paks based on 63 cases), the mortality caused by spinal muscular atrophy (high risk in Paks based on 8 cases), and the morbidity caused by malignant colon cancer (high zone risk at 0-10 km based on 136 cases) has been pointed out based on 1-1 statistically significant risk increase. The incidence of the developmental disorders of the gastrointestinal tract and the morbidity caused by other musculoskeletal developmental disorders were 2-2 based on the significant statistical test (high risk in Paks based on 13 and respectively 1936 cases, and high zone risk at 0-10 km 17 and respectively 2599 cases). Among them they are certainly statistical artifacts (we observed at 2 endpoints a significant risk increase from 7 compared to the expected 3.4). However, based on the available data the statistical artifacts and the endpoints showing a real accumulation cannot be isolated. To do this, the disorders should be evaluated by their etiological conditions or the intensity of the risk factors observed in the impact area should be known. The latter would be first of all important in case of the colon cancer, because this tumor showed an increase in both the mortality and in both the morbidity registered is specialized medical care showed a local risk increase.

The reliability of the base data of the endpoints showing the risk increase is not identical. The diseases registered in the special medical care are there is the first potential diagnosis established at the examination (it will be registered only on the basis of suspicion of the disease). The discipline of the reporting from the developmental disorders varies regionally. The tumoral cause of death based on histological diagnosis is considered as the most reliable indicator from the base indicators showing risk increase. This consideration also supports the need of clarification of the relation of incidence from colon cancer.

20.3.2 STUDY PHASE 2, INVOLVEMENT OF HOME PRACTITIONERS

In the program, the interpretation of lifestyle risk factor is difficult to be interpreted at individual level in the case we are not able to clear the role of the lifestyle factor (for example: smoking, alcohol, accumulation in the family, etc.). Therefore the analysis based on aggregated data should be completed with primer data collection on the study filed, describing not only the health status from the residents but also their risk profile.

The construction of such a database is possible with the help of the general practitioners but without the active interaction of the population. For this purpose a cooperating general practitioner service should be organized, as the general practitioners (due to the patient history they have to collect) are familiar with the elemental risk factors, which can have an important impact on the development of the diseases examined in the study. Therefore with their help the health status and the risk profile can be recorded taking into account the data protection, insuring the full coverage and the required quality needed for the study.

This survey undertook to report the incident cases from the last 3 years involving the general practitioners living in the 30 km area from the power plant voluntary joining the program. A longer recall period would significantly impair the reliability of the results thus it is not worthy to increase the case number this way. The statistical power of a higher case number would compensate the deteriorating data quality.

The study was conducted as follows:

1. Detailed elaboration of the study protocol and obtaining the ethical approval.
2. Organization of the network of the cooperating general practitioners and coordination of the data collection of the general practitioners:
    - preparing the cooperating general practitioners,
    - registration of the 2010-2012 diagnosed new tumoral diseases in the practice of the general practitioners,
    - matching control group persons to the incident cases using the general practitioners help,
    - filling out a questionnaire by asking the patients, the control group and their relatives regarding the diseases occurring in the family, lifestyle risk factors, risks related to employment.
3. To build up the base database based on the questionnaires collected by the general practitioners.
4. To produce a corrected odds ratio which is representing the risk increase due to the vicinity of the power plant without the independent risk increasing factors og each disease.
5. To compile a report assessing the potential point source role of the power plant by combining the results from each endpoint of the study.

The general practitioners have an important role in the care of oncological patients. This explains the possibility to gain information regarding oncological patients. Beside an oncological patient the general practitioner can also give data regarding a healthy patient from the same age, sex and educational level. Namely, a case-control database was built.

To overview the tumor risk factors we did not developed an own questionnaire, but we used that from World Health Organization (WHO) CINDI projects, which was validated and published, so we translated the freely usable questions. A questionnaire is widely used in Hungary. There was even no need to make changes on the level of formulation of the questions.

Since the questionnaire is filled out on voluntary basis, some answers could be refused by the answerers. Therefore in some cases the questionnaires were not completely filled, and the risk factors of the person participating in the study cannot be fully estimated. If the denied answer was in relation to an important rick factor regarding the development of tumors, the incomplete questionnaire (in the case when the fill shortage was not due to a technical error) were excluded from the data processing.

20.3.2.1 Data processing

Age was calculated by age year precision. We needed dichotomized variables for processing the age data, thus we determined a younger and an older population compared to the given age of life. The threshold was 70 years of age.

According to the extensive epidemiological experiences the educational level can be used to describe approximately the overall socio-economic status. The test sample was divided into two groups according to the completed secondary school. Low-skilled are those who have not completed the secondary school studies.

We distinguished two genders: male and female.

Regarding the development of tumors, the previous or actual long-term smoking is significant, thus according the data reported in the questionnaire, we made two groups. One group for those who were and are regularly smoking and those who smoked regularly in the past, but stopped smoking yet, and another group for those who never smoked.

Based on the questions from questionnaire we could define jobs needing special protection tools. The use of protection devices is an indicator of a potential workplace health effect indicator. Based on the description of the actual exposition we could identify the subjects who worked on a workplace hazardous in terms of ionizing radiation and have to wear some protection device/clothes. The latter group was defined as being on an occupational radiation exposure risk.

Behind the tumors they are often certain family specific genetic characteristics, which make a cumulative occurrence of tumors within a family. In addition the current study focuses on the enhancing role of the external risk factors, thus we had to control the cumulative tumor incidence within a family, to control the role of the genetic constitution. We considered a person's family history as positive if at least one first-degree relative (parent, sibling, children) has been diagnosed with a tumor.

By choosing the control group it was an obvious solution for the general practitioner to match non-cancer patients corresponding regarding age, gender and qualification. With this solution we allowed a distorting effect in the study, thus who are visiting the doctor are already sick and are not representative for the total non-cancer population. Since the

patients from general practitioner are mostly suffering from chronic degenerative diseases, as diabetes, ischemic heart disease and hypertension, these are over represented in the control sample. These diseases important in the point of view of public health have some risk factors which are increasing also the risks of cancer diseases. Therefore, it was absolutely necessary to taking into account them during data collection and calculation.

The (potential) residential exposures could be described in an approximate manner based on the distance between the domicile and the power plant. To determine the distance between the settlements we used the centers of the settlements. Based on this data, persons living within 20 km from Paks were considered as (potentially) exposed, those living farther than 20 km as non-exposed.

In the study, we were looking for an answer, whether there is a relationship between the occurrence of cancer diseases and the correlation between the exposure and the nuclear power plant/residence distance. The calculated linked measure was the odds ratio; which is showing graphically the number of times the incidence of cancer is higher among people living near to the power plant, than in among people living farther from the power plant.

By default, “a” cancer patients are living near the power plant and “C” subject are living farther. The number of non-cancer (control) subject living near to the power plant is “b”, the number of the subject living farther is “d”. The chance to became sick near the power plant is “a/b”, farther from the plant “c/d”. The ratio from the two chances (“ad/cb”) expresses the fact if there is a role in the distance from the power plant to the development of morbidity.

	related to power plant	
	near	farther
tumors	a	c
control	b	d
chance of cancer incidence:	a/b	c/d
	↓	
odds ratio:	ad/cb	

If the vicinity of the power plant, the risk of cancer is increasing, the odds ratio is greater than one. If the vicinity of the power plant has a protective effect, it reduces the incidence of cancer, and this manifests in an odds’ ratio of less than 1. If there is no relationship between the distance to the power plant and the tumor incidence, the odds ratio is equal to 1.

The odds ratio equal to 1 refers to a neutral relationship. A calculated odds ratio between the incidence and location of the residence of the patients in the cancer sample. To decide whether the deviation from a given odds ratio from 1 is significant or can be explained by chance, we apply a statistical test or we can set 95% confidence interval of the odds ratio. With the odds ratio we can differentiate factors increasing the incidence of tumors (odds ratio significantly over 1), factors decreasing the incidence of tumors (odds ratio significantly lower than 1), and factors not influencing the incidence of tumors (odds ratio not significantly differing from 1). Of course, these odds ratios can be specified separately for all risk factors and all tumor types.

In reality, the tumor formation has many factors. They describe those combined effect we employed a multivariate statistical methods, which define the odds ratio as risk factor. During the test, we calculated the risk factor per odds ratios by a logistic regression analysis for all tumor types For the statistical interpretation we give the result of the test of significance examining the difference of the 95% confidence interval for the neutral or the deviation (p) from the neutral value (odds ratio 1) value (odds ratio of 1 box).

20.3.2.2 Tumor disease groups used in the study

The tumoral disease groups used in the study:

- malignant tumor of the lip, oral cavity and pharynx
- malignant tumor of the gastric cancer
- malignant tumor of the colon cancer
- malignant tumor of the rectum
- malignant tumor of the larynx
- malignant tumor of the lung
- malignant tumor of the breast
- malignant tumor of the cervix
- malignant tumor of the prostate
- malignant renal tumor
- malignant tumor of the urinary bladder
- malignant tumor of the brain
- lymphomas
- leukemia
- other malignant tumors

20.3.2.3 Overall assessment of general practitioner involvement

By the involvement of general practitioners we used a testing approach that allowed by the correction of the effects of risk factors in the development of cancer, to quantifying the risk of cancer only affected by the exposure from the vicinity of the nuclear power plant.

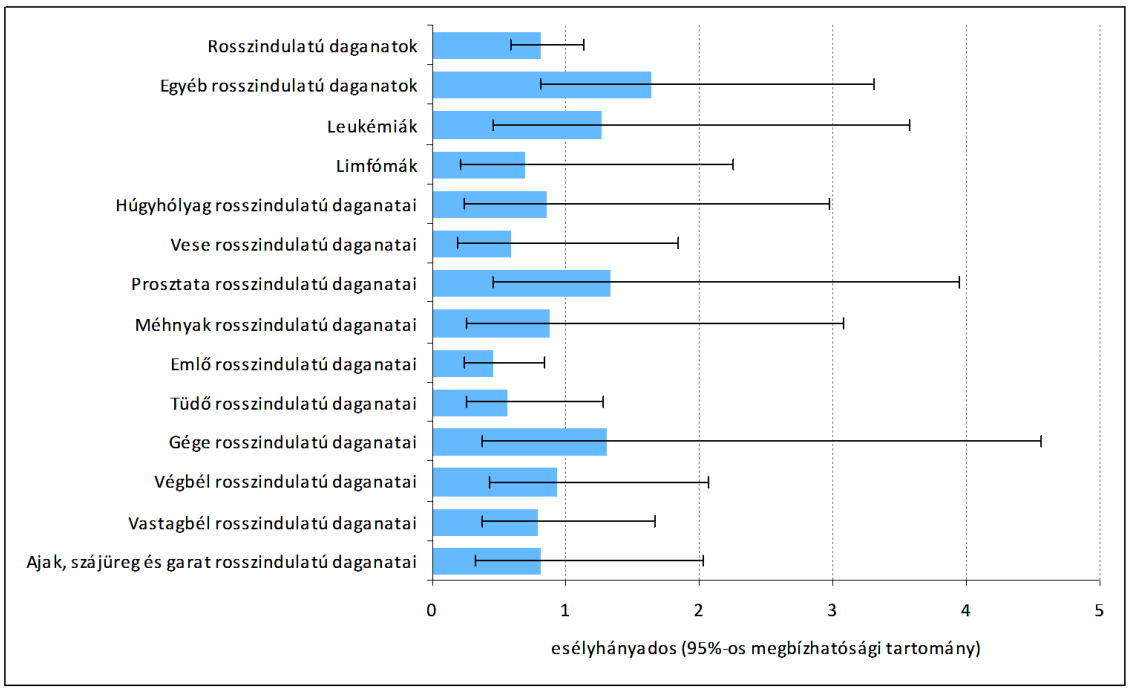
Instead the direct measurement of the examined exposition (dose of the ionizing radiation emitted directly to the environment by the Paks Power Plant), we estimated it based on the distance between the residence of the subjects and the nuclear power plant. The harm caused was the cancer incidence registered by the general practitioner. The controlled other risk factors were: age, sex, education, smoking, occupational radiation exposure, family clustering of cancer, diabetes, hypertension, ischemic heart disease.

During the study, the general practitioners collected the data in three counties, in settlements closer than 30 km to the Paks Nuclear Power Plant on the basis of international standards questionnaire. The general practitioner filled out the questionnaire regarding his/her cancer patients diagnosed between 1st January 2010 and 31st December 2012, the filled out another questionnaire based on data of a matching (age, sex, education) control subject.

During the data processing the risk factors were analyzed according the tumor type. We made a description of the case and control population, than we determined the influencing role of each risk factor by multiplex logistic regression.

By the section of analysis of the risk factors we got results, which matched to the nature of the given tumor (smoking increases laryngeal cancer, lung cancer, head and neck cancer and risk of developing bladder cancer), respectively, and which were reflecting the effects of sample selection. Since the database was built using matching controls for age, sex and education, in case of a perfect matching we would not have seen the property of these factors to influence the risk factors, despite they obviously got it. However, the general practitioner selected the controls from his/her non-cancer patients, so the control group was overrepresented compared to the overall population of the common non-cancerous diseases. As a result in many analyses, the hypertension seems to be a protective factor, which obviously does not have cancer risk reduction properties.)

During each tumor localizations rating one usually did not see a positive relationship between the proximity of the Paks Nuclear Power Plant and the incidence of tumors to occur. In the case of breast cancer we experienced a statistical significant statistical decrease in incidence in the vicinity of the power plant. Many tumor localization testing took place, thus only the evaluation of the distribution of the odds ratios makes only possible to assess the impact of the power plant. The odds ratios the tumor types are evenly dispersed around the neutral value (Figure 20.3.2-1).



Rosszindulatú daganatok – malignant tumors, egyéb rosszindulatú daganatok – other malignant tumors, leukémiák – leukemia, limfómák – lymphoma, húgyhólyag rosszindulatú daganatai – malignant tumors of bladder, vese rossindulatú daganatai – malignant tumors of kidney, prosztat rosszindulatú daganatai – malignant tumors of prostate, méhnyak rosszindulatú daganatai – malignant tumors of cervix, emlő rosszindulatú daganatai – malignant tumors of breasts, tüdő rosszindulatú daganatai – malignant tumors of lung, gége rosszindulatú daganatai – malignant tumors of larynx, végbél rosszindulatú daganatai – malignant tumors of rectum, vastagbél rosszindulatú daganatai – malignant tumors of colon, ajak, szájüreg és garat rosszindulatú daganatai – malignant tumors of lip, mouth, and pharynx, esélyhányados (95%-os megbízhatósági tartomány) – odds ratio (95% confidence ranges)

Figure 20.3.2-1: Odds ratio (95% confidence ranges) adjusted for age, sex, smoking, qualifications, occupational radiation exposition, accumulation in the family and some common diseases (diabetes, hypertension, ischemic heart disease), for the chance of morbidity for people living within 20 km of the impact area compared to the impact area in the 20-30 km zone from the power plant by tumor types.

(On the picture the blue bar is the odds ratio, which is showing graphically the number of times the incidence of cancer is higher among people living near to the power plant, than in among people living farther from the power plant (the black bar line shows the 95% confidential interval).

The joint results of the evaluation of test indicate that the rick of the tumor diseases experienced near the power plant is not increased by the vicinity of the power plant.

During the study we controlled important risk factors, thus the negative conclusion cannot be explained neither by the pattern of other risk factors.

In summary, the study did not found an increased risk for morbidity caused by cancer among people living in the vicinity of the Paks Power Plant.

20.4 Current Radiation Exposure of the Population Living within a 30 km Radius Area around the Site

The radiation exposure of the population was developed along the following lines:

- Radioactive emission data of the currently operating nuclear facilities located on-site, direct and scattered radiation dose rates, nuclear environmental monitoring data were used to estimate population radiation exposure.
- To estimate radiation exposure due to other artificial sources, other artificial radiation exposures arising from various activities like radioactive waste evacuation, fresh and spent fuel transportation, movement of radiation sources within the site, and finally industrial radiography tests were also taken into account.

The estimation of radiation exposure was limited to the 30 km area around the site, using measured data collected over a period of 11 years, applying internationally accepted, standard methods and programs.

20.4.1 STUDY AND EVALUATION METHODOLOGY

The implementation of the task required no supplemental in-field measurements, thus the evaluation was completed by gathering, arranging and analyzing the existing data set (made available). The objective of the study and evaluation was to determine and assess the radiation exposure of the population living around the site drawing on currently accessible sources. The criteria applied for study and evaluation to draw up the environmental impact study documents were to comply with radiological expectations (observe the limits imposed on population radiation exposure) and to establish the database necessary for site permit issuing.

To estimate the radiation exposure of the population, once the (technological, meteorological, geological, etc.) site and environmental characteristics determining the propagation of radioactive materials were established, scenarios were developed for the assumed releases. These scenarios described emissions into the atmosphere, discharges into surface and subsurface waters, including the combinations thereof. To estimate radiation exposure, other exposures from various sources and activities were also taken into account, including the evacuation of radioactive waste, the transportation of new, unused and spent fuel, the movement of radiation sources within the site, and finally industrial radiographic testing. It should be noted here that the direct and scattered radiation coming from the Paks NPP can be neglected for all practical purposes. Given that the measured dose rate data fall into the background range, it is impossible to calculate population radiation exposure from them with respect to nuclear facilities. Significant direct and scattered radiation can affect the population mainly due to moving fuel and other radiation sources, so the model calculations were performed to evaluate these.

Based on the model scenarios, the potential radiation exposures of the critical group were determined for particular and adequately combined cases. Radiation exposure was estimated applying internationally accepted methods and programs, using them with ICRP and IAEA recommendations and data.

In the light of the calculations, it was assessed whether or not the dose defined in the dose constraint is suitable for the operation of the Paks NPP and the ISFS Facility considering the critical population (hypothetical group including children living in Csámpa and Gerjén). This value was set in 1998 as 100 μSv/yr, of which 90 % can be used by the Paks NPP and 10 % by ISFS.

20.4.1.1 Propagation and radiation exposure from atmospheric emission

To describe atmospheric propagation during normal operation, a procedure based on the so-called sector averaged Gaussian plume model taken from international recommendations was used. The method assumes constant average atmospheric conditions for a prolonged period (e.g., 1 year) near the source, and calculates nuclide concentration in the air above ground level, plus ground surface depositions. For operational failure propagation, a model similar to the previous one was used, giving the concentrations assuming constant emission and meteorological conditions for a given time.

The description of the contamination of given elements of the terrestrial food chain rests on the so-called concentration factor technique. When describing the contamination of vegetation, the model also considers external deposition on the surface of plants, and the occlusion of long half-life isotopes through the roots. When estimating the contamination of animal products the model is rather conservative, because the feed used is selected exclusively from contaminated plants grown on the site. The concentration factors are taken from the international literature, while the parameters applicable to plants and animals were derived from Hungarian agricultural data.

Using the concentrations calculated above the following doses were obtained:

- External radiation exposure
    - Immersion gamma dose
    - Ground surface gamma dose
    - Resuspension caused gamma dose
    - Immersion beta dose (skin dose)
- Internal radiation exposure
    - Inhaled dose
    - Resuspension caused inhalation dose
    - Foodstuff consumption caused ingestion dose

The method also allows the determination of six age group doses.

The models and key parameters used were primarily taken from the IAEA Safety Series No. 57 [20.4-2] and IAIE Safety Report Series No. 19 publications; the inhalation and ingestion dose factors are given in the IAEA Safety Series No. 15 document, and age group external gamma dose factors were taken from FZK GSF 12/90.

20.4.1.2 Radiation exposure due to water discharge

The model describing discharge into the Danube accounts for the fact that lateral (sideways) mixing is only partially achieved – even at large distances from the point of discharge. The hydrological parameters permit the determination of the distance-dependent so-called partial mixing correction factors that specify how many times larger is the concentration of radionuclides on the right bank at some given distance from the point of discharge with respect to complete, uniform mixing.

River watercourse propagation - just like activity concentrations – is influenced by sediment binding, too. As a conservative guess, however, the activity concentration reducing effect of sedimentation was neglected in the calculations.

Assuming complex utilization, the food chain and dosimetry model built on the propagation scheme takes int account the following irradiation pathways:

- External radiation exposure due to
    - Contaminated water volumes,
    - Contaminated riverbank, and
    - Irrigated soils;
- Internal radiation exposure due to
    - Drinking water, and the consumption of
    - Fish,
    - Irrigated plants, and
    - Alimentary products of animal origin contaminated due to watering or feed based on irrigated plants.

The parameters required for the calculations can be grouped as shown below:

- Transfer coefficients (concentration factors),
- Lifestyle indicators (environment utilization),
- Drinking water and food consumption data,
- External radiation dose conversion aspects,
- Ingestion dose aspects.

The source of the above parameters is primarily the IAEA Safety Reports Series No. 19 publication [20.4-1], supplemented by domestic consumption and estimated lifestyle features. For certain radionuclides, transfer coefficients and indigestion dose aspects were taken from the IAEA Technical Reports Series No. 472 [20.4-4] and the IAEA Safety Series No. 115 or IAEA General Safety Requirements Part 3 recommendations, respectively, while the dose conversion factors required to calculate the external radiation exposure due to contaminated water volumes appeared in the US Federal Guidance Report No. 12 publication.

20.4.1.3 Other sources – external radiation exposure

In this exercise, the radiation exposure of the population was estimated along the individual external irradiation pathways and then compared with the available measurement data.

A computer model was developed to simulate the different activities based on the available data, and the finalized safety reports of the Paks NPP and the ISFS Facility were also used.

In source determination, the isotope ratios related to the activity to be investigated were used. The simulations were done by running the MCNP5 software program, an internationally acclaimed 3D neutron and gamma transport code. The program applies the Monte Carlo method to calculate particle trajectories, based on a principle that assigns random numbers to particles to represent their places and directions, to find out if they interact based on the cross section of the given nuclear reaction or not, and how the reaction changes their direction (velocity) and energy, or what new particles are produced. The model used sufficiently many input particles to ensure that the uncertainty (error) of the results obtained is generally below 5%, thus from time to time as many as several billion (10^9) particles were studied.

Regarding other sources the calculations accounted for the following:

The calculations of external radiation exposure consider the artificial radiation sources listed below:

- *Evacuation of radioactive wastes*
- *Transportation of cleared radioactive wastes*
- *Delivery of new fuel elements to the site*
- *Transportation of spent fuel to the ISFS Facility*
- *Movement of contaminated equipment and radiation sources within the site area*
- *Industrial radiographic tests*

ACCEPTABILITY CRITERIA

It is a crucial criterion concerning the implementation of this task to present the current population radiation exposure based on Government Decree 314/2005. (XII.25.) Korm. regarding the procedures of environmental impact assessment and the single procedure of authorization of utilization of the environment, and to perform the necessary analyses in view of site permit issuance according to Government Decree 118/2011. (VII. 11.) on the nuclear safety requirements of nuclear facilities and related regulatory activities, NSC Volume 7, to establish the expected database.

Calculations of population radiation exposure can rely on input measurement results obtained via accredited measurements. The calculations may use internationally accepted (IAEA, EU) data, calculation formulae and programs.

20.4.2 CALCULATION OF POPULATION RADIATION EXPOSURE

20.4.2.1 Atmospheric propagation of radioactive isotopes

Propagation during normal operation

Atmospheric propagation due to airborne emission, concentrations in terrestrial food chain elements and radiation exposures originating from particular irradiation paths were mainly determined by the in-house developed "SS57" program package based on the models described in the IAEA Safety Series No. 57 [20.4-2] and IAEA Safety Reports Series No. 19 [20.4-1] publications.

During the calculations, the so-called sector averaged Gaussian plume model based procedure was applied. This procedure is based on international recommendations, unites experience gained in many countries throughout the world, and combines routine practices with ease of use. The method assumes constant average atmospheric conditions for a prolonged period of time (e.g., 1 year) near the source.

The nuclide concentration in the air above ground level and ground surface concentration are the given by the following two formulae:

$$C(x,p) = Q \cdot f_r \cdot f_d \cdot f_w \cdot \frac{N}{\sqrt{2} \cdot \pi^2 \cdot x} \cdot \sum_{j=1}^{M} \frac{e^{-\frac{H^2}{2\sigma_{zj}^2}}}{\sigma_{zj}} \sum_{k=1}^{K} \frac{\delta_{pjk}}{u_{jk}}$$

where

C (x,p): air concentration in the pth directional sector at distance x from the source (Bq/m^3)
Q: source intensity (Bq/s)
H: effective emission height (m)
N: number of directional sectors (16 pcs)
M: number of Pasquill categories (6 pcs)
K: number of wind velocity categories (8 pcs)
σ_z: dispersion parameter depending on Pasquill category and distance (vertical plume extension) (m)
u_{jk}: wind velocity in the jth Pasquill and kth wind velocity category (m/s)
δp_{jk}: wind frequency in the pth sector in the jth Pasquill and kth wind velocity category (-)
f_r, f_d, f_w: reduction factors due to decomposition, deposition and washout (-).

$$\Phi(x,p) = C(x,p) \cdot (v + W \cdot I_p) \cdot (\frac{1 - e^{-\lambda\tau}}{\lambda})$$

where

Φ (x,p): deposition in the pth sector at distance x (Bq/m^2)
v: fallout velocity (m/s)
W: washout constant (-)
I_p: precipitation intensity in the pth sector (m/s)
λ: decay constant (1/s)
τ: investigation period (s).

With the aid of the formula it is possible to calculate stationary concentration and annual deposition subject to continuous emission.

Propagation under operational failure conditions

In this case, the atmospheric concentration subject to emission during a certain period and pre-defined meteorological conditions is given by the following formula:

$$C(x,z) = \frac{Q \cdot f_r \cdot f_d \cdot f_w}{2\pi \cdot \sigma_y \cdot \sigma_z \cdot T \cdot u} \cdot (e^{-\frac{(z-H)^2}{2\sigma_z^2}} + e^{-\frac{(z+H)^2}{2\sigma_z^2}})$$

where

C (x,z): atmospheric concentration in plume centre at distance x from source at height z (Bq/m^3)
Q: emitted quantity (Bq)
σ_y,σ_z: y and z direction plume widths (m)
T: length of emission period (s)
u: wind velocity (m/s)
(all other parameters as above).

C (x,z) can be approximated by a stationary state, assuming timewise constant concentration during the breakdown period.

Terrestrial food chain

The description of the radioactive matter content of certain components of the terrestrial food chain is based on the so-called concentration factor technique. In describing the activity concentration of the vegetation, this model takes into account external deposition on the surface of plants, and the absorption of long half-life isotopes through plant roots.

When estimating the activity concentration of animal origin products the model is rather conservative, as it assumes that all feed is taken from plants grown locally. The concentration factors were taken from the international literature, whereas the parameters relevant to plants and animals were derived from Hungarian agricultural data.

Dose calculation

External immersion doses were calculated using the following general formula:

$$E_{mer} = c \cdot DF_{bem} \cdot t \cdot R$$

where

c: atmospheric concentration (Bq/m^3)
DF_{bem}: appropriate dose factor (Sv m^3/(Bq s)
t: time spent in plume (s)
R: reduction factor expressing the rate of time spent free outdoors to time spent in building (-)

For ground surface gamma dose concentration is replaced by deposition, while t is the duration of stay there.

The dose induced by inhalation is given by the following formula:

$$E_{leg} = c \cdot V \cdot DF_{bel} \cdot t \cdot R$$

where

V : breathing performance (all other parameters the same as above, t is time spent in plume (m^3/s)
DF_{bel}: inhalation dose factor (Sv/Bq)
(all other parameters the same as above).

The radiation exposure due to the ingestion of a given type of food product is given by the formula below:

$$E_{leny} = c \cdot F \cdot DF_{le} \cdot t$$

where

c: concentration calculated for food type (Bq/kg)
F: consumption of food type (kg/s)
DF_{le}: ingestion dose factor (Sv/Bq)
t: duration of consumption (s).

During the calculation, doses due to resuspension and the effect of daughter elements were also taken into account. The method allows the determination of several age groups, too.

Population radiation exposure due to atmospheric emissions

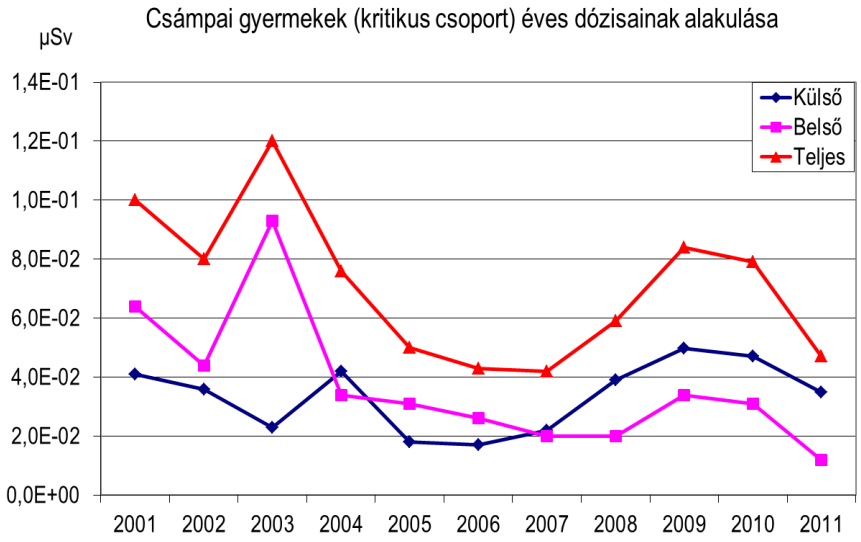
To obtain a conservative estimate of doses due to atmospheric propagation first the JERMS [20.2-10] and PERMS reports were reviewed to find out which was the actual year between 2001-2011 when the critical population group (Csámpa children) was subjected to the highest radiation exposure due to airborne emissions from the nuclear power plant; the corresponding doses during the study period are shown in Table 20.4.2-1.

Although here the YR 2003 116 nSv value (In Table 20.4.2-1 marked by *) appears to be the highest, due to the effect of the operational failure that took place then the normal operating dose was not unequivocally distinguishable from the total dose, therefore rather the YR 2009 (second highest) value was selected, so the typical – but still conservative – radiation exposures due to atmospheric propagation were obtained from the emissions and meteorological parameters of 2009.

Year	Total dose nSv
2001	25
2002	79
2003	116 *
2004	73
2005	50
2006	43
2007	42
2008	59
2009	85
2010	78
2011	47

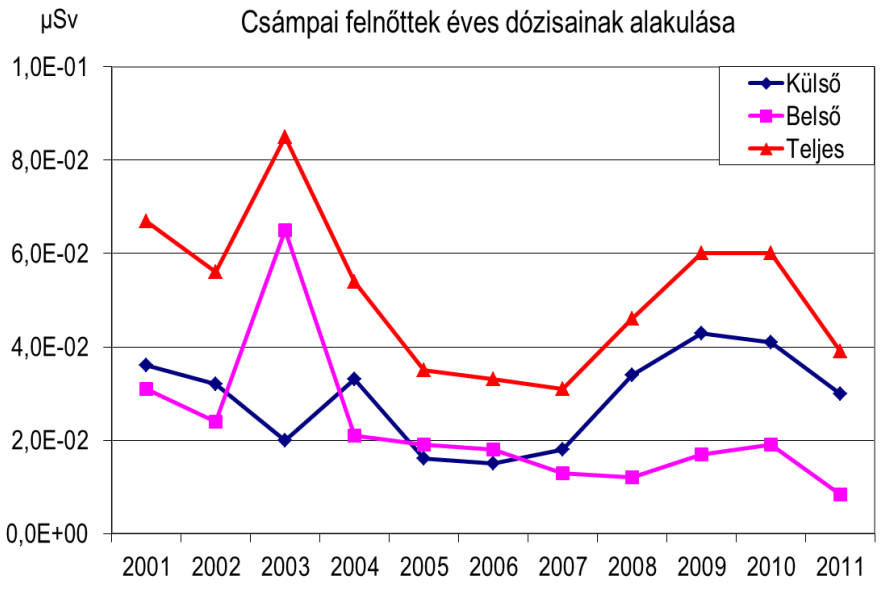
Table 20.4.2-1: Radiation exposure due to nuclear power plant atmospheric emissions.

The radiation exposures originating from the airborne emissions of the Paks NPP were calculated for each year between 2001-2011. These calculations for the Csámpa children (critical group) and adult age groups are shown in Figure 20.4.2-1 and Figure 20.4.2-2. Apart from the operational failure year, between 2001 and 2007 the total radiation exposure showed continuous decrease, which was followed by a period of increase till 2009 (the 2010-11 values again showed decrease).



Csámpai gyerekek (kritikus csoport) éves dózisának alakulása - Evolution of annual doses for Csámpa children (critical group)
Külső – external, Belső – Internal, Teljes – total

Figure 20.4.2-1: Evolution of annual doses for Csámpa children (critical group) due to power plant chimney emisisons

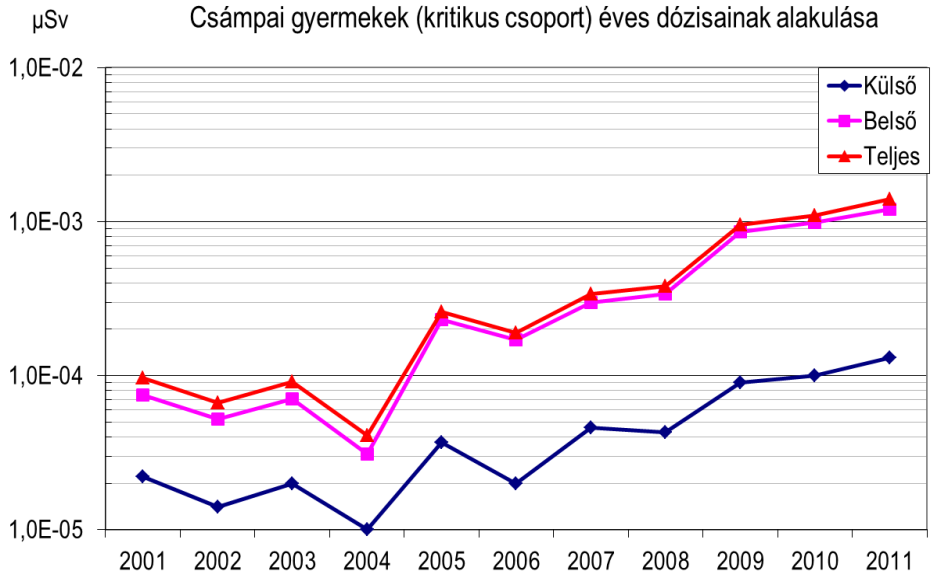


Csámpai felnőttek éves dózisának alakulása - Evolution of annual doses for Csámpa adults
Külső – external, Belső – Internal, Teljes – total

Figure 20.4.2-2: Evolution of annual doses for Csámpa adults due to power plant chimney emisisons

The calculations were repeated for ISFS emissions between 2001-2011 using the same initial conditions as applied for the atmospheric emissions of the Paks NPP, except the 20 height of emission and the annual wind frequency matrices corresponding to 20 m.

The figures below (Figure 20.4.2-3 and Figure 20.4.2-4) present the annual evolution of the dose received by the Csámpa population. The slight increase can be attributed to two factors: first, the use of a more accurate emission measuring system, and, second, the increasing number of spent fuel elements.



Csámpai gyermekek (kritikus csoport) éves dózisának alakulása - Evolution of annual doses for Csámpa children (critical group)
Külső – external, Belső – Internal, Teljes – total

Figure 20.4.2-3: Evolution of annual doses for Csámpa children (critical group due to ISFS emissions)

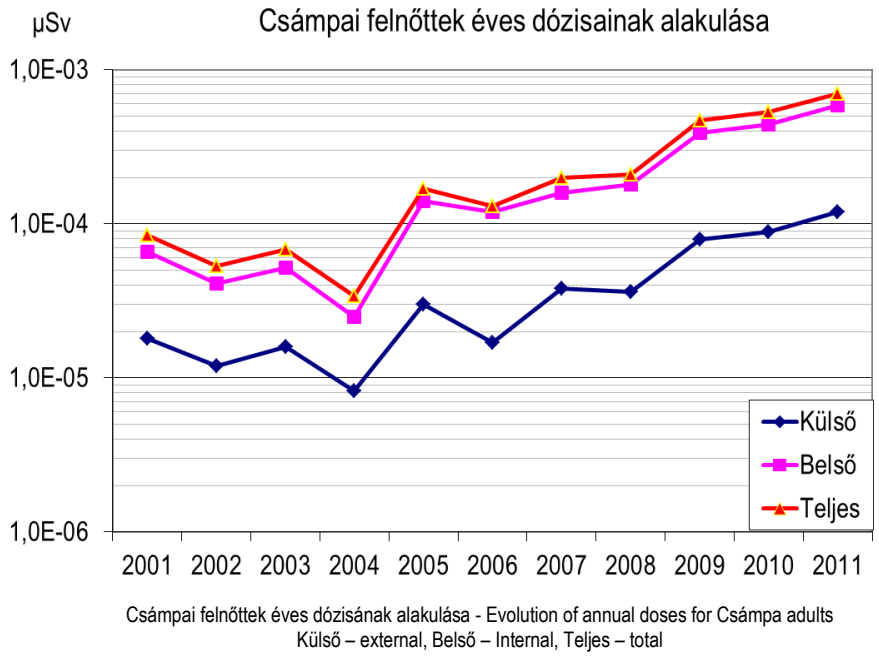


Figure 20.4.2-4: Evolution of annual doses for Csámpa adults due to ISFS emissions

20.4.2.2 Radiation exposure due to water discharge

Activity concentration calculation in aquatic environment

Calculation of running water propagation

The concentration of radioactive materials discharged into running (river) water – as those propagate with the receiving medium – decreases due to diffusive, sedimentation processes and radioactive decay. At the place of use – more precisely in its neighborhood – radionuclides are bound to environmental elements by physical or chemical processes, or are incorporated into biological organisms and tissues. Then radionuclides propagate further with physical or biological matter along diverse routes called irradiation pathways.

Liquid discharges from the nuclear power plant eventually reach the Danube as receptor mass of water. Using a conservative approach, here the dilution, sedimentation processes of the interim section – collection tanks, hot water canal – will be neglected (actually radioactive decay can be also disregarded for propagation with the Danube, it only counts for deposited radionuclides).

The simplest model applicable to describe dilution and propagation in running waters assumes complete mixing. This condition is necessarily violated close enough to the point of discharge, thus in the plume higher concentrations can be expected than those predicted by complete mixing. The degree of this departure is difficult to calculate accurately, as it depends on a large number of parameters (discharged and recipient water volumes, temperatures, flow velocities, etc.), and incidentally the mathematical treatment of the problem is also quite involved.

Due to the above, as a simplifying approximation for the dilution of radioactive materials in the Danube, to determine the eventual concentrations the model used in the IAEA SRS No. 19 publication was applied for the calculations.

Drinking and trough water activity concentration

In the SRS No. 19 publication – as a conservative approach – the activity concentration of drinking and trough water was taken equal to that of fluvial water, that is, the effect of water purification is neglected. Although under domestic conditions surface waters are not used for drinking in Hungary – in fact their use as trough water is not typical, either -, in the following calculations this conservative approach was accepted and adopted.

Activity concentration of irrigated soil and vegetation

Radionuclide concentration in soil is determined by three fundamental processes: deposition (sedimentation), physical decomposition and escape from the soil. The last one comprises several subprocesses like washdown to deeper soil layers – not accessible to plants –, absorption by plants and resuspension. (The importance of the effects decreases in this order.)

The vegetation can take up radioactive materials two ways:

- Deposition on plant surface, absorption, then migration to part to be consumed,
- Absorption through roots, then migration to part to be consumed.

For the first process, it must be kept in mind that the decisive factor governing deposition is the rate of plant/soil effective surfaces, and environmental effects (wind, precipitation) may also remove radionuclides from the surface of a plant.

The concentration of radionuclides absorbed in a plant as a result of the above two processes decreases as a result of physical decay (here the storage time, i.e. the period between harvest and consumption must be taken into account too).

Activity concentration of animal products

The radionuclide uptake of animals is caused by irrigation and nuclides are transmitted in feed, whereas in trough water nuclides are introduced directly (through running – irrigation water) (see sections above).

In line with domestic consumption habits, in the case of milk only cow milk and parameters relevant to cows were considered, in accordance with the SRS No. 19 publication; while regarding meat consumption both beef, poultry and pork and the associated animal characteristics parameters entered the calculations. As the latest IAEA publication does not show the parameters for the last two animal types, the data were taken from an earlier IAEA issue. Of course this relates to the parameters only, the activity concentration of meat was obtained the same way in all three cases.

External radiation exposure from stay at riverbank

Radionuclide concentration calculation in bank sediment. The surface activity concentration of riverbanks can be obtained the following way:

$$C_{S,S} = \frac{(0{,}1)\cdot(0{,}001)\cdot K_d \cdot 60 \cdot C_{w,tot}}{1+0{,}001\cdot K_d \cdot S_S} \times \frac{1-e^{-\lambda_i \cdot T_e}}{\lambda_i \cdot T_e}$$

where

0,1	ratio of bank and other sediment K_d values with respect to the suspended one,
0,001	conversion rate of the l/kg and m^3/kg units,
60	surface density of riverside sediment (kg/m^2),
T_e	radionuclide accumulation time ($T_e = 3{,}1\cdot10^7$ s).
K_d	distribution factor describing the concentration rate of sediment-bound and water dissolved radionuclides ((Bq/kg)/(Bq/l))

The calculated values of activity concentration resulting from river water – riverbank (sediment) interaction allow the determination of external radiation exposure from staying on the riverbank (swimming, sunbathing) as:

$$\mathrm{E_m} = \mathrm{C_{S,S}} \cdot \mathrm{DF_{gr}} \cdot \mathrm{O_f}$$

where

$C_{s,s}$	riverbank surface activity concentration (Bq/m^2),
$D\cdot F_{gr}$	ground surface dose factor for the ith radionuclide ((Sv/yr)/(Bq/m^2)),
Q_f	yearly exposure time rate.

It should be noted that the different models insert a correction factor into the above equation to account for different irradiation geometries – ground surface can be taken as an infinite plane, while the riverbank has finite dimensions –. In compliance with the SRS No. 19 publication this was neglected here, giving a conservative approach.

External radiation exposure from stay in river water

This irradiation pathway was neglected in the SRS No. 19 publication. Calculations confirmed that its contribution is indeed insignificant, but for the sake of completeness it was included in the model.

The irradiation pathway can in fact be split into two subpaths:

- Swimming, bathing (immersion in water),
- Boat trips, kayak-canoe sport (staying at water surface).

Radiation exposure was calculated with the following formula:

$$E_{im,w} = C_w \cdot DF_{im,w} \cdot g_{im,w} \cdot Q_f$$

where

C_w activity concentration of the ith radionuclide in river water (Bq/dm^3),
$DF_{im,w}$ water immersion dose factor for the ith radionuclide ((Sv/yr)/(Bq/dm^3)),
$g_{im,w}$ geometrical correction factor for the ith radionuclide (literature: swimming = 1, boat = 0,5),
Q_f yearly exposure time rate.

External radiation exposure from stay on irrigated fields

The calculation uses the same formula as for stay on riverbanks. The surface activity concentration of soil, the yearly rate of time spent on the irrigated areas and the dose conversion factors of external irradiation were all taken into account.

Internal radiation exposure from inhalation

During the time of stay in a cloud containing radionuclides not only external but internal radiation exposure also occurs due to the inhalation of air. This internal radiation exposure can be calculated as follows:

$$E_{inh} = C_A \cdot P_{inh} \cdot DF_{inh}$$

where

E_{inh} internal dose arising from inhalation (Sv/yr),
C_A atmospheric activity concentration of the ith radionuclide (Bq/m^3),
P_{inh} annual inhalation volume (m^3/yr),
DF_{inh} inhalation dose factor for the ith radionuclide (Sv/Bq).

The above equation is only valid for outdoor stay, in buildings due to the filtering effect of constructed edifices activity concentrations will be smaller. In the SRS No. 19 publication it was raised as a conservative approximation that the members of the reference group stayed in the outside atmosphere all year round. The calculations here employed a more realistic assumption, namely the filter effect of buildings was also incorporated. The internal radiation caused by the inhalation of radionuclides re-pulverized (resuspended) from the soil and the vegetation can be calculated similarly to the formula above.

Internal radiation exposure due to drinking water and food consumption (ingestion)

$$E_{ing,p} = C_{p,i} \cdot F \cdot DF_{ing}$$

where

$E_{ing,p}$ annual internal radiation dose for the ith radionuclide due to drinking water and food consumption (Sv/yr),
$C_{p,i}$ concentration of the ith radionuclide in food type p,
F annual consumption (kg/yr),
DF_{ing} ingestion dose factor for the ith radionuclide (Sv/Bq).

Special model for ^{3}H and ^{14}C isotopes

The description of tritium migration along the food chain fundamentally differs from the concentration factor-based models presented previously.

In the case of tritium, the basic assumption is that its specific activity – that is, the activity of tritium compared to that of unit mass water – is constant in every environmental component and living organism, so no so-called isotope effect occurs. According to the model, only tritium in HTO form – together with water – can be incorporated into living bodies, the gaseous, organic form can give rise to inhaled dose at most. (Given that tritium is a soft beta emitter, there is no need to consider external radiation exposure.)

The internal radiation exposure of the reference group due to tritium was obtained in line with the SRS No. 19 publication.

The SRS No. 19 publication does not mention the determination of radiation exposure due to liquid discharge ^{14}C. To solve this problem, specific activity-based models of tritium and ^{14}C were used as a starting point, supplemented with the application of the assumptions presented hereunder.

For the nuclear power plant, in liquid discharge the presence of ^{14}C in carbonate form is measured (according to annual radiation protection reports).

The activity concentration of ^{14}C at the receptor point can be determined similarly to tritium. The activity concentration of ^{14}C can be calculated the same was as the dilution of the other radionuclides, finally the carbon concentration of Danube water (34 mg/dm^3) can be derived from its dissolved hydrocarbonate content (175 mg/dm^3).

The present discussion was limited to the study of radiation exposure due to the aquatic food chain – in particular, fish consumption being the definitive contribution. (In this case, the contribution of the linked terrestrial food chain can be neglected, too.) Based on the activity concentration model, the ^{14}C activity concentrations of Danube water and fish are identical. Now, because – unlike for airborne emission – it cannot be expected that the same specific activity builds up in human beings due to the effect of this sole path, radiation exposure was calculated using annual fish consumption and ingestion dose factors.

Radiation exposure due to liquid discharges from the Paks NPP and the ISFS Facility

The calculation of external and internal radiation exposures due to liquids discharged from the Paks NPP and the ISFS Facility was carried out for each year between 2001-2011 in respect of the Gerjen children (1-2 years old) and adult age groups, the results are shown in Figure 20.4.2-5 and Figure 20.4.2-6.

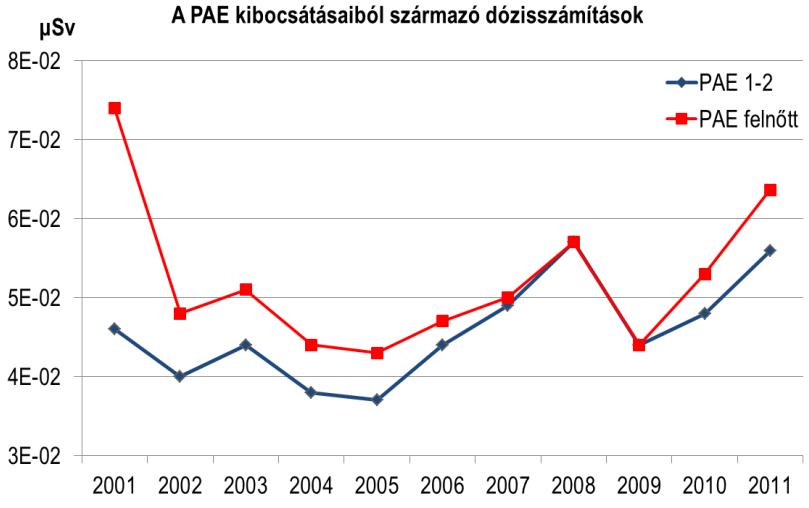
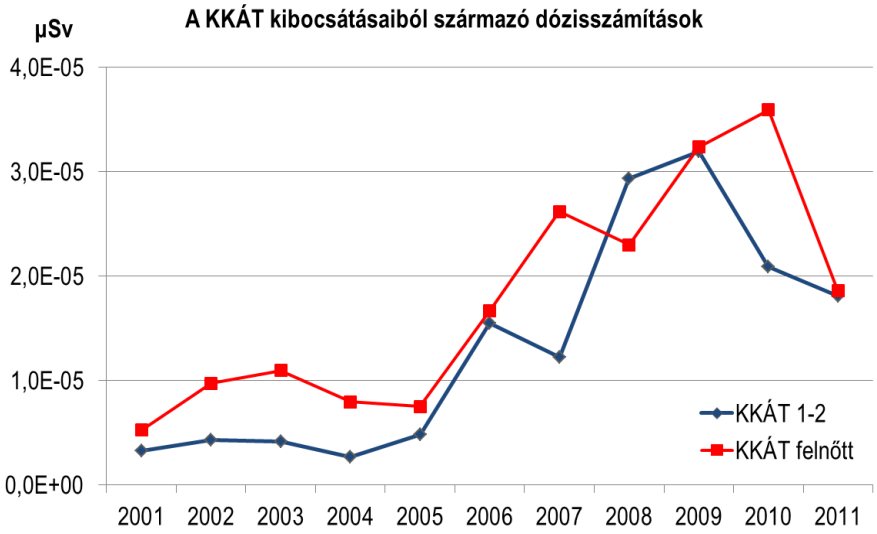


Figure 20.4.2-5: Radiation exposures due to liquid discharge from the Paks NPP of the Gerjen children (1-2 years old) and adult age groups



A KKÁT kibocsátásaiból származó dózisszámítások - Dose calculations from ISFS discharges
KKÁT 1-2 - ISFS 1-2 yrs, KKÁT felnőtt - ISFS adult

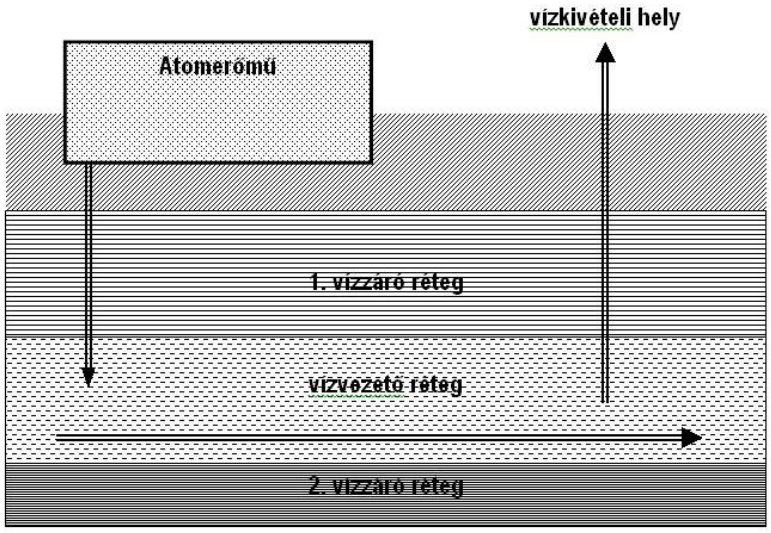
Figure 20.4.2-6: Radiation exposures due to liquid discharge from the ISFS of the Gerjen children (1-2 years old) and adult age groups

Estimation of radiation exposure due to tritium entering groundwater

Concerning the radioactive materials entering groundwater at the Paks NPP site, it is important to determine the potential radiation exposure of the population in case of entry into drinking water.

For the Paks NPP, to model migration in groundwater the source magnitude was obtained from data collected from the already existing wells, then the radiation exposure was derived on that basis.

The model itself was established using a simple scheme, assuming that the radionuclides having found a way into the soil first penetrate and traverse the confining layer and then propagate along with groundwater movement. This case is sketched in Figure 20.4.2-7.



Atomerőmű - NPP, vízzáró réteg - impermeable (watertight) layer, vízvezető réteg - water permeable layer, vízkivételi hely - water takeout location

Figure 20.4.2-7: Entry of radioactive materials from the nuclear power plant into groundwate.

The key processes and assumptions considered in the study were the following:

- The escaping water accumulates within the NPP area,
- The radioactive water slowly seeps through the soil layer beneath the NPP,
- The 1st impermeable layer absorbs a part of the radioactive isotopes,
- At the bottom of the clay layer the radioactive water enters the permeable layer and mixes with groundwater flowing there,
- The flow of groundwater in the permeable layer carries the radioactive isotopes to the water takeout location (a well dug at a distance of "l" m).

It was then determined how the activity concentration of tritium in groundwater changes at a water takeout location about 500 m away from the nuclear power plant (given that the only artificial source detectable in groundwater under the Paks NPP was tritium, conservatively the HTO form was used).

The value of the activity concentration so obtained turned out to be 16.5 Bq/ m^3 in the water of an imaginary well 500 m away. It should be stressed that the above results are most likely overestimated, as in the calculations the following conservative assumptions were used:

- In the permeable layer, the dispersion of isotopes perpendicular to groundwater flow was neglected, propagation was described assuming simple flow and mixing processes only,
- The entire amount of activity escaping the nuclear power plant was taken as soluble,
- The permeable layer was regarded undersaturated, meaning that all of the water seeping out of the clay layer can mix with the groundwater flowing in the permeable layer,
- All transport processes directed towards layers lying deeper were disregarded.

Assuming the very conservative case that a member of the population always drinks the water from a well at the boundary of the safety zone, the dose due to tritium in groundwater can be obtained as follows:

$$E_{leny} = c_{H-3} \cdot DF_e \cdot n \cdot d$$

where

c^3_H: calculated activity concentration of tritium in groundwater 500 m away from the NPP (16.5 Bq/m^3)
DF_e: effective dose factor due to tritium ingestion (1.8E-11 Sv/Bq)
n: number of days in a year (365 days/yr)
d: average quantity of water consumer daily (3 dm^3/day).

The effective dose calculated this way was 0.33 nSv/yr. According to Government Decree no. 201/2001 (X.25.) Korm. the limit value applicable to tritium concentration in drinking water is 100 Bq/dm^3, thus the value derived for 500 m falls almost 4 orders of magnitude below this, whereas the radiation exposure calculated with the conservative assumption (0.33 nSv/yr) is 6 orders of magnitude smaller than the 90 μSv/yr dose restriction.

20.4.2.3 Evacuation of radioactive wastes

The transport container used for modeling (see Figure 20.2.1-1) is able to hold 16 (200 l volume) barrels.

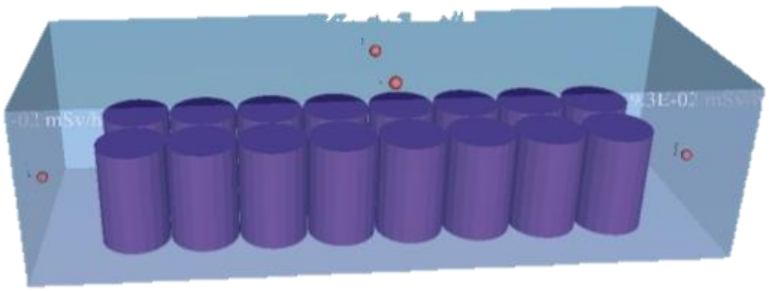


Figure 20.4.2-8: Transport container.

For transportation issues only gamma radiation was investigated. The radioisotope compositions were used to determine the gamma energies, which in turned defined the source. The source was assumed to be made up by filling the barrels

(drums) homogeneously with all materials (radioactive waste, concrete, etc.). Average and maximum radioisotope compositions are shown in Table 20.4.2-2 by average per barrel for current nuclear power plant data [20.4-22].

Isotope	Average activity [Bq/brl]	Maximum activity [Bq/brl]	Isotope	Average activity [Bq/brl]	Maximum activity [Bq/brl]
^{51}Cr	1.64E+08	6.72E+09	^{137}Cs	2.25E+06	8.71E+07
^{95}Nb	9.29E+07	6.94E+10	^{63}Ni	1.32E+07	1.92E+08
^{59}Fe	1.18E+07	1.12E+09	^{238}Pu	3.91E+01	2.59E+02
^{124}Sb	5.73E+06	1.75E+08	^{241}Am	1.6E+02	2.6E+03
^{95}Zr	2.26E+07	1.06E+09	^{14}C	5.8E+06	9.91E+07
^{58}Co	2.39E+07	1.13E+09	^{94}Nb	3.86E+06	1.01E+07
^{242}Cm	2.28E+01	4.13E+02	^{239}Pu+^{240}Pu	3.67E+01	3.09E+02
^{65}Zn	2.33E+06	1.22E+07	^{59}Ni	2.23E+05	1.85E+06
^{110m}Ag	1.76E+07	4.12E+08	^{41}Ca	1.69E+01	1.88E+02
^{54}Mn	2.41E+07	1.68E+09	^{99}Tc	5.47E+02	1.13E+03
^{134}Cs	2.64E+06	5.24E+07	^{234}U	1.5E+01	2.96E+01
^{55}Fe	1.83E+06	1.6E+07	^{36}Cl	4.38E+01	3.21E+02
^{60}Co	5.34E+07	1.46E+09	^{129}I	2.23E+00	2.34E+01
^{3}H	1.68E+07	3.19E+07	^{235}U	1.64E+00	2.93E+00
^{244}Cm	2.99E+01	2.56E+02	^{238}U	1.07E+01	1.87E+01
^{90}Sr	5.58E+03	4.06E+04			

Table 20.4.2-2: Average and maximum activity data per barrel.

If the rate of generation of radioactive waste follows the current trends, then ca. 850 pcs of 200 l barrels of waste can be expected annually. This quantity requires 54 trips to haul away, which means that the radiation exposure due to a single trip must be multiplied through by this figure. Some transportation routes run next to inhabited areas, so citizens may actually come close to the transport trucks. Thus in the calculations it was assumed that a truck turning out the road crossing may occasionally require as many as 5 minutes to complete the maneuver due to traffic reasons. In this situation, people staying alongside the road may be as close as only 5 m away. Assuming 5 occasions that the same individual is there next to the road during all deliveries, s/he may be subject to 2.1 μSv radiation exposure, provided the barrels in question carry average activity.

Waste clearance can be unconditional or subject to condition(s), depending on the permit issued by CMOS. Over the past years, wastes cleared unconditionally or subject to condition(s) manifested the tendency that the largest amounts of waste leave the site due to conditional clearance, waste cleared unconditionally is evacuated only in smaller quantity.

To perform the calculations, a relatively simple model was defined. Cleared waste is transported placed in metal containers. For simplicity, it was assumed that the distribution of waste within a container is homogeneous. The results are shown in Table 20.4.2-3.

s (m)	E' (μSv/h)
2	3,21E-03
5	8,09E-04
10	2,45E-04
20	6,76E-05
50	1,10E-05
100	2,44E-06
200	4,20E-07
500	1,30E-08

Table 20.4.2-3: Dose rate originating from cleared waste transported during 1 year.

Here the same assumption was used as for the transportation of low and intermediate activity radioactive wastes, namely that a person is there at 5 m from the transport truck. These values related to the quantity carried during 1 year. Assuming it is always the same person there next to the truck (which is a rather conservative guess) and taking the turn requires 10 minutes, then the value of radiation exposure is obtained as: 0.135 nSv/yr.

20.4.2.4 Delivery of fresh fuel to the site

In a single trip 400 fuel elements are delivered to the current nuclear power plant, so the block train composed of several wagons carries a total of 100 pcs TK-SZ4 type containers. The model used in the calculation was developed for two radiation exposure levels and assumed fuel elements with 3.82% enrichment [20.4-21]:

- In case 1, the dose due to gamma radiation emitted by the fuel element was considered. From the composition of the fuel element, first the energy and frequency of gamma photons was obtained, then the source was built up with these.
- In case 2, the reactions between neutrons released by the spontaneous fission of uranium in the fuel element produces gamma photons, where both the dose exerted by gamma radiation and the dose exerted by neutron radiation on the population can be readily calculated.

The results are derived in a form normalized to a single particle, therefore they must be multiplied with the activity values of ^{235}U, ^{234}Pa and ^{234m}Pa present in the fuel element. The summary results can be found by combining the separate values for the three isotopes. The calculations were performed for distances of 0,1, 2, 5, 10, 20 and 50 m to determine the radiation exposure of the population. The results can be found in Table 20.4.2-4.

s (m)	^{235}U		^{234}Pa		^{234m}Pa	
	E' (µSv/h)	Δ E'	E' (µSv/h)	Δ E'	E' (µSv/h)	Δ E'
0,1	2,68E-01	1,98%	2,31E-01	1,60%	1,96E+01	1,33%
2	3,69E-02	0,61%	3,61E-02	0,48%	3,00E+00	0,39%
5	1,66E-02	0,85%	1,52E-02	0,67%	1,27E+00	0,55%
10	7,21E-03	1,17%	5,92E-03	1,00%	4,86E-01	0,83%
20	2,58E-03	2,04%	1,87E-03	1,73%	1,52E-01	1,45%
50	3,60E-04	4,85%	2,86E-04	4,36%	2,37E-02	3,60%

Table 20.4.2-4: Dose rate values calculated near railway wagons carrying fresh fuel elements, for gamma source.

When considering the effect of neutrons, not only the radiation exposure caused by neutrons but also that caused by photons generated from neutron reactions and excitations must be evaluated. The final conclusions can be drawn for the cumulative doses, the results are shown in Table 20.4.2-5.

s (m)	Neutron		Gamma	
	E'	Δ E'	E'	Δ E'
	µSv/h	%	µSv/h	%
2	2,19E-02	0,15	4,89E-05	0,54
5	9,72E-03	0,21	2,17E-05	0,73
10	3,73E-03	0,33	8,32E-06	1,12
20	1,08E-03	0,62	2,40E-06	1,99
50	1,24E-04	1,75	2,50E-07	4,9

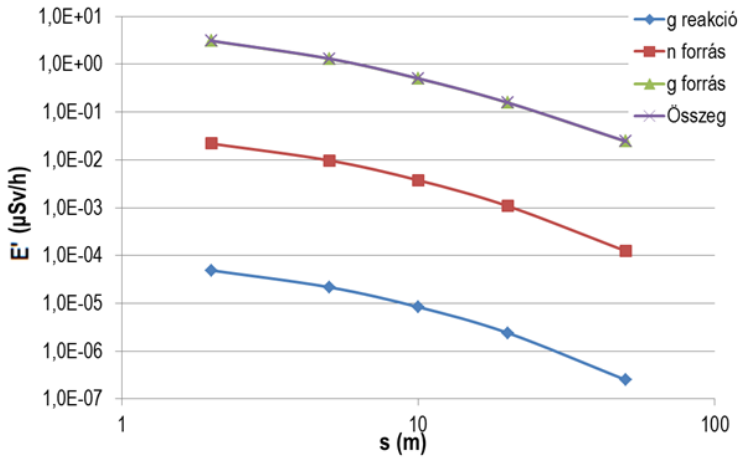
Table 20.4.2-5: Dose rate values calculated near railway wagons carrying fresh fuel elements, for neutron source.

Summarizing separately the neutron and gamma dose rates produced in different ways, then the gamma and neutron source dose rates calculated near railway wagons carrying fresh fuel elements are obtained (Table 20.4.2-6).

s (m)	E' g	E' n
	µSv/h	µSv/h
2	3,07E+00	2,19E-02
5	1,30E+00	9,72E-03
10	4,99E-01	3,73E-03
20	1,56E-01	1,08E-03
50	2,43E-02	1,24E-04

Table 20.4.2-6: Dose rate values calculated near railway wagons carrying fresh fuel elements.

The dose rate values arising from the three source modes and their sum are depicted in Figure 20.4.2-9, where ”g reaction” (in blue) means the dose rate due to photons from neutron source, ”n source” (in red) means the dose rate due to neutrons from neutron source, ”g source” (in green) means the dose rate due to photons from gamma source, and finally ”Sum” (in deep blue) is the effective dose rate of the three sources.



g reakció – g reaction, n forrás – n source, g forrás – g source, összeg – sum

Figure 20.4.2-9: Dose rate (E') values calculated near a V-60 SZK type railway wagon vs. distance.

The first scenario: The train enters the station, leaves it but then has to stop for some reason (traffic blocked). Then the people waiting for connections may stay near the train for some time (1/2 hour), relatively close, 5 m away, say. In this case, the population radiation exposure due to one railway wagon is: 0.66 µSv.

The second scenario: The train crosses the station without stopping. It is reasonable to take 30 km/h as velocity instead of the maximum 60 km/h, to incorporate the fact that due to the conditions of the domestic railway infrastructure network trains are often forced to slow down. The critical person, also present there at the station waiting for another train, is 5 m away from the external wagon wall. The length of the wagon is 26.4 m, so at 30 km/h its passing takes 3.2 s. Multiplying this time with the number of wagons in a block train (9) gives that during the passage of the train the critical member of the population is subject to 1.17 nSv radiation exposure.

20.4.2.5 Delivery of spent elements to the ISFS Facility

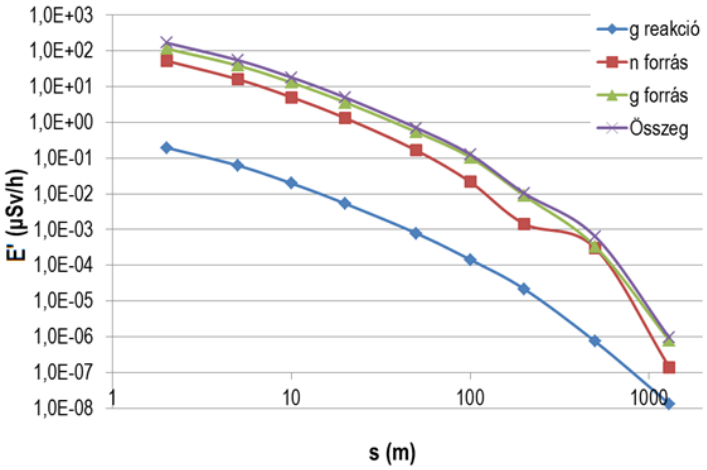
The neutron and gamma radiation exposure of the population was calculated for the transfer of spent fuel elements within the site using C-30 type transportation containers to ISFS, at different distances from the site boundary, also including the critical Csámpa population. In the calculations, the neutron and photon numbers by energy obtained for the isotope composition of an average burnup degree (40.9 GWday/tU) spent fuel element with 3 year decay time, assuming the presence of 30 such fuel elements in a C-30 container [20.4-23].

Similarly to fresh fuel elements, here the values calculated for the three source modes were also summarized, giving the results indicated in Table 20.4.2-7.

s (m)	E' g	E' n
	µSv/h	µSv/h
1	1,91E+02	9,23E+01
2	1,16E+02	5,27E+01
5	3,92E+01	1,61E+01
10	1,30E+01	5,04E+00
20	3,63E+00	1,32E+00
50	5,36E-01	1,63E-01
100	7,73E-02	2,14E-02
200	1,35E-02	1,45E-03
500	5,11E-04	3,02E-04
1300	1,33E-06	1,38E-07

Table 20.4.2-7: Dose rate values calculated near the spent fuel transport container.

The dose rate values arising from the three source modes and their sum are depicted in Figure 20.4.2-10, where ”g reaction” (in blue) means the dose rate due to photons from neutron source, ”n source” (in red) means the dose rate due to neutrons from neutron source, ”g source” (in green) means the dose rate due to photons from gamma source, and finally ”Sum” (in deep blue) is the effective dose rate of the three sources.



g reakció – g reaction, n forrás – n source, g forrás – g source, összeg – sum

Figure 20.4.2-10: Dose rates calculated near the C-30 container.

The figure plus the tabulated values both suggest that the highest dose is caused by gamma photons. This is due to the fact that there are so many radioactive isotopes present from the fission products in spent fuel even after cooling that the gamma photons accompanying the decay of nuclei are produced in vast numbers, but large penetration ability neutrons cannot be disregarded either during summation.

The calculated results were compared with the measured values. At 1 m from the surface of the C-30 transport container the measured maximum gamma (neutron) dose rate was 190 µSv/h (120 µSv/h), so the results fall into the correct order of magnitude, as the application of the model supplied 191 µSv/h gamma and 92.3 µSv/h neutron dose rates 1 m away from the container.

From this, the radiation exposure of the critical population (1300 m from the external container wall) was obtained by assuming a transfer loading time of 1 hour, and 480 pcs of transferred spent fuel elements each year, which can be seen as a maximum value. The corresponding radiation exposure turned out to be 0.0235 nSv.

In compliance with Government Decree no. 246/2011. (XI.24.) Korm. the ISFS Facility, or the boundary of the safety zone around the Paks NPP are no less than 500 m from the facility, so nothing prevents the population to stay at a distance of only 500 m during transfers. Taking identical conditions into account, it follows that the people there are subject to 13 nSv radiation exposure. It goes without saying that this is a very conservative estimate, as it assumes that the same population member stays at the same point during every transfer loading-unloading.

20.4.2.6 Moving equipment with surface radionuclides and radiation sources within the site

In this exercise, a simple model was developed, as at sufficiently large distances the source can always be taken as a point source, because here radiation sources, equipment with surface radionuclides were considered, to describe their effect on the population.

Again radioactive exposure was investigated at different distances, namely 100, 200, 500 and 1300 m. The radiation can only produce potentially detectable values when an asset or equipment is moved within the site area. The model and the source are established to give a 1 µSv/h (free zone value) dose rate at the outer wall protecting the transport vehicle or device.

The model first requires the determination of the source. This was done by calculating the activity for each nuclide which gives a 1 µSv/h measured dose rate 10 cm away from the surface of a 2 cm thick steel shielding.

s (m)	E'	ΔE'	E'	ΔE'	E'	Δ E'	E'	Δ E'
	^{60}Co		^{137}Cs		^{110m}Ag		^{54}Mn	
	µSv/h	%	µSv/h	%	µSv/h	%	µSv/h	%
100	8,98E-07	0,16	7,79E-07	0,19	8,40E-07	0,06	7,77E-07	0,08
200	1,53E-07	0,21	1,22E-07	0,26	1,37E-07	0,08	1,25E-07	0,11
500	5,33E-09	0,49	2,65E-09	0,78	3,81E-09	0,20	3,25E-09	0,29
1300	5,91E-12	5,88	5,00E-13	19,43	2,61E-12	3,05	1,20E-12	5,68

Table 20.4.2-8: Dose rate values due to moving equipment with radioactive materials on their surface.

The values so obtained led to the conclusion that the highest dose rate value occurred for the ^{60}Co isotope, therefore the statements were made for this case (Table 20.4.2-8).

For ^{60}Co at 500 m a 5.33E-09 µSv/h dose rate was calculated. This means that roughly 21 years would be required to pass for equipment with radioactive materials on its surface to produce 1 nSv radiation exposure.

20.4.2.7 Industrial radiographic tests

To perform industrial radiographic tests, high activity radiation sources are used in different applications, and these sources typically occupy two possible places:

- During transportation and placement for testing, the source is in its own shielded holder casing.

  There are two types of tests. In the first, tests are done outside the site, in the second, inside. In the first case, the population may be just 200 m away during test preparation, so the dose was calculated for this distance. The maximum allowed dose (rate) during test preparation is 100 GBq and is due to ^{60}Co. The preparations for such testing may well take several hours, so an average duration of 3 hours was taken. The radiation exposure due to preparation for testing was thus calculated at a distance of 200 m as 0.03 µSv.

- During testing, when the radiation source is present in the environment without protection.

The results of calculations assuming no protection are shown in Table 20.4.2-9 for distances equal to 2, 5, 10, 20, 50, 100, 200, 500 and 1300 m, respectively.

s (m)	E' (µSv/h) Isotope, activity					
	^{192}Ir		^{75}Se		^{60}Co	
	5 TBq		5 TBq		100 GBq	
2	1,78E+05	0,01%	9,63E+04	0,01%	8,82E+03	0,03%
5	2,79E+04	0,01%	1,52E+04	0,01%	1,37E+03	0,04%
10	6,92E+03	0,01%	3,81E+03	0,01%	3,37E+02	0,04%
20	1,72E+03	0,01%	9,59E+02	0,01%	8,21E+01	0,04%
50	2,62E+02	0,02%	1,50E+02	0,02%	1,22E+01	0,04%
100	5,65E+01	0,02%	3,21E+01	0,02%	2,64E+00	0,05%
200	8,59E+00	0,03%	4,52E+00	0,03%	4,66E-01	0,07%
500	1,39E-01	0,11%	5,59E-02	0,13%	1,82E-02	0,16%
1300	1,01E-05	4,73%	8,81E-06	4,90%	2,34E-05	1,69%

Table 20.4.2-9: Dose rates during radiographical testing as a function of radiation source used.

In this example, the critical population was not understood as living 1300 m away, as tests can be performed elsewhere too, not just on-site. It may happen that some test is required outside the site itself. In this case, the population may be just 200 m away. Currently about 430 X-ray images are recorded outside the operating area each year with 2 TBq initial activity ^{192}Ir and 5 TBq initial activity ^{75}Se radiation sources.

If these data are multiplied by the dose rate values measured for the individual sources, then – assuming maximum 5 minute test durations – the following results emerge:

Isotope	Dose/test
^{192}Ir	0,14 µSv
^{75}Se	0,23 µSv

The radiation exposure of radiographic testing outside the site may be supplemented by the radiation exposure coming from site operations. In this case, calculations must be done for 1300 m and 500 m distances. Assuming about 2,200 tests performed with the radiation sources mentioned above, it follows that the resulting radiation exposure is 0.67 µSv and 5.62 µSv, respectively.

20.4.3 SUMMARY

The annual levels of population radiation exposure determined via modeling were invariably several orders of magnitude smaller than the dose limitation (1 mSv) or the dose constraint level (100 µSv) imposed on the Paks NPP + ISFS facilities) even applying such conservative assumptions that can only be true in reality with very small probability. The radiation exposure values calculated from emissions and discharges fell into the nSv/yr range, while the effects due to additional sources (fresh or spent fuel, transportation of radioactive waste, radiographic tests) can in principle exceed this, but only during short periods, so taking a conservative approach the radiation exposure of individuals of the population is expected to be of the order of µSv/yr, which is several orders of magnitude smaller than the limit defined in the regulations.

Changes of this magnitude in annual radiation exposure cannot be verified in practice by measurements, therefore in what follows one will have to rely on model calculations and the like.

20.5 IMPACT OF PAKS II CONSTRUCTION ON THE RADIATION EXPOSURE OF THE POPULATION NEAR THE SITE

During implementation, the radiation exposure of the population may primarily originate from radiography testing. Taking into account the calculations of Chapter 20.4.2.7, knowing the number of radiographic tests it is possible to determine the annual radiation exposure of the population. The values can be expected to be of the same order of magnitude as the results found in the chapter referred to.

20.5.1 IMPACT AREAS OF PAKS II CONSTRUCTION

20.5.1.1 Direct impacts

Considering the radiation exposure of radiographic tests as direct impact, this corresponds to the results of Chapter 20.4.2.7.

20.5.1.2 Indirect impacts

Not applicable in implementation/construction phase.

20.5.1.3 Transboundary impacts

No transboundary (cross-border) impactss need to be considered during construction.

20.6 IMPACT OF PAKS II OPERATION ON THE RADIATION EXPOSURE OF THE POPULATION NEAR THE SITE

20.6.1 NORMAL OPERATION

The calculation of doses due to emissions during normal operation were performed like the JERMS calculations and in a way described in Chapter 20.4.1.1 with the same set of parameters with the following exceptions:

- The location of the Csámpa population was slightly shifted, according to the new chimney coordinates calculations were done for 1 500 m from the center in wind velocity sector 12.
- According to the data given two kinds of emission were calculated, then the results were summarized.

20.6.1.1 Normal operation emission data

During normal operation, emissions take place at 100 m (chimney) and at 40 m (turbine building) heights.

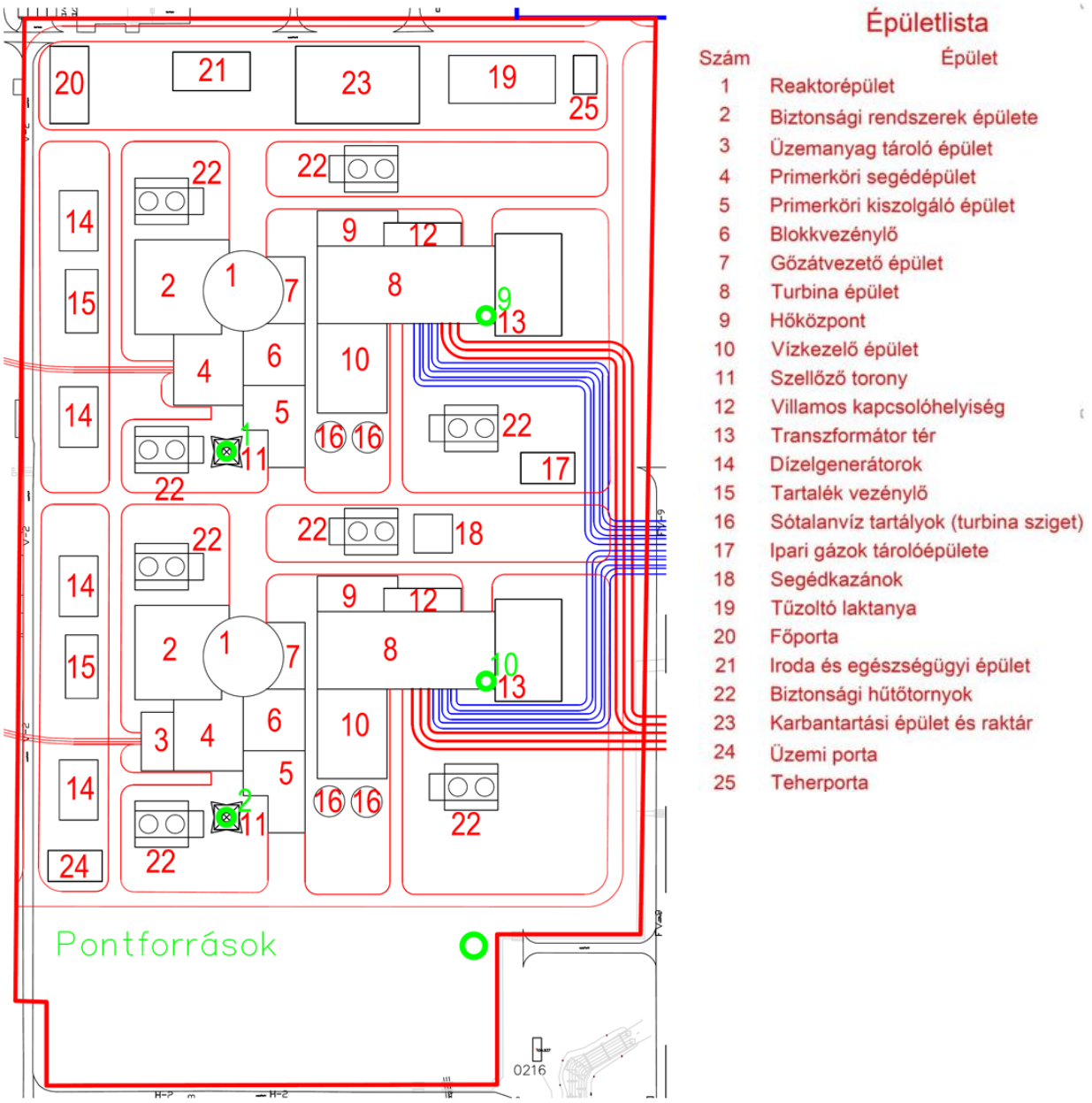
I. Emission through chimney: starting from the pre-defined 100 m chimney height and taking the similar features of the Paks NPP as basis a 120 m effective emission height and the data of a 120 m meteorology tower were used.

II. Emission above turbine building top: instead of the given 40 m emission height again a little more elevated, 50 m effective height was taken, adapted to the 50 m data of the meteorology tower.

The EOV coordinates of emissions during normal operation are the following:

	Description	Y	X
Unit 1	Ventilation chimney	635 030	137 110
	Turbine building	635 198	137 197
Unit 2	Ventilation chimney	635 030	137 346
	Turbine building	635 198	137 433

Table 20.6.1-1: Paks II. normal operation emission sources and their EOV coordinates



Legend: Building list: -

1. Reactor building,
2. Building for nuclear safety systems
3. Building for fuel storage
4. Auxiliary building for the primary circuit
5. Service building for the primary circuit
6. Control room
7. Building for steam transfer
8. Turbine hall
9. Heating center
10. Water treatment building
11. Ventilation tower
12. Electrical switch room
13. Current transformers
14. Diesel generators
15. Emergency control room
16. Purified water tanks
17. Storage building for industrial gases
18. Auxiliary boilers' building
19. Firehouse
20. Main reception building
21. Building for offices and health
22. Safety cooling towers
23. Building for maintenance and storage
24. Industrial reception building
25. Loading reception building

Figure 20.6.1-1: Normal operation emission points (green: chimney; turbine building)

For emission by nuclide, the normal operating values supplied by MVM Paks II Zrt (data of Russian party) were taken as starting point, with the following supplementary arguments (Table 20.6.1-2):

- Tritium was considered as 100 % vapor
- Radiocarbon was considered as 5 % CO_2 and 95 % organic, based on Paks NPP emission data tabulated over many years
- Radioiodines were considered 4 % aerosol, 40 % elemental and 56 % organic, based on Paks NPP emission data tabulated for the past few years
- Noble gases were identified as elemental gas, the rest of radionuclides as aerosol.

Radionuclide	Emission through chimney Emission I	Emission above turbine bdg roof Emission II
	Bq/yr	Bq/yr
^{3}H	7,80E+12	2,40E+09
^{14}C (CO_2)	3,00E+10	-
^{14}C (organic)	5,70E+11	-
^{83m}Kr	1,34E+12	5,40E+10
^{85m}Kr	4,56E+12	1,22E+10
^{85}Kr	7,12E+11	1,32E+08
^{87}Kr	2,76E+12	1,28E+11
^{88}Kr	1,01E+13	3,00E+11
^{131m}Xe	4,98E+11	3,20E+09
^{133}Xe	5,62E+13	9,40E+11
^{135}Xe	1,51E+13	6,60E+11
^{138}Xe	5,72E+11	6,20E+10
^{131}I (aerosol)	4,85E+07	2,48E+05
^{132}I (aerosol)	6,46E+07	8,00E+05
^{133}I (aerosol)	9,20E+07	7,44E+05
^{134}I (aerosol)	4,40E+07	2,24E+05
^{135}I (aerosol)	7,53E+07	5,68E+05
^{131}I (elemental)	4,85E+07	2,48E+06
^{132}I (elemental)	6,46E+07	8,00E+06
^{133}I (elemental)	9,20E+07	7,44E+06
^{134}I (elemental)	4,40E+07	2,24E+06
^{135}I (elemental)	7,53E+07	5,68E+06
^{131}I (organic)	4,85E+07	3,47E+06
^{132}I (organic)	6,46E+07	1,12E+07
^{133}I (organic)	9,20E+07	1,04E+07
^{134}I (organic)	4,40E+07	3,14E+06
^{135}I (organic)	7,53E+07	7,95E+06
^{51}Cr	1,57E+05	3,00E+02
^{54}Mn	9,66E+03	4,20E+02
^{60}Co	6,20E+04	4,80E+03
^{89}Sr	6,50E+05	2,80E+04
^{90}Sr	1,19E+03	8,80E+01
^{134}Cs	4,00E+07	2,00E+06
^{137}Cs	6,06E+07	2,60E+06

Source: MIR.1200 Preliminary data and information for safety and environmental licensing, Appendix 3

Table 20.6.1-2: Emission through chimney (I) and above turbine bdg (II) during normal operation for the two units (Bq/yr).

20.6.1.2 Dose calculations

As a conservative approximation to meteorological conditions for each year between 2001 and 2012 the total doses of the Csámpa children aged 1-2 due to the given chimney emissions (I) during normal operation were compared, and finally the 2009 meteorological year – where this value was maximum (see Table 20.6.1-3) was selected for detailed calculations. In 2009, the radiation dose was maximum subject to normal emission values due to worse climatic conditions.

The more detailed calculations based on YR 2009 meteorological data were performed including two age groups – small children aged 1-2 and adults. The results by nuclide relevant to the Csámpa population are presented in Table 20.6.1-4 to Table 20.6.1-6. The summary results corresponding to the entire area, broken down by irradiation pathway (the total dose is a sum of partial contributions from different irradiation pathways) are shown in Table 20.6.1-7 and Table 20.6.1-8 for the above two age groups. The following area split was applied:

Sector-group	Sector	Ring	Distance [km]
4-7	4,5,6,7	< 1 km	0,5
8-11	8,9,10,11	1-5 km	3
12-15	12,13,14,15	5-10 km	7,5
16-3	16,1,2,3	10-30 km	20
Csámpa	12	Csámpa	1,5

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
^{3}H	2,50E-09	3,70E-09	3,60E-09	2,70E-09	4,20E-09	3,40E-09	3,80E-09	3,30E-09	4,80E-09	3,90E-09	2,90E-09	3,20E-09
^{14}C (CO_2)	5,60E-09	8,40E-09	8,00E-09	6,20E-09	9,60E-09	7,80E-09	8,50E-09	7,50E-09	1,10E-08	8,90E-09	6,50E-09	7,20E-09
^{14}C (organic)	8,60E-10	1,30E-09	1,20E-09	9,40E-10	1,50E-09	1,20E-09	1,30E-09	1,10E-09	1,60E-09	1,40E-09	9,90E-10	1,10E-09
^{83m}Kr	3,10E-14	4,70E-14	4,40E-14	3,50E-14	5,20E-14	4,20E-14	4,70E-14	4,00E-14	6,00E-14	4,90E-14	3,60E-14	3,90E-14
^{85m}Kr	4,40E-10	6,60E-10	6,30E-10	4,90E-10	7,40E-10	6,00E-10	6,60E-10	5,70E-10	8,50E-10	7,00E-10	5,10E-10	5,60E-10
^{85}Kr	2,40E-12	3,60E-12	3,50E-12	2,70E-12	4,10E-12	3,30E-12	3,70E-12	3,20E-12	4,70E-12	3,80E-12	2,80E-12	3,10E-12
^{87}Kr	1,50E-09	2,30E-09	2,10E-09	1,70E-09	2,50E-09	2,00E-09	2,20E-09	1,90E-09	2,90E-09	2,40E-09	1,70E-09	1,90E-09
^{88}Kr	1,40E-08	2,10E-08	2,00E-08	1,60E-08	2,40E-08	2,00E-08	2,20E-08	1,80E-08	2,80E-08	2,30E-08	1,70E-08	1,80E-08
^{131m}Xe	3,00E-12	4,40E-12	4,30E-12	3,30E-12	5,10E-12	4,10E-12	4,50E-12	4,00E-12	5,70E-12	4,70E-12	3,50E-12	3,80E-12
^{133}Xe	1,10E-09	1,60E-09	1,60E-09	1,20E-09	1,90E-09	1,50E-09	1,70E-09	1,50E-09	2,10E-09	1,70E-09	1,30E-09	1,40E-09
^{135}Xe	2,50E-09	3,70E-09	3,50E-09	2,70E-09	4,20E-09	3,40E-09	3,70E-09	3,30E-09	4,70E-09	3,90E-09	2,90E-09	3,10E-09
^{138}Xe	3,40E-10	5,60E-10	5,00E-10	4,10E-10	5,70E-10	4,40E-10	5,10E-10	3,80E-10	6,90E-10	5,90E-10	4,20E-10	4,30E-10
^{131}I (aerosol)	7,40E-11	9,50E-11	8,60E-11	8,30E-11	1,50E-10	1,10E-10	9,80E-11	8,30E-11	1,10E-10	1,30E-10	6,60E-11	7,40E-11
^{132}I (aerosol)	4,00E-14	5,60E-14	5,10E-14	4,50E-14	7,40E-14	5,70E-14	5,60E-14	4,70E-14	6,90E-14	6,90E-14	4,10E-14	4,50E-14
^{133}I (aerosol)	3,90E-13	5,40E-13	5,00E-13	4,40E-13	7,20E-13	5,60E-13	5,60E-13	4,80E-13	6,80E-13	6,70E-13	4,00E-13	4,40E-13
^{134}I (aerosol)	1,70E-14	2,50E-14	2,20E-14	1,90E-14	3,00E-14	2,30E-14	2,40E-14	1,90E-14	3,00E-14	2,90E-14	1,80E-14	1,90E-14
^{135}I (aerosol)	9,10E-14	1,30E-13	1,20E-13	1,00E-13	1,70E-13	1,30E-13	1,30E-13	1,10E-13	1,50E-13	1,60E-13	9,20E-14	1,00E-13
^{131}I (elemental)	3,30E-09	5,10E-09	4,80E-09	3,70E-09	5,60E-09	4,60E-09	5,10E-09	4,30E-09	6,50E-09	5,30E-09	3,90E-09	4,30E-09
^{132}I (elemental)	1,20E-12	1,90E-12	1,80E-12	1,40E-12	2,10E-12	1,70E-12	1,90E-12	1,60E-12	2,50E-12	2,00E-12	1,50E-12	1,60E-12
^{133}I (elemental)	1,30E-11	2,00E-11	1,80E-11	1,40E-11	2,20E-11	1,80E-11	2,00E-11	1,70E-11	2,50E-11	2,10E-11	1,50E-11	1,70E-11
^{134}I (elemental)	4,20E-13	6,70E-13	6,10E-13	4,90E-13	7,10E-13	5,60E-13	6,50E-13	5,20E-13	8,50E-13	7,10E-13	5,10E-13	5,40E-13
^{135}I (elemental)	3,00E-12	4,60E-12	4,30E-12	3,40E-12	5,10E-12	4,10E-12	4,60E-12	3,90E-12	6,00E-12	4,80E-12	3,60E-12	3,90E-12
^{131}I (organic)	3,80E-11	5,60E-11	5,30E-11	4,20E-11	6,50E-11	5,30E-11	5,70E-11	5,00E-11	7,10E-11	6,00E-11	4,30E-11	4,70E-11
^{132}I (organic)	3,50E-13	5,30E-13	4,90E-13	3,90E-13	5,90E-13	4,70E-13	5,30E-13	4,50E-13	6,70E-13	5,50E-13	4,00E-13	4,40E-13
^{133}I (organic)	4,70E-12	7,10E-12	6,80E-12	5,20E-12	8,10E-12	6,50E-12	7,20E-12	6,30E-12	9,20E-12	7,50E-12	5,50E-12	6,00E-12
^{134}I (organic)	1,40E-13	2,30E-13	2,10E-13	1,60E-13	2,40E-13	1,90E-13	2,20E-13	1,80E-13	2,80E-13	2,40E-13	1,70E-13	1,80E-13
^{135}I (organic)	9,30E-13	1,40E-12	1,30E-12	1,00E-12	1,60E-12	1,30E-12	1,40E-12	1,20E-12	1,80E-12	1,50E-12	1,10E-12	1,20E-12
^{51}Cr	1,00E-14	1,30E-14	1,20E-14	1,10E-14	2,00E-14	1,60E-14	1,30E-14	1,10E-14	1,60E-14	1,80E-14	9,00E-15	1,00E-14
^{54}Mn	3,20E-14	4,10E-14	3,70E-14	3,60E-14	6,40E-14	4,90E-14	4,20E-14	3,60E-14	4,90E-14	5,70E-14	2,80E-14	3,20E-14
^{60}Co	1,40E-12	1,80E-12	1,70E-12	1,50E-12	2,80E-12	2,10E-12	1,80E-12	1,50E-12	2,10E-12	2,50E-12	1,20E-12	1,40E-12
^{89}Sr	3,60E-12	4,60E-12	4,10E-12	4,00E-12	7,20E-12	5,40E-12	4,70E-12	4,00E-12	5,40E-12	6,50E-12	3,10E-12	3,50E-12
^{90}Sr	4,40E-14	5,70E-14	5,20E-14	5,00E-14	8,80E-14	6,80E-14	5,90E-14	5,00E-14	6,80E-14	8,00E-14	3,90E-14	4,40E-14
^{134}Cs	1,00E-09	1,30E-09	1,20E-09	1,10E-09	2,00E-09	1,60E-09	1,30E-09	1,10E-09	1,60E-09	1,80E-09	8,90E-10	1,00E-09
^{137}Cs	1,10E-09	1,50E-09	1,20E-09	1,20E-09	2,20E-09	1,70E-09	1,50E-09	1,20E-09	1,70E-09	2,00E-09	9,60E-10	1,10E-09
Total	3,40E-08	5,10E-08	4,90E-08	3,80E-08	5,90E-08	4,80E-08	5,20E-08	4,50E-08	6,60E-08	5,50E-08	4,00E-08	4,40E-08

Table 20.6.1-3: Total doses affecting 1-2 years old Csámpa children – due to chimney emissions (I) during normal operation [Sv], 2001 – 2012.

Environmental element	Air	Soil	Meat	Cereal	Vegetable	Milk
Nuclide	Bq/m³	Bq/m²	Bq/kg	Bq/kg	Bq/kg	Bq/dm³
^{3}H	1,86E-02	0,00E+00	4,87E-02	2,48E-01	1,36E+00	5,66E-02
^{14}C (CO_2)	7,15E-05	0,00E+00	1,91E-01	4,00E-02	9,53E-03	3,19E-02
^{14}C (organic)	1,36E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
^{83m}Kr	3,12E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
^{85m}Kr	1,05E-02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
^{85}Kr	1,70E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
^{87}Kr	6,26E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
^{88}Kr	2,39E-02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
^{131m}Xe	1,20E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
^{133}Xe	1,38E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
^{135}Xe	3,79E-02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
^{138}Xe	9,11E-04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
^{131}I (aerosol)	1,47E-08	9,68E-05	3,70E-07	5,39E-06	2,95E-06	1,94E-06
^{132}I (aerosol)	1,99E-08	1,55E-06	5,52E-21	4,79E-20	1,44E-20	1,94E-20
^{133}I (aerosol)	2,86E-08	2,01E-05	7,48E-14	8,05E-11	6,69E-09	3,82E-08
^{134}I (aerosol)	1,12E-08	3,32E-07	1,19E-21	1,03E-20	3,10E-21	1,59E-21
^{135}I (aerosol)	2,30E-08	5,16E-06	1,81E-20	1,57E-19	1,21E-14	1,14E-11
^{131}I (elemental)	1,37E-07	5,53E-03	2,11E-05	3,08E-04	1,68E-04	1,11E-04
^{132}I (elemental)	1,84E-07	8,78E-05	3,13E-19	2,71E-18	8,14E-19	1,10E-18
^{133}I (elemental)	2,65E-07	1,14E-03	4,23E-12	4,55E-09	3,79E-07	2,16E-06
^{134}I (elemental)	1,05E-07	1,92E-05	6,86E-20	5,95E-19	1,79E-19	9,15E-20
^{135}I (elemental)	2,13E-07	2,95E-04	1,03E-18	8,95E-18	6,93E-13	6,53E-10
^{131}I (organic)	2,08E-07	4,51E-05	1,73E-07	2,52E-06	1,37E-06	9,04E-07
^{132}I (organic)	2,83E-07	7,24E-07	2,58E-21	2,24E-20	6,71E-21	9,07E-21
^{133}I (organic)	4,07E-07	9,43E-06	3,50E-14	3,77E-11	3,13E-09	1,79E-08
^{134}I (organic)	1,58E-07	1,55E-07	5,54E-22	4,80E-21	1,44E-21	7,39E-22
^{135}I (organic)	3,26E-07	2,42E-06	8,47E-21	7,34E-20	5,69E-15	5,36E-12
^{51}Cr	3,71E-10	8,36E-06	2,81E-07	6,82E-07	2,44E-07	3,73E-08
^{54}Mn	2,45E-11	3,43E-06	4,26E-09	9,12E-08	3,07E-08	1,77E-09
^{60}Co	1,65E-10	3,18E-05	1,06E-06	6,27E-07	1,90E-07	9,48E-08
^{89}Sr	1,64E-09	6,66E-05	5,74E-08	4,18E-06	1,41E-06	1,59E-07
^{90}Sr	3,15E-12	6,41E-07	4,36E-10	1,25E-08	4,09E-09	9,71E-10
^{134}Cs	1,02E-07	1,78E-02	4,07E-04	9,50E-04	1,16E-04	2,21E-04
^{137}Cs	1,53E-07	3,12E-02	6,72E-04	1,46E-03	1,78E-04	3,59E-04

Table 20.6.1-4: Activity concentrations in 2009 in the Csámpa region based on meteorological data (I+II).

Dose / Nuclide	Gamma cloud	Gamma soil	Gamma resusp.	Beta*	Inhalation	Inhalation resusp.	Ingestion	External	Internal	Total
^{3}H	0,00E+00	0,00E+00	0,00E+00	0,00E+00	6,75E-10	0,00E+00	4,13E-09	0,00E+00	4,80E-09	**4,80E-09**
^{14}C (CO_2)	1,81E-16	0,00E+00	0,00E+00	1,50E-13	1,03E-12	0,00E+00	1,09E-08	1,68E-15	1,10E-08	**1,10E-08**
^{14}C (organic)	3,45E-15	0,00E+00	0,00E+00	2,85E-12	1,64E-09	0,00E+00	0,00E+00	3,19E-14	1,60E-09	**1,60E-09**
^{83m}Kr	5,17E-14	0,00E+00	0,00E+00	1,24E-12	0,00E+00	0,00E+00	0,00E+00	6,41E-14	0,00E+00	**6,39E-14**
^{85m}Kr	8,37E-10	0,00E+00	0,00E+00	1,51E-09	0,00E+00	0,00E+00	0,00E+00	8,52E-10	0,00E+00	**8,54E-10**
^{85}Kr	2,43E-12	0,00E+00	0,00E+00	2,25E-10	0,00E+00	0,00E+00	0,00E+00	4,68E-12	0,00E+00	**4,70E-12**
^{87}Kr	3,04E-09	0,00E+00	0,00E+00	5,39E-09	0,00E+00	0,00E+00	0,00E+00	3,09E-09	0,00E+00	**3,11E-09**
^{88}Kr	2,82E-08	2,12E-10	9,56E-18	1,36E-08	4,46E-10	2,18E-18	2,14E-22	2,87E-08	4,47E-10	**2,94E-08**
^{131m}Xe	5,16E-12	0,00E+00	0,00E+00	6,35E-11	0,00E+00	0,00E+00	0,00E+00	5,79E-12	0,00E+00	**5,76E-12**
^{133}Xe	2,13E-09	0,00E+00	0,00E+00	4,85E-09	0,00E+00	0,00E+00	0,00E+00	2,17E-09	0,00E+00	**2,16E-09**
^{135}Xe	5,02E-09	0,00E+00	0,00E+00	7,12E-09	0,00E+00	0,00E+00	0,00E+00	5,10E-09	0,00E+00	**5,05E-09**
^{138}Xe	7,53E-10	2,93E-11	2,24E-18	7,24E-10	1,33E-11	2,13E-19	5,71E-24	7,90E-10	1,32E-11	**8,00E-10**
^{131}I (aerosol)	3,07E-15	4,06E-13	5,83E-18	4,86E-15	8,00E-13	1,51E-15	1,20E-10	4,09E-13	1,18E-10	**1,18E-10**
^{132}I (aerosol)	2,64E-14	3,93E-14	7,72E-21	3,51E-14	1,45E-14	4,23E-21	1,35E-26	6,60E-14	1,41E-14	**8,00E-14**
^{133}I (aerosol)	9,79E-15	1,40E-13	2,31E-19	1,80E-13	3,89E-13	9,22E-18	2,09E-13	1,51E-13	6,01E-13	**7,56E-13**
^{134}I (aerosol)	1,73E-14	1,17E-14	7,39E-22	2,34E-14	3,13E-15	1,34E-22	6,86E-28	2,93E-14	3,09E-15	**3,20E-14**
^{135}I (aerosol)	2,11E-14	8,55E-14	5,15E-20	2,79E-14	6,42E-14	1,58E-19	1,18E-17	1,07E-13	6,40E-14	**1,66E-13**
^{131}I (elemental)	2,87E-14	2,32E-11	3,33E-16	4,54E-14	1,65E-11	1,92E-13	6,88E-09	2,32E-11	6,89E-09	**6,89E-09**
^{132}I (elemental)	2,45E-13	2,23E-12	4,39E-19	3,26E-13	3,21E-13	5,76E-19	7,66E-25	2,48E-12	3,20E-13	**2,85E-12**
^{133}I (elemental)	9,09E-14	7,94E-12	1,31E-17	1,68E-12	8,23E-12	1,19E-15	1,18E-11	8,05E-12	1,97E-11	**2,74E-11**
^{134}I (elemental)	1,63E-13	6,77E-13	4,27E-20	2,21E-13	5,51E-14	1,44E-20	3,95E-26	8,42E-13	5,50E-14	**8,99E-13**
^{135}I (elemental)	1,96E-13	4,87E-12	2,94E-18	2,59E-13	1,37E-12	2,07E-17	6,74E-16	5,07E-12	1,41E-12	**6,52E-12**
^{131}I (organic)	4,35E-14	1,89E-13	2,71E-18	6,87E-14	2,04E-11	1,28E-15	5,62E-11	2,34E-13	7,62E-11	**7,62E-11**
^{132}I (organic)	3,75E-13	1,83E-14	3,62E-21	5,00E-13	3,85E-13	3,72E-21	6,32E-27	3,98E-13	3,85E-13	**7,80E-13**
^{133}I (organic)	1,39E-13	6,56E-14	1,09E-19	2,56E-12	9,87E-12	7,69E-18	9,80E-14	2,30E-13	1,00E-11	**1,02E-11**
^{134}I (organic)	2,44E-13	5,46E-15	3,44E-22	3,32E-13	5,14E-14	7,24E-23	3,19E-28	2,53E-13	5,12E-14	**2,99E-13**
^{135}I (organic)	2,98E-13	4,00E-14	2,41E-20	3,96E-13	1,66E-12	1,34E-19	5,53E-18	3,42E-13	1,66E-12	**1,99E-12**
^{51}Cr	6,14E-18	2,86E-15	1,08E-19	6,96E-18	5,90E-17	1,03E-18	1,26E-14	2,87E-15	1,30E-14	**1,60E-14**
^{54}Mn	1,19E-17	3,11E-14	3,69E-18	1,30E-17	1,15E-16	3,56E-17	2,11E-14	3,11E-14	2,14E-14	**5,25E-14**
^{60}Co	2,37E-16	8,44E-13	1,19E-16	2,73E-16	1,07E-14	5,35E-15	1,55E-12	8,44E-13	1,58E-12	**2,38E-12**
^{89}Sr	7,98E-18	5,15E-14	3,72E-19	6,35E-16	3,73E-14	1,74E-15	5,76E-12	5,15E-14	5,79E-12	**5,79E-12**
^{90}Sr	3,44E-21	7,79E-16	1,84E-21	3,09E-18	9,54E-16	5,15E-16	7,38E-14	7,79E-16	7,53E-14	**7,64E-14**
^{134}Cs	9,13E-14	2,95E-10	3,90E-14	1,07E-13	5,65E-13	2,42E-13	1,36E-09	2,95E-10	1,41E-09	**1,73E-09**
^{137}Cs	1,05E-13	1,93E-10	2,83E-14	9,29E-14	6,38E-13	3,38E-13	1,60E-09	1,93E-10	1,61E-09	**1,82E-09**
Total	**4,01E-08**	**7,69E-10**	**6,78E-14**	**3,35E-08**	**2,83E-09**	**7,83E-13**	**2,50E-08**	**4,12E-08**	**2,77E-08**	**6,88E-08**

***** 1% of the immersion beta dose (skin dose) value is included in the external and total (effective) doses.

Table 20.6.1-5: Doses relevant to 1-2 years old children in the Csámpa region based on 2009 meteorological data (I+II, Sv).

Dose / Nuclide	Gamma cloud	Gamma soil	Gamma resusp.	Beta*	Inhalation	Inhalation resusp.	Ingestion	External	Internal	Total
^{3}H	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,05E-09	0,00E+00	1,87E-09	0,00E+00	2,90E-09	2,90E-09
^{14}C (CO_2)	1,81E-16	0,00E+00	0,00E+00	1,50E-13	1,40E-12	0,00E+00	6,60E-09	1,68E-15	6,60E-09	6,60E-09
^{14}C (organic)	3,45E-15	0,00E+00	0,00E+00	2,85E-12	2,48E-09	0,00E+00	0,00E+00	3,19E-14	2,50E-09	2,50E-09
^{83m}Kr	5,17E-14	0,00E+00	0,00E+00	1,24E-12	0,00E+00	0,00E+00	0,00E+00	6,41E-14	0,00E+00	6,39E-14
^{85m}Kr	7,43E-10	0,00E+00	0,00E+00	1,51E-09	0,00E+00	0,00E+00	0,00E+00	7,58E-10	0,00E+00	7,63E-10
^{85}Kr	2,25E-12	0,00E+00	0,00E+00	2,25E-10	0,00E+00	0,00E+00	0,00E+00	4,49E-12	0,00E+00	4,50E-12
^{87}Kr	2,70E-09	0,00E+00	0,00E+00	5,39E-09	0,00E+00	0,00E+00	0,00E+00	2,75E-09	0,00E+00	2,79E-09
^{88}Kr	2,73E-08	1,96E-10	8,23E-18	1,36E-08	2,48E-10	1,21E-18	4,95E-23	2,75E-08	2,45E-10	2,73E-08
^{131m}Xe	5,16E-12	0,00E+00	0,00E+00	6,35E-11	0,00E+00	0,00E+00	0,00E+00	5,79E-12	0,00E+00	5,76E-12
^{133}Xe	1,97E-09	0,00E+00	0,00E+00	4,85E-09	0,00E+00	0,00E+00	0,00E+00	2,03E-09	0,00E+00	2,06E-09
^{135}Xe	4,61E-09	0,00E+00	0,00E+00	7,12E-09	0,00E+00	0,00E+00	0,00E+00	4,68E-09	0,00E+00	4,72E-09
^{138}Xe	6,62E-10	2,74E-11	2,07E-18	7,24E-10	7,40E-12	1,18E-19	1,61E-24	6,97E-10	7,40E-12	7,08E-10
^{131}I (aerosol)	2,75E-15	3,42E-13	5,21E-18	4,86E-15	3,43E-13	6,48E-16	2,24E-11	3,45E-13	2,25E-11	2,25E-11
^{132}I (aerosol)	2,19E-14	3,08E-14	6,44E-21	3,51E-14	6,90E-15	2,02E-21	2,55E-27	5,31E-14	6,88E-15	5,95E-14
^{133}I (aerosol)	8,53E-15	1,22E-13	2,01E-19	1,80E-13	1,36E-13	3,20E-18	2,55E-14	1,32E-13	1,56E-13	2,89E-13
^{134}I (aerosol)	1,48E-14	7,33E-15	6,34E-22	2,34E-14	1,94E-15	8,30E-23	1,67E-28	2,24E-14	1,92E-15	2,45E-14
^{135}I (aerosol)	1,90E-14	6,84E-14	4,66E-20	2,79E-14	2,32E-14	5,68E-20	1,55E-18	8,77E-14	2,32E-14	1,10E-13
^{131}I (elemental)	2,57E-14	1,95E-11	2,98E-16	4,54E-14	8,63E-12	1,00E-13	1,28E-09	1,96E-11	1,27E-09	1,27E-09
^{132}I (elemental)	2,04E-13	1,75E-12	3,66E-19	3,26E-13	1,81E-13	3,24E-19	1,44E-25	1,95E-12	1,83E-13	2,17E-12
^{133}I (elemental)	7,92E-14	6,93E-12	1,15E-17	1,68E-12	3,35E-12	4,85E-16	1,44E-12	7,03E-12	4,82E-12	1,20E-11
^{134}I (elemental)	1,40E-13	4,23E-13	3,66E-20	2,21E-13	4,98E-14	1,31E-20	9,60E-27	5,65E-13	4,97E-14	6,13E-13
^{135}I (elemental)	1,76E-13	3,91E-12	2,65E-18	2,59E-13	6,19E-13	9,30E-18	8,87E-17	4,08E-12	6,20E-13	4,68E-12
^{131}I (organic)	3,89E-14	1,60E-13	2,42E-18	6,87E-14	9,82E-12	6,12E-16	1,04E-11	1,99E-13	2,04E-11	2,04E-11
^{132}I (organic)	3,12E-13	1,44E-14	3,01E-21	5,00E-13	1,69E-13	1,63E-21	1,19E-27	3,32E-13	1,74E-13	5,01E-13
^{133}I (organic)	1,21E-13	5,72E-14	9,46E-20	2,56E-12	3,99E-12	3,11E-18	1,19E-14	2,05E-13	4,01E-12	4,23E-12
^{134}I (organic)	2,09E-13	3,41E-15	2,95E-22	3,32E-13	2,49E-14	3,51E-23	7,75E-29	2,16E-13	2,45E-14	2,45E-13
^{135}I (organic)	2,70E-13	3,20E-14	2,18E-20	3,96E-13	6,99E-13	5,64E-20	7,28E-19	3,06E-13	6,96E-13	1,01E-12
^{51}Cr	5,74E-18	2,31E-15	1,01E-19	6,96E-18	4,33E-17	7,62E-19	3,58E-15	2,31E-15	3,61E-15	5,92E-15
^{54}Mn	1,05E-17	3,03E-14	3,27E-18	1,30E-17	1,16E-16	3,59E-17	8,30E-15	3,04E-14	8,47E-15	3,86E-14
^{60}Co	2,19E-16	7,02E-13	1,09E-16	2,73E-16	1,62E-14	8,04E-15	3,46E-13	7,02E-13	3,72E-13	1,07E-12
^{89}Sr	7,06E-18	4,41E-14	3,29E-19	6,35E-16	4,09E-14	1,91E-15	1,42E-12	4,41E-14	1,50E-12	1,50E-12
^{90}Sr	2,81E-21	7,08E-16	1,51E-21	3,09E-18	1,60E-15	8,58E-16	4,77E-14	7,08E-16	5,05E-14	5,16E-14
^{134}Cs	8,12E-14	2,35E-10	3,47E-14	1,07E-13	2,12E-12	9,09E-13	2,75E-09	2,35E-10	2,71E-09	2,93E-09
^{137}Cs	9,13E-14	1,79E-10	2,47E-14	9,29E-14	2,27E-12	1,20E-12	2,94E-09	1,79E-10	2,90E-09	3,11E-09
Total	**3,79E-08**	**6,72E-10**	**5,98E-14**	**3,35E-08**	**3,82E-09**	**2,22E-12**	**1,55E-08**	**3,89E-08**	**1,95E-08**	**5,85E-08**

***** 1% of the immersion beta dose (skin dose) value is included in the external and total (effective) doses.

Table 20.6.1-6: Doses relevant to adults in the Csámpa region based on 2009 meteorological data (I+II, Sv).

Distance	<1 km				1-5 km				5-10 km				10-30 km				1,5 km
Route/Sector	**4-7**	**8-11**	**12-15**	**16-3**	**4-7**	**8-11**	**12-15**	**'16-3**	**'4-7**	**'8-11**	**'12-15**	**'16-3**	**'4-7**	**'8-11**	**'12-15**	**'16-3**	**'12**
Immersion gamma	1,1E-07	1,3E-07	8,4E-08	7,2E-08	1,5E-08	2,2E-08	9,2E-09	1,4E-08	3,3E-09	5,0E-09	1,8E-09	3,2E-09	5,0E-10	7,7E-10	2,5E-10	5,1E-10	4,0E-08
Surface gamma	1,7E-09	2,1E-09	1,4E-09	1,2E-09	3,2E-10	4,8E-10	2,1E-10	3,0E-10	8,8E-11	1,4E-10	5,2E-11	8,7E-11	1,6E-11	2,5E-11	8,3E-12	1,7E-11	7,7E-10
Resusp. gamma	1,9E-13	2,3E-13	1,5E-13	1,3E-13	2,6E-14	3,8E-14	1,6E-14	2,4E-14	5,9E-15	8,8E-15	3,3E-15	5,7E-15	1,1E-15	1,6E-15	5,5E-16	1,1E-15	6,8E-14
Immersion beta*	7,8E-08	9,7E-08	6,2E-08	5,3E-08	1,3E-08	2,0E-08	8,6E-09	1,3E-08	3,5E-09	5,4E-09	2,0E-09	3,5E-09	6,1E-10	9,4E-10	3,1E-10	6,3E-10	3,4E-08
Total external	**1,1E-07**	**1,3E-07**	**8,6E-08**	**7,4E-08**	**1,6E-08**	**2,3E-08**	**9,5E-09**	**1,4E-08**	**3,4E-09**	**5,2E-09**	**1,9E-09**	**3,3E-09**	**5,2E-10**	**8,0E-10**	**2,6E-10**	**5,3E-10**	**4,1E-08**
Inhalation	6,4E-09	7,5E-09	5,0E-09	3,8E-09	1,2E-09	1,8E-09	7,4E-10	1,1E-09	3,1E-10	4,7E-10	1,8E-10	3,0E-10	6,3E-11	9,3E-11	3,2E-11	6,1E-11	2,8E-09
Resusp. Inhalation	2,2E-12	2,7E-12	1,7E-12	1,5E-12	3,0E-13	4,4E-13	1,8E-13	2,7E-13	6,5E-14	9,7E-14	3,6E-14	6,2E-14	1,1E-14	1,7E-14	5,8E-15	1,1E-14	7,8E-13
Ingestion	6,7E-08	7,9E-08	5,1E-08	4,2E-08	9,6E-09	1,4E-08	5,8E-09	8,6E-09	2,2E-09	3,2E-09	1,2E-09	2,0E-09	4,0E-10	5,9E-10	2,1E-10	3,9E-10	2,5E-08
Total internal	**7,4E-08**	**8,7E-08**	**5,6E-08**	**4,5E-08**	**1,1E-08**	**1,6E-08**	**6,5E-09**	**9,8E-09**	**2,5E-09**	**3,7E-09**	**1,4E-09**	**2,3E-09**	**4,7E-10**	**6,9E-10**	**2,4E-10**	**4,5E-10**	**2,8E-08**
Total	**1,8E-07**	**2,2E-07**	**1,4E-07**	**1,2E-07**	**2,6E-08**	**3,9E-08**	**1,6E-08**	**2,4E-08**	**5,8E-09**	**9,0E-09**	**3,3E-09**	**5,7E-09**	**9,9E-10**	**1,5E-09**	**5,0E-10**	**9,7E-10**	**6,9E-08**

* 1% of the immersion beta dose (skin dose) value is included in the external and total (effective) doses.

Table 20.6.1-7: Doses relevant to 1-2 years old children in different areas based on 2009 meteorological data, by irradiation pathway (I+II, Sv).

Distance	<1 km				1-5 km				5-10 km				10-30 km				1,5 km
Route/Sector	**'4-7**	**'8-11**	**'12-15**	**'16-3**	**'4-7**	**'8-11**	**'12-15**	**'16-3**	**'4-7**	**'8-11**	**'12-15**	**'16-3**	**'4-7**	**'8-11**	**'12-15**	**'16-3**	**'12**
Immersion gamma	1,0E-07	1,3E-07	8,0E-08	6,8E-08	1,4E-08	2,1E-08	8,7E-09	1,3E-08	3,1E-09	4,7E-09	1,7E-09	3,0E-09	4,7E-10	7,2E-10	2,4E-10	4,8E-10	3,8E-08
Surface gamma	1,4E-09	1,8E-09	1,2E-09	1,0E-09	2,8E-10	4,3E-10	1,8E-10	2,7E-10	7,8E-11	1,2E-10	4,6E-11	7,8E-11	1,4E-11	2,2E-11	7,4E-12	1,5E-11	6,7E-10
Resusp. gamma	1,6E-13	2,1E-13	1,3E-13	1,2E-13	2,3E-14	3,4E-14	1,4E-14	2,1E-14	5,2E-15	7,7E-15	2,9E-15	5,0E-15	9,5E-16	1,4E-15	4,9E-16	9,3E-16	6,0E-14
Immersion beta*	7,8E-08	9,7E-08	6,2E-08	5,3E-08	1,3E-08	2,0E-08	8,6E-09	1,3E-08	3,5E-09	5,4E-09	2,0E-09	3,5E-09	6,1E-10	9,4E-10	3,1E-10	6,3E-10	3,4E-08
Total external	**1,0E-07**	**1,3E-07**	**8,2E-08**	**7,0E-08**	**1,5E-08**	**2,2E-08**	**8,9E-09**	**1,3E-08**	**3,2E-09**	**4,8E-09**	**1,8E-09**	**3,1E-09**	**4,9E-10**	**7,5E-10**	**2,5E-10**	**5,0E-10**	**3,9E-08**
Inhalation	9,3E-09	1,1E-08	7,1E-09	5,4E-09	1,6E-09	2,3E-09	9,5E-10	1,4E-09	3,9E-10	5,8E-10	2,2E-10	3,6E-10	7,9E-11	1,1E-10	4,0E-11	7,5E-11	3,8E-09
Resusp. Inhalation	6,1E-12	7,6E-12	4,8E-12	4,3E-12	8,5E-13	1,3E-12	5,2E-13	7,8E-13	1,9E-13	2,9E-13	1,1E-13	1,8E-13	3,5E-14	5,1E-14	1,8E-14	3,4E-14	2,2E-12
Ingestion	4,1E-08	4,9E-08	3,2E-08	2,6E-08	6,0E-09	8,8E-09	3,6E-09	5,4E-09	1,4E-09	2,1E-09	7,7E-10	1,3E-09	2,7E-10	3,9E-10	1,4E-10	2,6E-10	1,5E-08
Total internal	**5,0E-08**	**6,0E-08**	**3,9E-08**	**3,1E-08**	**7,5E-09**	**1,1E-08**	**4,6E-09**	**6,8E-09**	**1,8E-09**	**2,6E-09**	**1,0E-09**	**1,7E-09**	**3,5E-10**	**5,0E-10**	**1,7E-10**	**3,3E-10**	**2,0E-08**
Total	**1,5E-07**	**1,9E-07**	**1,2E-07**	**1,0E-07**	**2,2E-08**	**3,3E-08**	**1,3E-08**	**2,0E-08**	**5,0E-09**	**7,5E-09**	**2,8E-09**	**4,8E-09**	**8,4E-10**	**1,3E-09**	**4,2E-10**	**8,2E-10**	**5,9E-08**

* 1% of the immersion beta dose (skin dose) value is included in the external and total (effective) doses.

Table 20.6.1-8: Doses relevant to adults in different areas based on 2009 meteorological data, by irradiation pathway (I+II, Sv).

From Table 20.6.1-3 - Table 20.6.1-8 it is clear that the results are essentially similar to the values calculated for the previous units, while the total dose figures obtained for the Csámpa small children fall short of the past maxima of many years. This is due, in part, to the fact that Csámpa is located further away from and in a slightly different direction with respect to the new chimneys, and to the – obviously different – average emission values supplied.

Streamlined with emissions the proportion of each nuclide departs from the case of the former units, nevertheless the external dose due to noble gases (^{88}Kr ruling) and ingestion due to radiocarbons prevail as dominant. Apart from these, tritium, (elemental) ^{131}I and Cs isotopes possess significant dose contributions. The dose affecting 1-2 years old children appears slightly higher than that for adults, and in both cases external doses dominate.

Given that the calculated effective doses do not exceed the 90 μSv value anywhere in the study area, actually the highest calculated values (even the 220 nSv obtained for small children at 500 m) are two and a half order of magnitude smaller than this threshold, it is fair to conclude that the normal operation of the nuclear power plant will not introduce any additional risk (on top of the neutral 90 μSv baseline) beyond the safety zone.

20.6.2 DESIGN-BASED FAILURE (DBC4)

For each operating state of the planned units it is possible to determine those events that result in the largest degree of emission in that particular mode. The design-based failure events of the planned units are presented in Chapter 6.13.4 based on preliminary data supplied by the Russian party.

Pursuant to Clause 3.2.2.3300. of the NSC code published in Government Decree no. 118/2011. (VII.11) Korm., in respect of new nuclear power plant units the occurrence of internal initial events arising from the failure of systems, system elements, human error, or both, can be eliminated from the range of assumed initial events, if their frequency is less than 10^{-6}/yr.

Having regard to this, when determining failure effects and impact areas, of the events included in the Design Basis the very low frequency DBC4 design breakdown will be taken into account in compliance with NSC Appendix 3 Clause 3.2.2.0200 and Appendix 10 Clause 163 – Operating State (Design Basis 4: Events included in Design Basis, very low frequency design breakdowns: $10^{-4} > f > 10^{-6}$ [1/yr]). This was selected as a blanket case.

To investigate design breakdown events, the data made available for the DBC4 (Design Basis Category 4 Conditions) case included in the preliminary Russian data supply document titled ”Data for NPP environmental impact analysis (AES-2006 with VVER-1200)” were used.

Regarding the DBC4 event, emissions through the 100 m high chimney were translated to 120 m effective height, while for "surface" emissions the 35 m height of building rooftop fans was indicative.

The emission EOV coordinates of the DBC4 event are given below:

	Description	X	Y
Unit 1	Ventilation chimney	635 030	137 110
	Building fan	635 074	137 442
Unit 2	Ventilation chimney	635 030	137 346
	Building fan	635 074	137 206

Table 20.6.2-1: DBC4 event emission EOV coordinates.

Figure 20.6.2-1: DBC4 event emission points (green: chimney; yellow: building fan).

For calculation purposes here again the ”SS57” codename model presented in Chapter 20.4.2.1 was used. Early (10 days emission-based) and late (30 days emission-based) doses were distinguished as two separate cases. In both cases, the doses were calculated for a single meteorological status quo for the age groups of 1-2 years old small children and adults. Summertime emissions were assumed, all other parameters were the same as those for normal conditions.

Common meteorological conditions, low precipitation level:

- Stability (Pasquill) category: D
- Wind velocity: 5 m/s (18 km/h)
- Precipitation: 1 mm/h

To define the impact area, first the distance where the doses are maximum was approximated. Because at this distance the calculated dose never exceeded the neutral (effective dose <90 μSv/yr) background effect, among the results the maximum doses were specified by nuclide and accumulated (for the corresponding distance), plus some typical distances were also indicated with their calculated doses.

In the framework of the assumed scenarios, the calculations were performed for the following distances:

- 300 m,
- 400 m (distance of maximum dose),
- 600 m,
- 800 m,
- 3 km,
- 10 km,
- 20 km,
- 30 km

20.6.2.1 DBC4 category event

20.6.2.1.1 Emissions – DBC4

Early doses: Using the 10 day ”surface” and chimney emissions (see Table 20.6.2-2) first the doses below originating from the cloud and the ground surface were calculated, then their sum was taken and shown:

- *Immersion gamma dose*
- *Immersion beta dose (represented by 1 % in sum)*
- *Ground surface gamma dose*
- *Dose due to inhalation*
- *Doses due to resuspension*

Nuclide	10-day chimney emission	10-day "surface" emission
131I (elemental)	2,90E+08	2,10E+09
132I (elemental)	1,50E+07	1,00E+08
133I (elemental)	5,80E+07	4,00E+08
134I (elemental)	3,20E+06	2,30E+07
135I (elemental)	1,00E+07	7,10E+07
131I (organic)	8,70E+09	6,10E+09
132I (organic)	1,70E+08	1,20E+08
133I (organic)	1,40E+09	9,80E+08
134I (organic)	2,00E+07	1,40E+07
135I (organic)	1,90E+08	1,30E+08
85mKr	9,60E+10	6,70E+08
87Kr	4,40E+10	3,10E+08
88Kr	1,80E+11	1,20E+09
133Xe	9,70E+13	6,80E+11
135Xe	3,30E+11	2,30E+09
138Xe	7,00E+09	4,90E+07
134Cs	6,20E+05	4,30E+07
137Cs	2,20E+05	1,60E+07

Source: Data for NPP environmental impact analysis (AES-2006 with VVER-1200), Rusatom Overseas JSC, 2014.09.23.]

Table 20.6.2-2: Early dose emissions (Bq).

Late doses: Using the 30 day ”surface” and chimney emissions (see Table 20.6.2-3) first the doses below originating from the cloud and the ground surface were calculated, then their sum was taken and shown:

- *Immersion gamma dose*
- *Immersion beta dose (represented by 1 % in sum)*
- *Ground surface gamma dose*
- *Dose due to inhalation*
- *Doses due to resuspension*
- *Dose due to ingestion*

Nuclide	30-day chimney emission	30-day "surface" emission
131I (elemental)	4,30E+08	3,00E+09
132I (elemental)	1,50E+07	1,00E+08
133I (elemental)	5,80E+07	4,00E+08
134I (elemental)	3,20E+06	2,30E+07
135I (elemental)	1,00E+07	7,10E+07
131I (organic)	1,40E+10	9,80E+09
132I (organic)	1,70E+08	1,20E+08
133I (organic)	1,40E+09	9,80E+08
134I (organic)	2,00E+07	1,40E+07
135I (organic)	1,90E+08	1,30E+08
85mKr	9,60E+10	6,70E+08
87Kr	4,40E+10	3,10E+08
88Kr	1,80E+11	1,20E+09
133Xe	1,30E+14	9,20E+11
135Xe	3,30E+11	2,30E+09
138Xe	7,00E+09	4,90E+07
134Cs	6,20E+05	4,30E+07
137Cs	2,20E+05	1,60E+07

Table 20.6.2-3: Late dose emissions (Bq).

The calculations were a carried out for both the adult and 1-2 years old children age groups, with the late doses due to ground surface deposition integrated for 50 and 70 years, respectively, while for internal doses always committed dose factors were used. As an additional conservative constraint permanent presence and the exclusive consumption of locally produced food were assumed, and no potential protective measures were considered.

In the calculations chimney and ”surface” emissions were equally taken into account, the tables show the results obtained for the particular cases with the two effects cumulated (summed for a given distance).

In all cases it way assumed in conservative spirit that the wind constantly blows in the same direction with an average speed of 5 m/s, while an average precipitation rate of 1 mm/h is constantly present. The calculations were performed fro the plume maximum along the y axis, at ground surface.

20.6.2.1.2 Doses – DBC4

Table 20.6.2-4 - Table 20.6.2-7 present the total doses and doses by nuclide summed by route for each case, Table 20.6.2-8 separately shows the grand total of the total sums.

Nuclide/Distance	300m	400m	600m	800m	3km	10km	20km	30km
^{131}I (elemental)	3,60E-07	4,50E-07	3,41E-07	2,22E-07	1,47E-08	8,00E-10	1,26E-10	4,00E-11
^{132}I (elemental)	1,10E-09	1,40E-09	1,00E-09	6,68E-10	4,34E-11	2,12E-12	2,90E-13	7,80E-14
^{133}I (elemental)	1,80E-08	2,20E-08	1,71E-08	1,11E-08	7,39E-10	3,90E-11	6,20E-12	1,94E-12
^{134}I (elemental)	1,40E-10	1,70E-10	1,30E-10	8,39E-11	5,19E-12	2,07E-13	2,06E-14	4,30E-15
^{135}I (elemental)	1,60E-09	1,90E-09	1,50E-09	9,50E-10	6,34E-11	3,33E-12	4,90E-13	1,49E-13
^{131}I (organic)	4,50E-07	5,61E-07	4,43E-07	3,09E-07	4,40E-08	5,40E-09	1,47E-09	7,47E-10
^{132}I (organic)	2,50E-10	3,11E-10	2,37E-10	1,76E-10	2,40E-11	2,53E-12	6,11E-13	2,49E-13
^{133}I (organic)	1,80E-08	2,30E-08	1,85E-08	1,22E-08	1,79E-09	2,14E-10	5,98E-11	2,82E-11
^{134}I (organic)	2,00E-11	2,50E-11	1,96E-11	1,43E-11	1,77E-12	1,53E-13	2,93E-14	9,08E-15
^{135}I (organic)	5,90E-10	7,41E-10	5,87E-10	4,21E-10	6,00E-11	6,80E-12	1,81E-12	8,53E-13
^{85m}Kr	4,03E-11	5,88E-11	1,58E-10	2,85E-10	2,12E-10	3,51E-11	1,10E-11	5,10E-12
^{87}Kr	1,11E-10	1,64E-10	4,30E-10	8,01E-10	5,65E-10	8,02E-11	2,00E-11	7,51E-12
^{88}Kr	1,01E-09	1,54E-09	4,10E-09	8,08E-09	7,16E-09	1,40E-09	4,41E-10	1,90E-10
^{133}Xe	7,95E-09	1,17E-08	3,06E-08	5,71E-08	4,34E-08	7,62E-09	2,50E-09	1,30E-09
^{135}Xe	2,32E-10	3,31E-10	8,70E-10	1,64E-09	1,21E-09	2,11E-10	6,71E-11	3,30E-11
^{138}Xe	2,72E-11	4,12E-11	1,13E-10	2,20E-10	1,82E-10	1,30E-11	6,71E-13	5,00E-14
^{134}Cs	3,90E-08	4,80E-08	3,70E-08	2,40E-08	1,62E-09	7,37E-11	8,95E-12	2,24E-12
^{137}Cs	5,50E-09	6,80E-09	5,10E-09	3,40E-09	2,33E-10	1,04E-11	1,29E-12	3,12E-13
Total	**9,00E-07**	**1,10E-06**	**9,02E-07**	**6,56E-07**	**1,17E-07**	**1,59E-08**	**4,78E-09**	**2,38E-09**

Table 20.6.2-4: Early doses of 1-2 years old children (Sv).

Nuclide/Distance	300m	400m	600m	800m	3km	10km	20km	30km
^{131}I (elemental)	2,40E-07	3,00E-07	2,21E-07	1,42E-07	9,70E-09	5,30E-10	8,30E-11	2,60E-11
^{132}I (elemental)	8,40E-10	1,00E-09	7,73E-10	5,06E-10	3,31E-11	1,57E-12	2,24E-13	6,00E-14
^{133}I (elemental)	1,10E-08	1,40E-08	1,10E-08	6,98E-09	4,66E-10	2,52E-11	4,00E-12	1,23E-12
^{134}I (elemental)	9,70E-11	1,20E-10	8,83E-11	5,76E-11	3,51E-12	1,39E-13	1,44E-14	3,00E-15
^{135}I (elemental)	1,10E-09	1,40E-09	1,10E-09	6,97E-10	4,64E-11	2,37E-12	3,60E-13	1,09E-13
^{131}I (organic)	2,20E-07	2,80E-07	2,16E-07	1,54E-07	2,18E-08	2,54E-09	7,45E-10	3,68E-10
^{132}I (organic)	1,60E-10	2,00E-10	1,55E-10	1,10E-10	1,53E-11	1,64E-12	3,96E-13	1,62E-13
^{133}I (organic)	7,60E-09	9,42E-09	7,41E-09	5,30E-09	7,50E-10	8,80E-11	2,49E-11	1,19E-11
^{134}I (organic)	1,60E-11	2,00E-11	1,55E-11	1,09E-11	1,39E-12	1,23E-13	2,26E-14	7,14E-15
^{135}I (organic)	3,10E-10	3,81E-10	3,09E-10	2,11E-10	3,10E-11	3,52E-12	9,60E-13	4,43E-13
^{85m}Kr	3,52E-11	5,19E-11	1,34E-10	2,53E-10	1,92E-10	3,21E-11	9,61E-12	4,60E-12
^{87}Kr	9,97E-11	1,42E-10	3,74E-10	7,03E-10	5,04E-10	7,12E-11	1,70E-11	6,71E-12
^{88}Kr	9,87E-10	1,43E-09	3,96E-09	7,75E-09	6,75E-09	1,30E-09	4,01E-10	1,80E-10
^{133}Xe	7,45E-09	1,08E-08	2,80E-08	5,37E-08	4,03E-08	7,12E-09	2,30E-09	1,20E-09
^{135}Xe	2,11E-10	3,06E-10	8,00E-10	1,53E-09	1,11E-09	1,91E-10	6,11E-11	3,10E-11
^{138}Xe	2,42E-11	3,65E-11	1,00E-10	1,97E-10	1,71E-10	1,20E-11	6,01E-13	4,50E-14
^{134}Cs	3,20E-08	4,00E-08	3,00E-08	2,00E-08	1,32E-09	6,02E-11	7,33E-12	1,80E-12
^{137}Cs	5,30E-09	6,60E-09	5,00E-09	3,30E-09	2,23E-10	1,01E-11	1,18E-12	3,01E-13
Total	**5,30E-07**	**6,53E-07**	**5,22E-07**	**3,95E-07**	**8,40E-08**	**1,20E-08**	**3,65E-09**	**1,85E-09**

Table 20.6.2-5: Early doses of adults (Sv).

Nuclide/Distance	300m	400m	600m	800m	3km	10km	20km	30km
^{131}I (elemental)	2,10E-06	2,50E-06	1,91E-06	1,21E-06	8,39E-08	4,60E-09	7,30E-10	2,30E-10
^{132}I (elemental)	1,10E-09	1,40E-09	1,00E-09	6,68E-10	4,44E-11	2,12E-12	2,90E-13	7,80E-14
^{133}I (elemental)	1,80E-08	2,20E-08	1,71E-08	1,11E-08	7,49E-10	4,10E-11	6,30E-12	1,97E-12
^{134}I (elemental)	1,40E-10	1,80E-10	1,30E-10	8,39E-11	5,20E-12	2,07E-13	2,06E-14	4,30E-15
^{135}I (elemental)	1,60E-09	1,90E-09	1,50E-09	9,60E-10	6,45E-11	3,34E-12	5,00E-13	1,51E-13
^{131}I (organic)	7,80E-07	9,82E-07	7,73E-07	5,51E-07	7,70E-08	9,40E-09	2,71E-09	1,30E-09
^{132}I (organic)	2,50E-10	3,11E-10	2,37E-10	1,76E-10	2,40E-11	2,53E-12	6,11E-13	2,49E-13
^{133}I (organic)	1,90E-08	2,30E-08	1,85E-08	1,22E-08	1,80E-09	2,14E-10	5,98E-11	2,92E-11
^{134}I (organic)	2,00E-11	2,50E-11	1,96E-11	1,43E-11	1,77E-12	1,53E-13	2,93E-14	9,08E-15
^{135}I (organic)	5,90E-10	7,41E-10	5,87E-10	4,21E-10	6,00E-11	6,80E-12	1,81E-12	8,53E-13
^{85m}Kr	4,03E-11	5,88E-11	1,58E-10	2,85E-10	2,12E-10	3,51E-11	1,10E-11	5,10E-12
^{87}Kr	1,11E-10	1,64E-10	4,30E-10	8,01E-10	5,65E-10	8,02E-11	2,00E-11	7,51E-12
^{88}Kr	1,01E-09	1,54E-09	4,10E-09	8,08E-09	7,16E-09	1,40E-09	4,41E-10	1,90E-10
^{133}Xe	1,11E-08	1,53E-08	4,10E-08	7,69E-08	5,85E-08	1,00E-08	3,40E-09	1,70E-09
^{135}Xe	2,32E-10	3,31E-10	8,70E-10	1,64E-09	1,21E-09	2,11E-10	6,71E-11	3,30E-11
^{138}Xe	2,72E-11	4,12E-11	1,13E-10	2,20E-10	1,82E-10	1,30E-11	6,71E-13	5,00E-14
^{134}Cs	6,60E-06	8,20E-06	6,20E-06	4,10E-06	2,73E-07	1,25E-08	1,51E-09	3,81E-10
^{137}Cs	7,60E-06	9,40E-06	7,20E-06	4,80E-06	3,14E-07	1,45E-08	1,72E-09	4,35E-10
Total	**1,70E-05**	**2,10E-05**	**1,61E-05**	**1,12E-05**	**8,30E-07**	**5,30E-08**	**1,07E-08**	**4,34E-09**

Table 20.6.2-6: Late doses of 1-2 years old children (Sv).

Nuclide/Distance	300m	400m	600m	800m	3km	10km	20km	30km
^{131}I (elemental)	7,90E-07	9,80E-07	7,32E-07	4,85E-07	3,29E-08	1,80E-09	2,80E-10	9,00E-11
^{132}I (elemental)	8,50E-10	1,00E-09	7,83E-10	5,06E-10	3,31E-11	1,58E-12	2,25E-13	6,00E-14
^{133}I (elemental)	1,20E-08	1,50E-08	1,10E-08	7,18E-09	4,78E-10	2,54E-11	4,10E-12	1,26E-12
^{134}I (elemental)	9,70E-11	1,20E-10	8,83E-11	5,76E-11	3,51E-12	1,39E-13	1,44E-14	3,00E-15
^{135}I (elemental)	1,20E-09	1,40E-09	1,10E-09	6,98E-10	4,64E-11	2,38E-12	3,70E-13	1,09E-13
^{131}I (organic)	3,70E-07	4,61E-07	3,70E-07	2,54E-07	3,70E-08	4,41E-09	1,35E-09	6,16E-10
^{132}I (organic)	1,60E-10	2,00E-10	1,55E-10	1,10E-10	1,53E-11	1,64E-12	3,96E-13	1,62E-13
^{133}I (organic)	7,60E-09	9,42E-09	7,41E-09	5,30E-09	7,50E-10	8,80E-11	2,49E-11	1,19E-11
^{134}I (organic)	1,60E-11	2,00E-11	1,55E-11	1,09E-11	1,39E-12	1,23E-13	2,26E-14	7,14E-15
^{135}I (organic)	3,10E-10	3,81E-10	3,09E-10	2,11E-10	3,10E-11	3,52E-12	9,60E-13	4,43E-13
^{85m}Kr	3,52E-11	5,19E-11	1,34E-10	2,53E-10	1,92E-10	3,21E-11	9,61E-12	4,60E-12
^{87}Kr	9,97E-11	1,42E-10	3,74E-10	7,03E-10	5,04E-10	7,12E-11	1,70E-11	6,71E-12
^{88}Kr	9,87E-10	1,43E-09	3,96E-09	7,75E-09	6,75E-09	1,30E-09	4,01E-10	1,80E-10
^{133}Xe	1,01E-08	1,42E-08	3,75E-08	7,14E-08	5,45E-08	9,53E-09	3,10E-09	1,60E-09
^{135}Xe	2,11E-10	3,06E-10	8,00E-10	1,53E-09	1,11E-09	1,91E-10	6,11E-11	3,10E-11
^{138}Xe	2,42E-11	3,65E-11	1,00E-10	1,97E-10	1,71E-10	1,20E-11	6,01E-13	4,50E-14
^{134}Cs	8,30E-06	1,00E-05	7,80E-06	5,21E-06	3,54E-07	1,56E-08	1,94E-09	4,71E-10
^{137}Cs	6,80E-06	8,50E-06	6,50E-06	4,30E-06	2,83E-07	1,35E-08	1,61E-09	3,91E-10
Total	**1,60E-05**	**2,00E-05**	**1,51E-05**	**1,01E-05**	**7,75E-07**	**4,60E-08**	**8,80E-09**	**3,46E-09**

Table 20.6.2-7: Late doses of adults (Sv).

Case/Distance	300m	400m	600m	800m	3km	10km	20km	30km
Small child early	9,00E-07	**1,10E-06**	9,02E-07	6,56E-07	1,17E-07	1,59E-08	4,78E-09	2,38E-09
Adult early	5,30E-07	**6,53E-07**	5,22E-07	3,95E-07	8,40E-08	1,20E-08	3,65E-09	1,85E-09
Small child late	1,70E-05	**2,10E-05**	1,61E-05	1,12E-05	8,30E-07	5,30E-08	1,07E-08	4,34E-09
Adult late	1,60E-05	**2,00E-05**	1,51E-05	1,01E-05	7,75E-07	4,60E-08	8,80E-09	3,46E-09

Table 20.6.2-8: Cumulative total doses by case (Sv).

From **Table 20.6.2-4 - Table 20.6.2-8 it can be clearly seen that the calculated dose never exceeded the neutral (effective dose <90 μSv/yr) effect (highest value: 21 μSv – late dose of small children at 400 m), thus it can be concluded that beyond the safety zone (an in fact within it too) only neutral effect can be expected.**

In respect of early doses, it can be stated that at close distances (e.g., also for the 400 m maximum) the largest part of the dose comes from **"surface emitted" ^{131}I (mainly via inhalation),** at larger distances **noble gases, in particular the immersion gamma dose of ^{133}Xe originating from chimney emission becomes prominent (but of course remains smaller than the dose calculated at maximum by orders of magnitude). In this scenario, adult doses are markedly smaller (roughly half at close distances) than doses of small children.**

At close (near) distances, the better part of late doses originates from the **"surface" emission of the two Cs isotopes (and to a smaller extent ^{131}I) (mainly via ground surface gamma and ingestion),** whereas at larger distances **here also the immersion gamma dose of ^{133}Xe due to chimney emission becomes dominant. In this case, adult doses are again smaller than child doses but only by a little at close distances (as the larger ground surface gamma dose of children is almost compensated by the higher ingestion dose of adults).**

20.6.3 RADIATION EXPOSURE DUE TO LIQUID DISCHARGES

Model of aquatic propagation

Along the liquid discharge pathways of the Paks NPP (hot water canal) the liquid radioactive wastes entering the Danube undergo mixing and dilution, then reach the water takeout and other utilization points. Thus by virtue of making use of the Danube radioactive contaminations get into direct or indirect (through the aquatic food chain) contact with people, potentially resulting in external or internal radiation exposure. The model used to calculate radiation exposure is based on IAEA recommendations [20.6.4-1].

Concerning the dilution of discharged liquid materials in masses of water it was assumed – in accordance with the literature, see [20.6.4-1] – that complete mixing is accomplished in the vertical direction only, laterally, perpendicular to the plume axis only partial mixing takes place, both at the residence of the critical group of the current and planned units (Gerjen, 10 km), both at the southern country border (100 km). The partial mixing index is calculated according to [20.6.4-1] as:

$$A = \frac{1{,}5Dx}{B^2}$$

where

D – average river depth in riverbed section (m),
x – distance of receptor point along flow direction (m),
B – river width (m).

Substituting parameter values typical for the multi-annual hydrological minimum (D=2.2 m, B=370 m, [20.6.4-2]) the numerical value of the A index is 0.241 at x=10 km, and 2.4 at 100 km distance. According to [20.6.4-1] publication the value of the (P_r) correction factor accounting for partial mixing and related to the indices is 4.5 and 1.9.

Thus the activity concentration of Danube water at distance x can be calculated as:

$$C_{w,tot} = C_t \cdot P_r \ ,$$

where

C_t - concentration corresponding to total mixing (Bq/m^3).

$$C_t = \frac{Q_i}{q_r} \exp\left(-\frac{\lambda_i x}{U}\right)$$

where

Q_i – average release rate of the ith radionuclide (Bq/s),
q_r – river water yield (m^3/s),
λ_i – physical decay rate of the ith radionuclide (1/s),
x – distance between discharge and receptor points (m),
U – average river flow speed (m/s).

It should be noted that in a conservative approach again a multi-annual minimum was used for the q_r water flux (664 m^3/s, see [20.6.4-2-3]).

Model of the aquatic food chain

The propagation of radionuclides along the aquatic food chain was described by the so-called concentration factor method applicable to steady state conditions [20.6.4-1]. In this model, the material transfer between system components (called compartments) is characterized by first order kinetics and by virtue of assuming equilibrium (balance) conditions can be treated with a system of algebraic equations.

In estimating the external and internal doses due to the discharge of radionuclides into the aquatic environment all major irradiation pathways relevant to the utilization of the Danube were taken into account, namely:

External irradiation from

- The contaminated river,
- The river bank,
- The irrigated agricultural areas,

Internal irradiation from

- Drinking water consumption,
- Fish consumption,
- Consumption of vegetables contaminated due to irrigation, and
- The milk and meat of farm animals consuming contaminated feed and drinking water.

It should be noted that the incorporation of all important – or more precisely theoretically possible – utilization, irradiation pathways certainly leads to a conservative estimate, because the complete, full-blown use and utilization of Danube water containing contamination perhaps cannot be expected.

In a steady (equilibrium state), the activity concentration of a radioisotope originating from liquid discharge and diluted to concentration C_v in the recipient surface water in some element p of the food chain is:

$$C_t = C_{w,tot} \cdot P_{v,p} \ ,$$

where

$P_{v,p}$ concentration (bio-accumulation) factor, or some linear combination of such.

The use of water coming from the Danube provides a ”coupling” to the terrestrial food chain. This description differs from the food chain model applied to gaseous releases (see preceding section) only in terms of the input – the source of radionuclides -, there dry and wet fallout, here irrigation is the source.

The external and internal radiation exposures due to discharges to water can be calculated from the above $C_{w,tot}$, C_p activity concentrations using the following general formula.

External radiation exposure:

$$E_k = C_{w,tot} \cdot \mathrm{DFK}_v \cdot g_v \cdot t_{w,tot} \quad \text{and}$$
$$E_k = C_p \cdot \mathrm{DFK}_p \cdot g_p \cdot t_p$$

where

DFK – appropriate dose conversion factor,
g – irradiation geometry correction factor,
t - environment utilization time corresponding to the given environmental element (medium) and activity.

Internal radiation exposure:

$$E_b = C_{w,tot} \cdot \mathrm{DFB}_v \cdot k_v \cdot F_{w,tot} \quad \text{and}$$
$$E_b = C_p \cdot \mathrm{DFB}_p \cdot k_p \cdot F_p$$

where

DFB – ingestion dose factor,
k – correction factor expressing purification and other losses,
F – consumption of given food type.

The calculations are described in detail in publication [20.6.4-1], and also in study [20.6.4-4] using the model presented there. Here only the key parameters used are shown below.

Element	Fv – food plant (Bq/kg)/(Bq/kg)	Fv - feed (Bq/kg)/(Bq/kg)	Fm – milk (Bq/dm³)/(Bq/d)	Ff - meat (Bq/kg)/(Bq/d)	Kd (Bq/kg)/(Bq/dm³)	Bp (Bq/kg)/(Bq/dm³)
Co	0,08	2	0,01	0,07	5000	300
Cr	1E-03	0,1	2E-04	0,09	10000	200
Cs	0,04	1	0,01	0,05	1000	10000
I	0,02	0,1	0,01	0,05	10	40
Mn	0,3	10	3E-04	7,0E-04	1000	400
Sr	0,3	10	3E-03	0,01	1000	75

Kd: river water – sediment distribution factor (Bq/kg dry mass) / (Bq/dm³)
Bp: river water – fish bioaccumulation factor (Bq/kg dry mass) / (Bq/dm³)

Table 20.6.3-1: Environmental transfer factors (concentration factors).

It should be noted that H and C are not included in the table above, as publication [20.6.4-1] applies a special model to them based on the constancy of activity concentrations which was also adopted here. The dose conversion factor applicable to tritium – more precisely HTO – is: 2.6E-08 (Sv/yr)/(Bq/dm³), while the dose conversion factor published for ^{14}C is 5.6E-06 (Sv/yr)/(Bq/g) with reference to the specific radiocarbon concentration of the population.

Radionuclide	Water immersion (Sv/s)/(Bq/m^3)	Ground surface (Sv/yr)/(Bq/m^2)	Ingestion (Sv/Bq)	
			1 year old child	Adult
^{58}Co	1,0E-16	3,0E-08	4,4E-09	7,4E-10
^{60}Co	2,7E-16	7,5E-08	2,7E-08	3,4E-09
^{51}Cr	3,3E-18	9,8E-10	2,3E-10	3,8E-11
^{134}Cs	1,6E-16	4,9E-08	1,6E-08	1,9E-08
^{137}Cs	6,3E-17	1,8E-08	1,2E-08	1,3E-08
^{131}I	4,0E-17	1,2E-08	1,8E-07	2,2E-08
^{132}I	2,4E-16	7,2E-08	2,4E-09	2,9E-10
^{133}I	6,4E-17	2,0E-08	4,4E-08	4,3E-09
^{134}I	2,8E-16	8,3E-08	7,5E-10	1,1E-10
^{135}I	1,7E-16	4,8E-08	8,9E-09	9,3E-10
^{54}Mn	8,9E-17	2,6E-08	3,1E-09	7,1E-10
^{89}Sr	1,5E-19	2,2E-09	1,8E-08	2,6E-09
^{90}Sr	3,8E-19	3,5E-09	7,3E-08	2,8E-08

Table 20.6.3-2: Dose conversion factors.

Food	Consumption (kg/yr)	
	1-2 years old children	Adult
Drinking water	125	152
Fish (*)	1	10
Vegetable origin (1)	43,4	136
Vegetable origin (2)	68	184
Milk and dairy products	119	132
Meat	28,3	91

(1) – leafy vegetable, bulbous vegetable, fruit,
(2) – root vegetable, potato, cereals

Table 20.6.3-3: Consumption data [20.6.4-4].

Activity	Activity (h/yr)	
	1-2 years old children	Adult
Bathing, swimming	150	150
Boat trip, rowing	50	300
Staying at waterfront	150	150
Staying on irrigated fields	500	500

Table 20.6.3-4: Lifestyle characteristics [20.6.4-4].

20.6.3.1 Liquid discharge data

The planned liquid discharges of the Russian VVER 1200 MW type unit are summarized in Table 20.6.3-5. The data refer to a single unit and are based on the data communicated by the Russian supplier [20.6.4-4].

Radionuclide	^{3}H	^{14}C	^{131}I	^{132}I	^{133}I	^{134}I	^{135}I	^{89}Sr
Discharge/Unit	9,1E+12	1,05E+09*	3,5E+07	2,3E+06	1,2E+07	1,4E+06	3,9E+06	8,1E+05
Radionuclide	^{90}Sr	^{134}Cs	^{137}Cs	^{51}Cr	^{54}Mn	^{60}Co	^{58}Co	
Discharge/Unit	2,3E+03	8,0E+07	1,2E+08	5,5E+05	6,1E+05	2,5E+06	5,6E+05	

* Value estimated by Isotoptech Zrt.
Source: MIR.1200 Preliminary data and information for safety and environmental licensing, Appendix 4.

Table 20.6.3-5: Planned liquid discharges of the Russian VVER 1200 MW type unit (Bq/yr) [20.6.4-4].

20.6.3.2 Results relevant to population radiation exposure

Radiation exposure of the Gerjen population reference (critical) group

The annual radiation exposure of the children aged 1-2 and adult age groups of the Gerjen population – at the same time representing the reference (critical) population group of the planned new units with respect to liquid releases – is recapitulated in Table 20.6.3-6. As shown by the results, the dose of the adult population – subject to the given annual releases, assumed consumption data and lifestyle characteristics – exceeds that of children aged 1-2. In practice for both groups it is internal radiation exposure that is 100% dominating, in particular the contributions of ^{3}H and ^{14}C are the most significant (representing 90% (almost 70%) of the total for children (adults)). For adults the contributions of ^{134}Cs and ^{137}Cs can also be labeled considerable (30 % combined). All things considered, however, these radiation exposures – in spite of the heavily conservatively biased approximations – are small, and even taken for two units only amount to 2-3 parts in one thousand of the dose restriction.

Radionuclide	1-2 years old children			Adult		
	external	internal	total	external	internal	total
^{58}Co	4,2E-04	1,2E-03	1,7E-03	4,3E-04	5,8E-04	1,0E-03
^{60}Co	1,8E-02	5,2E-02	7,0E-02	1,8E-02	1,6E-02	3,4E-02
^{51}Cr	9,0E-06	6,8E-05	7,7E-05	9,2E-06	4,2E-05	5,1E-05
^{134}Cs	9,5E-02	2,6E+00	2,7E+00	9,6E-02	1,9E+01	1,9E+01
^{137}Cs	1,4E-01	3,4E+00	3,5E+00	1,4E-01	2,0E+01	2,1E+01
^{3}H (HTO)	0,0E+00	5,1E+01	5,1E+01	0,0E+00	5,1E+01	5,1E+01
^{14}C	0	3,9E+01	3,9E+01	0	3,9E+01	3,9E+01
^{131}I	2,2E-04	9,3E-01	9,3E-01	3,5E-04	2,1E-01	2,2E-01
^{132}I	7,6E-05	2,0E-04	2,7E-04	1,3E-04	7,9E-05	2,1E-04
^{133}I	1,1E-04	2,5E-02	2,6E-02	1,8E-04	6,9E-03	7,0E-03
^{134}I	5,3E-05	3,7E-05	9,1E-05	9,2E-05	1,8E-05	1,1E-04
^{135}I	9,2E-05	1,3E-03	1,4E-03	1,6E-04	4,4E-04	5,9E-04
^{54}Mn	2,7E-04	5,9E-04	8,6E-04	2,8E-04	6,2E-04	9,0E-04
^{89}Sr	8,1E-06	3,8E-03	3,8E-03	8,2E-06	1,4E-03	1,4E-03
^{90}Sr	5,1E-07	1,7E-04	1,7E-04	5,1E-07	1,5E-04	1,5E-04
Total	**2,5E-01**	**9,7E+01**	**9,7E+01**	**2,6E-01**	**1,3E+02**	**1,3E+02**

Table 20.6.3-6: Doses of the 1-2 years old children and adult age groups of the Gerjen population from the annual liquid discharges by Russian VVER 1200 MW type unit (nSv/yr).

20.6.4 DETECTABILITY STUDY OF ENVIRONMENTAL ACTIVITY CONCENTRATIONS AND POTENTIAL ACCUMULATIONS DUE TO PAKS II RELEASES

Detectability study of environmental activity concentrations / potential accumulations due to airborne Paks II emissions

The objective was to investigate whether or not the effect of the airborne emissions of the 2 pcs of Russian VVER-1200 type units is measurable in individual environmental elements and potential accumulations. A conservative approach was used in the sense that the highest activity concentrations were compared with the detection limits of the environmental monitoring program routinely executed by the nuclear power plant. Thus the calculated activity concentrations due to YR 2009 releases were compared with the typical detection levels of NPP environmental monitoring measurements.

For the activity concentrations (air, surface, meat, cereal, vegetable, milk) determined for given distances (<1; 1-5 km, 5-10 km, 10-30 km) the different directional maxima were taken, together with the value obtained for 1.5 km, and these were expressed in proportions of the detection limits.

In the tables the rates were also highlighted with the following color code:

- white, if the rate is: detection level / maximum activity concentration <10,
- light gray, if the rate is: detection level / maximum activity concentration > 10 but < 100,
- *deep gray*, if the rate is: detection level / maximum activity concentration > *100.*

Nuclide	<1km	1,5km	1-5km	5-10km	10-30km	BDL	Rate/<1km	Rate/1,5km	Rate/1-5km	Rate/5-10km	Rate/10-30km
^{3}H (HTO)	5.48E-02	1.86E-02	1.08E-02	2.60E-03	5.19E-04	1.00E-03	1.82E-02	5.37E-02	9.23E-02	3.84E-01	1.93E+00
^{14}C (CO2)	2.11E-04	7.15E-05	4.16E-05	1.00E-05	2.00E-06	1.00E-04	4.74E-01	1.40E+00	2.40E+00	1.00E+01	5.01E+01
^{14}C (organic)	4.01E-03	1.36E-03	7.91E-04	1.90E-04	3.79E-05	1.00E-04	2.50E-02	7.35E-02	1.26E-01	5.26E-01	2.64E+00
^{83m}Kr	1.10E-02	3.12E-03	1.67E-03	3.26E-04	4.21E-05	-	-	-	-	-	-
^{85m}Kr	3.20E-02	1.05E-02	5.94E-03	1.30E-03	2.04E-04	-	-	-	-	-	-
^{85}Kr	5.00E-03	1.70E-03	9.87E-04	2.38E-04	4.73E-05	-	-	-	-	-	-
^{87}Kr	2.30E-02	6.26E-03	3.27E-03	6.02E-04	6.94E-05	-	-	-	-	-	-
^{88}Kr	8.03E-02	2.39E-02	1.31E-02	2.71E-03	3.90E-04	-	-	-	-	-	-
^{131m}Xe	3.61E-03	1.20E-03	6.96E-04	1.67E-04	3.30E-05	-	-	-	-	-	-
^{133}Xe	4.29E-01	1.38E-01	7.94E-02	1.89E-02	3.72E-03	-	-	-	-	-	-
^{135}Xe	1.30E-01	3.79E-02	2.14E-02	4.83E-03	8.33E-04	-	-	-	-	-	-
^{138}Xe	5.01E-03	9.11E-04	3.93E-04	4.02E-05	1.32E-06	-	-	-	-	-	-
^{131}I (aerosol)	4.98E-08	1.47E-08	8.32E-09	1.91E-09	3.43E-10	5.00E-06	1.00E+02	3.41E+02	6.01E+02	2.62E+03	1.46E+04
^{132}I (aerosol)	8.14E-08	1.99E-08	1.05E-08	2.03E-09	2.65E-10	5.00E-06	6.15E+01	2.51E+02	4.77E+02	2.46E+03	1.88E+04
^{133}I (aerosol)	1.04E-07	2.86E-08	1.60E-08	3.56E-09	6.10E-10	5.00E-06	4.81E+01	1.75E+02	3.13E+02	1.40E+03	8.19E+03
^{134}I (aerosol)	4.22E-08	1.12E-08	5.64E-09	9.55E-10	9.10E-11	5.00E-06	1.19E+02	4.47E+02	8.86E+02	5.24E+03	5.50E+04
^{135}I (aerosol)	8.33E-08	2.30E-08	1.27E-08	2.72E-09	4.25E-10	5.00E-06	6.00E+01	2.18E+02	3.95E+02	1.84E+03	1.18E+04
^{131}I (elemental)	4.86E-07	1.37E-07	7.27E-08	1.41E-08	2.00E-09	5.00E-06	1.03E+01	3.66E+01	6.88E+01	3.54E+02	2.50E+03
^{132}I (elemental)	7.88E-07	1.84E-07	9.25E-08	1.61E-08	1.81E-09	5.00E-06	6.34E+00	2.72E+01	5.41E+01	3.11E+02	2.76E+03
^{133}I (elemental)	1.01E-06	2.65E-07	1.39E-07	2.67E-08	3.67E-09	5.00E-06	4.95E+00	1.89E+01	3.59E+01	1.88E+02	1.36E+03
^{134}I (elemental)	4.13E-07	1.05E-07	5.13E-08	7.93E-09	6.67E-10	5.00E-06	1.21E+01	4.74E+01	9.75E+01	6.30E+02	7.50E+03
^{135}I (elemental)	8.11E-07	2.13E-07	1.11E-07	2.07E-08	2.70E-09	5.00E-06	6.17E+00	2.35E+01	4.51E+01	2.41E+02	1.85E+03
^{131}I (organic)	7.00E-07	2.08E-07	1.19E-07	2.81E-08	5.47E-09	2.00E-05	2.86E+01	9.62E+01	1.69E+02	7.13E+02	3.66E+03
^{132}I (organic)	1.15E-06	2.83E-07	1.50E-07	2.97E-08	3.99E-09	2.00E-05	1.74E+01	7.08E+01	1.33E+02	6.75E+02	5.01E+03
^{133}I (organic)	1.47E-06	4.07E-07	2.30E-07	5.29E-08	9.69E-09	2.00E-05	1.36E+01	4.91E+01	8.71E+01	3.78E+02	2.06E+03
^{134}I (organic)	5.93E-07	1.58E-07	8.02E-08	1.37E-08	1.34E-09	2.00E-05	3.37E+01	1.27E+02	2.50E+02	1.46E+03	1.49E+04
^{135}I (organic)	1.17E-06	3.26E-07	1.82E-07	3.99E-08	6.57E-09	2.00E-05	1.70E+01	6.14E+01	1.10E+02	5.01E+02	3.04E+03
^{51}Cr	1.11E-09	3.71E-10	2.14E-10	4.95E-11	9.03E-12	5.00E-06	4.50E+03	1.35E+04	2.34E+04	1.01E+05	5.54E+05
^{54}Mn	8.30E-11	2.45E-11	1.38E-11	3.18E-12	5.75E-13	5.00E-06	6.02E+04	2.04E+05	3.61E+05	1.57E+06	8.69E+06
^{60}Co	6.10E-10	1.65E-10	9.25E-11	2.10E-11	3.79E-12	5.00E-06	8.20E+03	3.03E+04	5.40E+04	2.38E+05	1.32E+06
^{89}Sr	5.57E-09	1.64E-09	9.30E-10	2.14E-10	3.86E-11	1.00E-06	1.79E+02	6.10E+02	1.07E+03	4.68E+03	2.59E+04
^{90}Sr	1.15E-11	3.15E-12	1.77E-12	4.03E-13	7.25E-14	1.00E-06	8.66E+04	3.18E+05	5.65E+05	2.48E+06	1.38E+07
^{134}Cs	3.53E-07	1.02E-07	5.78E-08	1.32E-08	2.39E-09	5.00E-06	1.42E+01	4.89E+01	8.65E+01	3.78E+02	2.09E+03
^{137}Cs	5.19E-07	1.53E-07	8.69E-08	1.99E-08	3.61E-09	5.00E-06	9.63E+00	3.26E+01	5.75E+01	2.52E+02	1.39E+03

Table 20.6.4-1: Air activity concentration maxima calculated from 2009 normal operation chimney and turbine bdg emissions (I+II) (Bq/m^3), prorated to BDL value

Nuclide	<1km	1,5km	1-5km	5-10km	10-30km	BDL	Rate/<1km	Rate/1,5km	Rate/1-5km	Rate/5-10km	Rate/10-30km
^{3}H (HTO)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{14}C (CO2)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{14}C (organic)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{83m}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{85m}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{85}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{87}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{88}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{131m}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{133}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{135}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{138}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{131}I (aerosol)	3.29E-04	9.68E-05	5.49E-05	1.26E-05	2.26E-06	2.00E-01	6.09E+02	2.07E+03	3.64E+03	1.59E+04	8.86E+04
^{132}I (aerosol)	6.33E-06	1.55E-06	8.16E-07	1.58E-07	2.06E-08	2.00E-01	3.16E+04	1.29E+05	2.45E+05	1.27E+06	9.70E+06
^{133}I (aerosol)	7.30E-05	2.01E-05	1.12E-05	2.50E-06	4.28E-07	2.00E-01	2.74E+03	9.94E+03	1.78E+04	8.00E+04	4.67E+05
^{134}I (aerosol)	1.25E-06	3.32E-07	1.68E-07	2.83E-08	2.70E-09	2.00E-01	1.60E+05	6.02E+05	1.19E+06	7.06E+06	7.41E+07
^{135}I (aerosol)	1.88E-05	5.16E-06	2.85E-06	6.12E-07	9.59E-08	2.00E-01	1.06E+04	3.87E+04	7.02E+04	3.27E+05	2.09E+06
^{131}I (elemental)	1.97E-02	5.53E-03	2.94E-03	5.71E-04	8.09E-05	2.00E-01	1.02E+01	3.62E+01	6.81E+01	3.50E+02	2.47E+03
^{132}I (elemental)	3.76E-04	8.78E-05	4.41E-05	7.64E-06	8.61E-07	2.00E-01	5.33E+02	2.28E+03	4.54E+03	2.62E+04	2.32E+05
^{133}I (elemental)	4.35E-03	1.14E-03	5.99E-04	1.15E-04	1.58E-05	2.00E-01	4.60E+01	1.76E+02	3.34E+02	1.75E+03	1.27E+04
^{134}I (elemental)	7.51E-05	1.92E-05	9.34E-06	1.45E-06	1.21E-07	2.00E-01	2.66E+03	1.04E+04	2.14E+04	1.38E+05	1.65E+06
^{135}I (elemental)	1.12E-03	2.95E-04	1.53E-04	2.86E-05	3.72E-06	2.00E-01	1.79E+02	6.78E+02	1.31E+03	7.00E+03	5.38E+04
^{131}I (organic)	1.52E-04	4.51E-05	2.58E-05	6.10E-06	1.19E-06	2.00E-01	1.31E+03	4.43E+03	7.75E+03	3.28E+04	1.68E+05
^{132}I (organic)	2.94E-06	7.24E-07	3.84E-07	7.59E-08	1.02E-08	2.00E-01	6.80E+04	2.76E+05	5.20E+05	2.63E+06	1.95E+07
^{133}I (organic)	3.40E-05	9.43E-06	5.32E-06	1.22E-06	2.23E-07	2.00E-01	5.89E+03	2.12E+04	3.76E+04	1.64E+05	8.95E+05
^{134}I (organic)	5.80E-07	1.55E-07	7.85E-08	1.34E-08	1.31E-09	2.00E-01	3.45E+05	1.29E+06	2.55E+06	1.49E+07	1.52E+08
^{135}I (organic)	8.71E-06	2.42E-06	1.35E-06	2.96E-07	4.88E-08	2.00E-01	2.30E+04	8.27E+04	1.49E+05	6.75E+05	4.10E+06
^{51}Cr	2.50E-05	8.36E-06	4.81E-06	1.12E-06	2.03E-07	2.00E-01	8.00E+03	2.39E+04	4.16E+04	1.79E+05	9.84E+05
^{54}Mn	1.17E-05	3.43E-06	1.95E-06	4.46E-07	8.08E-08	2.00E-01	1.71E+04	5.83E+04	1.03E+05	4.48E+05	2.47E+06
^{60}Co	1.18E-04	3.18E-05	1.78E-05	4.06E-06	7.30E-07	2.00E-01	1.70E+03	6.28E+03	1.12E+04	4.93E+04	2.74E+05
^{89}Sr	2.26E-04	6.66E-05	3.77E-05	8.65E-06	1.56E-06	2.00E-01	8.84E+02	3.00E+03	5.30E+03	2.31E+04	1.28E+05
^{90}Sr	2.35E-06	6.41E-07	3.60E-07	8.17E-08	1.47E-08	2.00E-01	8.50E+04	3.12E+05	5.55E+05	2.45E+06	1.36E+07
^{134}Cs	6.15E-02	1.78E-02	1.01E-02	2.30E-03	4.17E-04	2.00E-01	3.25E+00	1.13E+01	1.99E+01	8.69E+01	4.80E+02
^{137}Cs	1.06E-01	3.12E-02	1.77E-02	4.05E-03	7.34E-04	2.00E-01	1.89E+00	6.41E+00	1.13E+01	4.93E+01	2.72E+02

Table 20.6.4-2: Soil activity concentration maxima calculated from 2009 normal operation chimney and turbine bdg emissions (I+II) (Bq/m^3), prorated to BDL value.

Nuclide	<1km	1,5km	1-5km	5-10km	10-30km	BDL	Rate/<1km	Rate/1,5km	Rate/1-5km	Rate/5-10km	Rate/10-30km
^{3}H (HTO)	1.43E-01	4.87E-02	2.83E-02	6.80E-03	1.36E-03	5.00E-01	3.49E+00	1.03E+01	1.76E+01	7.35E+01	3.69E+02
^{14}C (CO2)	5.62E-01	1.91E-01	1.11E-01	2.67E-02	5.32E-03	5.00E-01	8.90E-01	2.62E+00	4.51E+00	1.88E+01	9.40E+01
^{14}C (organic)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{83m}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{85m}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{85}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{87}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{88}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{131m}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{133}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{135}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{138}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{131}I (aerosol)	1.26E-06	3.70E-07	2.10E-07	4.80E-08	8.63E-09	5.00E-01	3.98E+05	1.35E+06	2.38E+06	1.04E+07	5.79E+07
^{132}I (aerosol)	2.25E-20	5.52E-21	2.91E-21	5.63E-22	7.35E-23	5.00E-01	2.22E+19	9.05E+19	1.72E+20	8.88E+20	6.81E+21
^{133}I (aerosol)	2.71E-13	7.48E-14	4.18E-14	9.29E-15	1.59E-15	5.00E-01	1.84E+12	6.69E+12	1.20E+13	5.38E+13	3.14E+14
^{134}I (aerosol)	4.49E-21	1.19E-21	6.01E-22	1.01E-22	9.68E-24	5.00E-01	1.11E+20	4.20E+20	8.32E+20	4.93E+21	5.17E+22
^{135}I (aerosol)	6.57E-20	1.81E-20	9.98E-21	2.14E-21	3.36E-22	5.00E-01	7.61E+18	2.77E+19	5.01E+19	2.34E+20	1.49E+21
^{131}I (elemental)	7.51E-05	2.11E-05	1.12E-05	2.18E-06	3.09E-07	5.00E-01	6.66E+03	2.36E+04	4.45E+04	2.29E+05	1.62E+06
^{132}I (elemental)	1.34E-18	3.13E-19	1.57E-19	2.72E-20	3.07E-21	5.00E-01	3.74E+17	1.60E+18	3.18E+18	1.84E+19	1.63E+20
^{133}I (elemental)	1.61E-11	4.23E-12	2.23E-12	4.25E-13	5.86E-14	5.00E-01	3.10E+10	1.18E+11	2.25E+11	1.18E+12	8.54E+12
^{134}I (elemental)	2.69E-19	6.86E-20	3.35E-20	5.18E-21	4.34E-22	5.00E-01	1.86E+18	7.28E+18	1.49E+19	9.64E+19	1.15E+21
^{135}I (elemental)	3.92E-18	1.03E-18	5.36E-19	1.00E-19	1.30E-20	5.00E-01	1.28E+17	4.84E+17	9.33E+17	5.00E+18	3.84E+19
^{131}I (organic)	5.82E-07	1.73E-07	9.86E-08	2.33E-08	4.54E-09	5.00E-01	8.60E+05	2.90E+06	5.07E+06	2.15E+07	1.10E+08
^{132}I (organic)	1.05E-20	2.58E-21	1.37E-21	2.71E-22	3.65E-23	5.00E-01	4.77E+19	1.94E+20	3.65E+20	1.85E+21	1.37E+22
^{133}I (organic)	1.26E-13	3.50E-14	1.98E-14	4.53E-15	8.30E-16	5.00E-01	3.96E+12	1.43E+13	2.53E+13	1.10E+14	6.03E+14
^{134}I (organic)	2.08E-21	5.54E-22	2.81E-22	4.80E-23	4.70E-24	5.00E-01	2.41E+20	9.03E+20	1.78E+21	1.04E+22	1.06E+23
^{135}I (organic)	3.05E-20	8.47E-21	4.71E-21	1.04E-21	1.71E-22	5.00E-01	1.64E+19	5.90E+19	1.06E+20	4.82E+20	2.93E+21
^{51}Cr	8.41E-07	2.81E-07	1.62E-07	3.75E-08	6.84E-09	5.00E-01	5.95E+05	1.78E+06	3.09E+06	1.33E+07	7.31E+07
^{54}Mn	1.45E-08	4.26E-09	2.42E-09	5.54E-10	1.00E-10	5.00E-01	3.45E+07	1.17E+08	2.07E+08	9.02E+08	4.98E+09
^{60}Co	3.92E-06	1.06E-06	5.94E-07	1.35E-07	2.43E-08	5.00E-01	1.28E+05	4.72E+05	8.42E+05	3.70E+06	2.06E+07
^{89}Sr	1.95E-07	5.74E-08	3.26E-08	7.46E-09	1.35E-09	5.00E-01	2.56E+06	8.71E+06	1.54E+07	6.70E+07	3.71E+08
^{90}Sr	1.60E-09	4.36E-10	2.45E-10	5.56E-11	1.00E-11	5.00E-01	3.12E+08	1.15E+09	2.04E+09	8.99E+09	4.98E+10
^{134}Cs	1.41E-03	4.07E-04	2.31E-04	5.27E-05	9.55E-06	5.00E-01	3.55E+02	1.23E+03	2.17E+03	9.48E+03	5.24E+04
^{137}Cs	2.28E-03	6.72E-04	3.81E-04	8.73E-05	1.58E-05	5.00E-01	2.20E+02	7.44E+02	1.31E+03	5.73E+03	3.16E+04

Table 20.6.4-3: Meat activity concentration maxima calculated from 2009 normal operation chimney and turbine bdg emissions (I+II) (Bq/m^3), prorated to BDL value.

Nuclide	<1km	1,5km	1-5km	5-10km	10-30km	BDL	Rate/<1km	Rate/1,5km	Rate/1-5km	Rate/5-10km	Rate/10-30km
^{3}H (HTO)	7.31E-01	2.48E-01	1.44E-01	3.47E-02	6.91E-03	5.00E-01	6.84E-01	2.02E+00	3.46E+00	1.44E+01	7.23E+01
^{14}C (CO2)	1.18E-01	4.00E-02	2.33E-02	5.60E-03	1.12E-03	5.00E-01	4.24E+00	1.25E+01	2.15E+01	8.93E+01	4.48E+02
^{14}C (organic)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{83m}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{85m}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{85}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{87}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{88}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{131m}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{133}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{135}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{138}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{131}I (aerosol)	1.83E-05	5.39E-06	3.06E-06	7.00E-07	1.26E-07	5.00E-01	2.73E+04	9.27E+04	1.63E+05	7.14E+05	3.97E+06
^{132}I (aerosol)	1.96E-19	4.79E-20	2.52E-20	4.88E-21	6.37E-22	5.00E-01	2.56E+18	1.04E+19	1.98E+19	1.02E+20	7.85E+20
^{133}I (aerosol)	2.92E-10	8.05E-11	4.49E-11	1.00E-11	1.71E-12	5.00E-01	1.71E+09	6.21E+09	1.11E+10	5.00E+10	2.92E+11
^{134}I (aerosol)	3.89E-20	1.03E-20	5.21E-21	8.80E-22	8.39E-23	5.00E-01	1.28E+19	4.84E+19	9.60E+19	5.68E+20	5.96E+21
^{135}I (aerosol)	5.70E-19	1.57E-19	8.65E-20	1.86E-20	2.91E-21	5.00E-01	8.77E+17	3.19E+18	5.78E+18	2.69E+19	1.72E+20
^{131}I (elemental)	1.09E-03	3.08E-04	1.64E-04	3.18E-05	4.51E-06	5.00E-01	4.57E+02	1.62E+03	3.05E+03	1.57E+04	1.11E+05
^{132}I (elemental)	1.16E-17	2.71E-18	1.36E-18	2.36E-19	2.66E-20	5.00E-01	4.31E+16	1.84E+17	3.67E+17	2.12E+18	1.88E+19
^{133}I (elemental)	1.74E-08	4.55E-09	2.39E-09	4.58E-10	6.30E-11	5.00E-01	2.88E+07	1.10E+08	2.09E+08	1.09E+09	7.93E+09
^{134}I (elemental)	2.33E-18	5.95E-19	2.90E-19	4.50E-20	3.77E-21	5.00E-01	2.14E+17	8.40E+17	1.72E+18	1.11E+19	1.33E+20
^{135}I (elemental)	3.40E-17	8.95E-18	4.65E-18	8.68E-19	1.13E-19	5.00E-01	1.47E+16	5.59E+16	1.08E+17	5.76E+17	4.43E+18
^{131}I (organic)	8.48E-06	2.52E-06	1.44E-06	3.40E-07	6.61E-08	5.00E-01	5.89E+04	1.99E+05	3.48E+05	1.47E+06	7.56E+06
^{132}I (organic)	9.08E-20	2.24E-20	1.19E-20	2.35E-21	3.17E-22	5.00E-01	5.50E+18	2.23E+19	4.21E+19	2.13E+20	1.58E+21
^{133}I (organic)	1.36E-10	3.77E-11	2.13E-11	4.88E-12	8.93E-13	5.00E-01	3.68E+09	1.33E+10	2.35E+10	1.02E+11	5.60E+11
^{134}I (organic)	1.80E-20	4.80E-21	2.44E-21	4.16E-22	4.08E-23	5.00E-01	2.78E+19	1.04E+20	2.05E+20	1.20E+21	1.23E+22
^{135}I (organic)	2.64E-19	7.34E-20	4.09E-20	8.99E-21	1.48E-21	5.00E-01	1.89E+18	6.81E+18	1.22E+19	5.56E+19	3.38E+20
^{51}Cr	2.04E-06	6.82E-07	3.92E-07	9.10E-08	1.66E-08	5.00E-01	2.45E+05	7.33E+05	1.27E+06	5.49E+06	3.01E+07
^{54}Mn	3.10E-07	9.12E-08	5.17E-08	1.19E-08	2.15E-09	5.00E-01	1.61E+06	5.48E+06	9.67E+06	4.22E+07	2.33E+08
^{60}Co	2.32E-06	6.27E-07	3.51E-07	7.99E-08	1.44E-08	5.00E-01	2.16E+05	7.97E+05	1.42E+06	6.26E+06	3.48E+07
^{89}Sr	1.42E-05	4.18E-06	2.37E-06	5.42E-07	9.81E-08	5.00E-01	3.52E+04	1.20E+05	2.11E+05	9.22E+05	5.10E+06
^{90}Sr	4.59E-08	1.25E-08	7.03E-09	1.60E-09	2.88E-10	5.00E-01	1.09E+07	4.00E+07	7.11E+07	3.13E+08	1.74E+09
^{134}Cs	3.29E-03	9.50E-04	5.38E-04	1.23E-04	2.23E-05	5.00E-01	1.52E+02	5.27E+02	9.29E+02	4.07E+03	2.25E+04
^{137}Cs	4.97E-03	1.46E-03	8.30E-04	1.90E-04	3.45E-05	5.00E-01	1.01E+02	3.41E+02	6.02E+02	2.63E+03	1.45E+04

Table 20.6.4-4: Cereal activity concentration maxima calculated from 2009 normal operation chimney and turbine bdg emissions (I+II) (Bq/m^3), prorated to BDL value.

Nuclide	<1km	1,5km	1-5km	5-10km	10-30km	BDL	Rate/<1km	Rate/1,5km	Rate/1-5km	Rate/5-10km	Rate/10-30km
^{3}H (HTO)	4.02E+00	1.36E+00	7.95E-01	1.91E-01	3.80E-02	5.00E-01	1.24E-01	3.66E-01	6.29E-01	2.62E+00	1.31E+01
^{14}C (CO2)	2.81E-02	9.53E-03	5.55E-03	1.33E-03	2.66E-04	5.00E-01	1.78E+01	5.24E+01	9.01E+01	3.75E+02	1.88E+03
^{14}C (organic)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{83m}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{85m}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{85}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{87}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{88}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{131m}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{133}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{135}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{138}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{131}I (aerosol)	1.00E-05	2.95E-06	1.67E-06	3.83E-07	6.87E-08	5.00E-01	5.00E+04	1.70E+05	2.99E+05	1.31E+06	7.27E+06
^{132}I (aerosol)	5.87E-20	1.44E-20	7.56E-21	1.47E-21	1.91E-22	5.00E-01	8.52E+18	3.48E+19	6.61E+19	3.41E+20	2.62E+21
^{133}I (aerosol)	2.43E-08	6.69E-09	3.74E-09	8.32E-10	1.42E-10	5.00E-01	2.06E+07	7.47E+07	1.34E+08	6.01E+08	3.51E+09
^{134}I (aerosol)	1.17E-20	3.10E-21	1.56E-21	2.64E-22	2.52E-23	5.00E-01	4.28E+19	1.61E+20	3.20E+20	1.89E+21	1.99E+22
^{135}I (aerosol)	4.41E-14	1.21E-14	6.70E-15	1.44E-15	2.25E-16	5.00E-01	1.13E+13	4.12E+13	7.46E+13	3.48E+14	2.22E+15
^{131}I (elemental)	5.98E-04	1.68E-04	8.95E-05	1.74E-05	2.46E-06	5.00E-01	8.36E+02	2.97E+03	5.59E+03	2.88E+04	2.03E+05
^{132}I (elemental)	3.48E-18	8.14E-19	4.09E-19	7.08E-20	7.98E-21	5.00E-01	1.44E+17	6.14E+17	1.22E+18	7.06E+18	6.26E+19
^{133}I (elemental)	1.45E-06	3.79E-07	1.99E-07	3.81E-08	5.24E-09	5.00E-01	3.46E+05	1.32E+06	2.51E+06	1.31E+07	9.54E+07
^{134}I (elemental)	7.00E-19	1.79E-19	8.71E-20	1.35E-20	1.13E-21	5.00E-01	7.14E+17	2.80E+18	5.74E+18	3.71E+19	4.42E+20
^{135}I (elemental)	2.63E-12	6.93E-13	3.60E-13	6.72E-14	8.75E-15	5.00E-01	1.90E+11	7.21E+11	1.39E+12	7.44E+12	5.72E+13
^{131}I (organic)	4.63E-06	1.37E-06	7.85E-07	1.86E-07	3.61E-08	5.00E-01	1.08E+05	3.64E+05	6.37E+05	2.69E+06	1.38E+07
^{132}I (organic)	2.73E-20	6.71E-21	3.57E-21	7.04E-22	9.50E-23	5.00E-01	1.83E+19	7.45E+19	1.40E+20	7.10E+20	5.26E+21
^{133}I (organic)	1.13E-08	3.13E-09	1.77E-09	4.06E-10	7.43E-11	5.00E-01	4.43E+07	1.60E+08	2.83E+08	1.23E+09	6.73E+09
^{134}I (organic)	5.41E-21	1.44E-21	7.32E-22	1.25E-22	1.22E-23	5.00E-01	9.25E+19	3.47E+20	6.83E+20	4.01E+21	4.09E+22
^{135}I (organic)	2.05E-14	5.69E-15	3.17E-15	6.97E-16	1.15E-16	5.00E-01	2.44E+13	8.79E+13	1.58E+14	7.18E+14	4.36E+15
^{51}Cr	7.29E-07	2.44E-07	1.40E-07	3.25E-08	5.93E-09	5.00E-01	6.85E+05	2.05E+06	3.56E+06	1.54E+07	8.43E+07
^{54}Mn	1.05E-07	3.07E-08	1.74E-08	4.00E-09	7.24E-10	5.00E-01	4.78E+06	1.63E+07	2.87E+07	1.25E+08	6.90E+08
^{60}Co	7.03E-07	1.90E-07	1.07E-07	2.42E-08	4.36E-09	5.00E-01	7.11E+05	2.63E+06	4.69E+06	2.06E+07	1.15E+08
^{89}Sr	4.80E-06	1.41E-06	8.00E-07	1.83E-07	3.32E-08	5.00E-01	1.04E+05	3.54E+05	6.25E+05	2.73E+06	1.51E+07
^{90}Sr	1.50E-08	4.09E-09	2.30E-09	5.21E-10	9.41E-11	5.00E-01	3.33E+07	1.22E+08	2.18E+08	9.59E+08	5.32E+09
^{134}Cs	4.01E-04	1.16E-04	6.56E-05	1.50E-05	2.72E-06	5.00E-01	1.25E+03	4.32E+03	7.62E+03	3.33E+04	1.84E+05
^{137}Cs	6.03E-04	1.78E-04	1.01E-04	2.31E-05	4.19E-06	5.00E-01	8.29E+02	2.81E+03	4.96E+03	2.16E+04	1.19E+05

Table 20.6.4-5: Vegetable activity concentration maxima calculated from 2009 normal operation chimney and turbine bdg emissions (I+II) (Bq/m^3), prorated to BDL value.

Nuclide	<1km	1,5km	1-5km	5-10km	10-30km	BDL	Rate/<1km	Rate/1,5km	Rate/1-5km	Rate/5-10km	Rate/10-30km
^{3}H (HTO)	1.67E-01	5.66E-02	3.30E-02	7.91E-03	1.58E-03	5.00E-01	3.00E+00	8.83E+00	1.52E+01	6.32E+01	3.17E+02
^{14}C (CO2)	9.41E-02	3.19E-02	1.86E-02	4.47E-03	8.91E-04	5.00E-01	5.31E+00	1.57E+01	2.69E+01	1.12E+02	5.61E+02
^{14}C (organic)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{83m}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{85m}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{85}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{87}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{88}Kr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{131m}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{133}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{135}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{138}Xe	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-	-	-	-
^{131}I (aerosol)	6.58E-06	1.94E-06	1.10E-06	2.52E-07	4.52E-08	5.00E-01	7.60E+04	2.58E+05	4.55E+05	1.99E+06	1.11E+07
^{132}I (aerosol)	7.92E-20	1.94E-20	1.02E-20	1.98E-21	2.58E-22	5.00E-01	6.31E+18	2.58E+19	4.89E+19	2.53E+20	1.94E+21
^{133}I (aerosol)	1.39E-07	3.82E-08	2.13E-08	4.75E-09	8.13E-10	5.00E-01	3.61E+06	1.31E+07	2.34E+07	1.05E+08	6.15E+08
^{134}I (aerosol)	5.99E-21	1.59E-21	8.01E-22	1.35E-22	1.29E-23	5.00E-01	8.35E+19	3.15E+20	6.24E+20	3.69E+21	3.88E+22
^{135}I (aerosol)	4.16E-11	1.14E-11	6.31E-12	1.35E-12	2.12E-13	5.00E-01	1.20E+10	4.37E+10	7.92E+10	3.69E+11	2.35E+12
^{131}I (elemental)	3.93E-04	1.11E-04	5.88E-05	1.14E-05	1.62E-06	5.00E-01	1.27E+03	4.51E+03	8.50E+03	4.37E+04	3.09E+05
^{132}I (elemental)	4.71E-18	1.10E-18	5.52E-19	9.57E-20	1.08E-20	5.00E-01	1.06E+17	4.55E+17	9.05E+17	5.23E+18	4.64E+19
^{133}I (elemental)	8.25E-06	2.16E-06	1.14E-06	2.17E-07	2.99E-08	5.00E-01	6.06E+04	2.31E+05	4.40E+05	2.30E+06	1.67E+07
^{134}I (elemental)	3.59E-19	9.15E-20	4.46E-20	6.91E-21	5.79E-22	5.00E-01	1.39E+18	5.46E+18	1.12E+19	7.23E+19	8.64E+20
^{135}I (elemental)	2.48E-09	6.53E-10	3.39E-10	6.33E-11	8.24E-12	5.00E-01	2.02E+08	7.66E+08	1.47E+09	7.90E+09	6.07E+10
^{131}I (organic)	3.05E-06	9.04E-07	5.16E-07	1.22E-07	2.38E-08	5.00E-01	1.64E+05	5.53E+05	9.68E+05	4.10E+06	2.10E+07
^{132}I (organic)	3.68E-20	9.07E-21	4.82E-21	9.51E-22	1.28E-22	5.00E-01	1.36E+19	5.51E+19	1.04E+20	5.26E+20	3.90E+21
^{133}I (organic)	6.45E-08	1.79E-08	1.01E-08	2.32E-09	4.24E-10	5.00E-01	7.76E+06	2.80E+07	4.95E+07	2.16E+08	1.18E+09
^{134}I (organic)	2.77E-21	7.39E-22	3.75E-22	6.40E-23	6.27E-24	5.00E-01	1.81E+20	6.77E+20	1.33E+21	7.82E+21	7.98E+22
^{135}I (organic)	1.93E-11	5.36E-12	2.98E-12	6.56E-13	1.08E-13	5.00E-01	2.59E+10	9.33E+10	1.68E+11	7.62E+11	4.63E+12
^{51}Cr	1.12E-07	3.73E-08	2.15E-08	4.98E-09	9.08E-10	5.00E-01	4.48E+06	1.34E+07	2.33E+07	1.00E+08	5.51E+08
^{54}Mn	6.01E-09	1.77E-09	1.00E-09	2.30E-10	4.16E-11	5.00E-01	8.32E+07	2.83E+08	4.99E+08	2.18E+09	1.20E+10
^{60}Co	3.50E-07	9.48E-08	5.31E-08	1.21E-08	2.17E-09	5.00E-01	1.43E+06	5.28E+06	9.41E+06	4.14E+07	2.30E+08
^{89}Sr	5.41E-07	1.59E-07	9.02E-08	2.07E-08	3.74E-09	5.00E-01	9.24E+05	3.14E+06	5.54E+06	2.42E+07	1.34E+08
^{90}Sr	3.56E-09	9.71E-10	5.45E-10	1.24E-10	2.23E-11	5.00E-01	1.40E+08	5.15E+08	9.17E+08	4.04E+09	2.24E+10
^{134}Cs	7.63E-04	2.21E-04	1.25E-04	2.85E-05	5.17E-06	5.00E-01	6.55E+02	2.27E+03	4.00E+03	1.75E+04	9.67E+04
^{137}Cs	1.22E-03	3.59E-04	2.03E-04	4.66E-05	8.45E-06	5.00E-01	4.11E+02	1.39E+03	2.46E+03	1.07E+04	5.92E+04

Table 20.6.4-6: Milk activity concentration maxima calculated from 2009 normal operation chimney and turbine bdg emissions (I+II) (Bq/m^3), prorated to BDL value.

The data presented in Table 20.6.4-1 - Table 20.6.4-6 show that in the first group (comprising feasible measurements) enable the detection of only a few radionuclides, primarily in regard to tritium and radiocarbon. It should be noted that these are also global pollutants at the same time which makes it rather difficult to identify the added load originating from the nuclear power plant. The second group (comprising measurements that take more of an effort to carry out) in addition to a few radionuclides of the ambient air concentration some of the elements of ground surface activity could be measured in theory, such as elemental iodine, radiocesium (which is, on the other hand, present irrespective of the presence of the nuclear power plant, in a concentration higher than the level referred to herein), but those could be detected rather within shorter distances from the Paks Nuclear Power Plant. Calculations show that all of the other radionuclides fall in the non-measurable category.

Assessment of the environmental activity concentrations originating from the liquid discharges of Paks II and the detectability of any accumulation

Our goal was to examine whether the impacts of the liquid discharges of the power plant equipped with 2 Russian VVER-1200 units can be measured in the various elements of the environment and in any accumulation. We applied a conservative approach in the sense that the highest activity concentrations expected to be found in the various elements were compared to the detection limits of the environment of the routine environmental monitoring programmed pursued by the power plant.

Since in this case no operational emission data or emission data series had yet been available for us, our calculations were carried out in the way described in Chapter 20.6.3 using the planned emission levels and the multi-annual minimum hydrological parameters specified there. The resulting activity concentrations were established by radionuclide for the analysis and then on the basis of the maximum activity concentrations we identified the 5 most typical radionuclides for each environmental element.

Further aspects taken into account in the selection process:

- the ^{3}H and the ^{14}C radioisotopes could only be taken into account for the water of the Danube since it is not from the activity concentrations building up in the various environmental elements that the applied special model [20.6-1] calculates the radiation to which residents are exposed,
- to arrive at a more complete picture only the radionuclide of the highest level was chosen for the given environmental element from among a given element's repeatedly detected radionuclides.

In this way the following 8 radionuclides were taken into account on the whole: ^{3}H, ^{14}C, ^{137}Cs, ^{131}I, ^{60}Co, ^{89}Sr, ^{54}Mn and ^{51}Cr (Table 20.6.4-7).

The activity concentrations were calculated for the following environmental elements using the technique described in Chapter 20.6.4.

- from the aquatic food chain: the water of the Danube, sediment and fish,
- soil, leafy vegetables, livestock feed, cow's milk and beef – each affected through irrigation.

The maximum activity concentrations identified as described above are summed up in Table 20.6.4-7.

Radionuclide	c_Danube (Bq/dm^3)	c_sedim. (Bq/kg)	c_fish (Bq/kg)	c_soil (Bq/kg)	c_vegetables (Bq/kg)	c_feed (Bq/kg)*	c_milk (Bq/dm^3)	c_meat (Bq/kg)
^{3}H	4,0E+00	-	-	-	-	-	-	-
^{14}C	4,5E-04**							
^{137}Cs	5,2E-05	4,9E-03	2,3E-01	1,4E-03	4,3E-04	5,3E-03	8,8E-04	3,3E-03
^{131}I	1,5E-05	-	6,0E-04	5,9E-07	4,3E-05	4,3E-04	5,7E-05	2,1E-04
^{60}Co	1,1E-06	4,0E-04	3,2E-04	9,9E-06	8,7E-06	1,0E-04	1,7E-05	8,8E-05
^{89}Sr	3,5E-07	6,6E-06	-	8,6E-08	2,1E-06	2,3E-05	8,9E-07	2,2E-06
^{54}Mn	2,6E-07	1,7E-05	1,0E-04	4,0E-07	2,0E-06	2,2E-05	1,1E-07	-
^{51}Cr	-	1,7E-05	4,7E-05	-	-	-	-	1,0E-05

* projected on dry mass
** value estimated by Isotoptech Zrt.

Table 20.6.4-7: Maximum activity concentrations in different environmental elements due to the planned liquid discharges of the nuclear power plant equipped with 2 Russian VVER-1200 units.

The detection limits characterizing the environment monitoring programmed applied by the existing Paks Nuclear Power Plant are presented in Table 20.6.4-8 on the basis of the YR 2011 report. In the absence of other information it is assumed that the environment monitoring system of the power plant with the new units will apply similar detection limits.

Radionuclide	c_Danube (Bq/dm^3)	c_sedim. (Bq/kg)	c_fish (Bq/kg)	c_soil (Bq/kg)	c_vegetables (Bq/kg)	c_feed (Bq/kg)*	c_milk (Bq/dm3)	c_meat (Bq/kg)
^{3}H	2,0E-00	-	-	-	-	-	-	-
^{14}C	1,0E-03							
^{137}Cs	5,0E-03	5,0E-01	5,0E-01	5,0E-01	5,0E-02*	5,0E-01	5,0E-01	5,0E-01*
^{131}I	5,0E-03	-	5,0E-01	5,0E-01	5,0E-02*	5,0E-01	5,0E-01	5,0E-01*
^{60}Co	5,0E-03	5,0E-01	5,0E-01	5,0E-01	5,0E-02*	5,0E-01	5,0E-01	5,0E-01*
^{89}Sr	1,0E-03*	5,0E-01*	-	5,0E-01*	5,0E-02*	5,0E-01*	5,0E-01*	5,0E-01*
^{54}Mn	5,0E-03	5,0E-01	5,0E-01	5,0E-01	5,0E-02*	5,0E-01	5,0E-01	-
^{51}Cr	-	5,0E-00*	5,0E-00	-	-	-	-	5,0E-00*

* detection levels estimated by pro-rating
** projected on dry mass

Table 20.6.4-8: Detection limits typical of the environmental monitoring program of the Paks NPP.

The ratios of the detection limits to the maximum activity concentrations, rounded to two decimals, are presented in Table 20.6.4-9. In addition to displaying the figures, in order to highlight differences amounting to orders of magnitude the various cells in the table are marked with different shades of grey, as detailed below:

- white, if the rate is: detection level / maximum activity concentration <10,
- light gray, if the rate is: detection level / maximum activity concentration > 10 but < 100,
- *deep gray*, if the rate is: detection level / maximum activity concentration > *100.*

Radionuclide	c_Danube (Bq/dm^3)	c_sedim. (Bq/kg)	c_fish (Bq/kg)	c_soil (Bq/kg)	c_vegetables (Bq/kg)	c_feed (Bq/kg)*	c_milk (Bq/dm3)	c_meat (Bq/kg)
^{3}H	0,50	-	-	-	-	-	-	-
^{14}C	2,2							
^{137}Cs	97	100	2,2	360	120	94	560	150
^{131}I	330	-	830	850000	1200	1200	8800	2400
^{60}Co	4700	1200	1600	51000	5700	4900	30000	5700
^{89}Sr	2900	76000	-	5800000	23000	21000	560000	230000
^{54}Mn	19000	29000	4800	1300000	25000	23000	4500000	-
^{51}Cr	-	290000	110000	-	-	-	-	480000

* projected on dry mass

Table 20.6.4-9: Detection level to maxium activity concentration ratios.

In the first group – this includes only the tritium and radiocarbon content of Danube water and the ^{137}Cs activity concentration expected to be found in fish – a targeted monitoring taking not significantly more resources than the routine monitoring program would, in theory, be likely to make it possible to detect the impacts of the new units. The following, however, should be noted:

- the actual flow rate of the Danube is many times the multi-annual minimum, (e.g. in 2012 it was more than three times the minimum taken into account in the calculations), i.e. the resulting concentrations would actually be as many times lower,
- the background level of tritium in the water of the Danube was as high as 1-4 Bq/dm^3 in recent years, definitely making it difficult to detect the concentrations of relevance,
- as a consequence of the impacts of the Chernobyl disaster on the environment in Hungary there is, unfortunately, no realistic chance for detecting 2-3 tenth of Bq/kg increase in the ^{137}Cs activity concentration. (This impact is evidently expected to decrease over time but in a 10-20-year time horizon not more than a 1.5-2.0 time decrease may be expected.),
- during the interim years when the existing and the new units will be operating in parallel, it will be difficult to identify the power plant from whose emission any increment that may be detected originates.

In the second group the measurement of the impact would take multiple times as great an effort (very large number of samples, extremely sensitive measuring instruments, very long measuring times). (The impacts of the residual ^{137}Cs contamination from the Chernobyl catastrophe could, in this case again, interfere with the measurements.) It is believed that in the case of the third group there is no realistic chance at all for detecting the power plant's environmental impact.

On the whole, it is concluded that in the case of normal operation the radiological impact is neutral in regard to atmospheric and aquatic releases (effective dose <90 μSv/year), and according to conclusions drawn from modeling exercises the accumulations are of so low levels that it will be practically impossible to detect them in the environment.

20.6.5 IMPACT AREAS OF PAKS II OPERATION

Radiological impacts are categorized as follows:

Category	Radiological impact (E=effective dose)
neutral	E < 90 μSv/year
tolerable	90 μSv/year < E < 1 mSv/year
burdensome	1 mSv/year < E < 10 mSv/2 days or 10 mSv/incident*
damaging	10 mSv/2 days or 10 mSv/incident < E < 1 Sv/incident**
eliminating	1 Sv/lifetime < E

* without food chain effect

** for the entire lifetime (50 years for adults, 70 years for children), without food chain effect

where

90 μSv/year effective dose is the dose restriction level prescribed by the ÁNTSZ-OTH office
1 mSv/year effective dose is the population dose limit
10 mSv avoidable effective dose over 2 days is the intervention dose level in regard to sheltering in cases other than the normal operation of the facility
1 Sv/lifetime is the emergency intervention level pertaining to permanent evacuation.

A level of 90 μSv/year is regarded to be the upper limit of the neutral effect, because the dose restriction applying to the reactor units operating in the Paks Nuclear Power Plant is also 90 μSv/year, and because the Paks Nuclear Power Plant and Paks II will be engaged in identical operations, with similar capacities (2000 – 2400 MWe). From the aspect of neutral impact this is acceptable because the level of dose restriction is way below the dose limit (1 mSv/year) and this dose restriction is even lower than the radiation exposure fluctuation stemming from the natural background radiation.

1 mSv/year is regarded to be the maximum of the tolerable impacts, because according to Decree 16/2000. (VI. 8.) EüM issued by the Ministry of Health on the execution of certain provisions of Act CXVI of 1996 on Nuclear Energy the sum of the external and internal radiation exposures from man-made sources to which the population is exposed – not including the radiation exposure resulting from medical diagnostic and therapeutical interventions, other than occupational patient care, voluntary participation in medical research – must not exceed this dose limit.

10 mSv/year is regarded as the maximum of the burdensome impact. According to the provisions set out in Decree 16/2000. (VI. 8.) EüM issued by the Ministry of Health a 10 mSv/2 days avoidable effective dose in the lowest intervention dose level at which any protective measure (e.g. sheltering) needs to be taken in case of emergency. If the expected dose does not reach the intervention level over a one-year period, the avoidable dose cannot reach it in 2 days either. Another conservative element is that the avoidable dose applies exclusively to the irradiation path(s) covered by the measure, while the radiological impact area is established on the basis of the effective dose applying to all pathways of radiation. Accordingly, the intervention level is accepted – on a conservative basis – as the dose criterion.

The optimized general intervention level for the permanent evacuation of the population is, according to Decree 16/2000. (VI.8.) EüM, a > 1 Sv/lifetime in the case of an emergency radiation exposure.

20.6.5.1 Direct impacts

The direct impacts can be established on the basis of the calculations set out in Chapter 20.4.2. (new fuel, spent fuel, radioactive waste transport, industrial radiography, movement of objects containing radioactive materials). Similar cases will occur in the case of Paks II as well, therefore the results of calculations show that the radiological impact within 500 m is not beyond the dose restriction limit. The boundary of the safety zone (500 m from the external technological building) is outside the 500 m radius, therefore the requirement that the radiological impact is below the dose restriction is also met even at the boundary of the safety zone.

20.6.5.2 Indirect impacts

According to the discussions in Chapters 20.6.1 and 20.6.3, the emission calculations indicate that the radiological impact does not exceed the dose restriction limit beyond a 500 m radius. The boundary of the safety zone (500 m from the external technological building) is outside the 500 m radius, therefore the requirement that the radiological impact is below the dose restriction is also met even at the boundary of the safety zone.

The summed-up radiological impacts (direct, indirect) remain – within a 500 m radius – below the dose restriction (neutral impact) in the case of normal operation since this requirement is met even at the boundary of the safety zone, therefore ***in the case of normal operation*** the boundary of the safety zone is to be regarded as the boundary of the impact area (Figure 20.6.5-1).

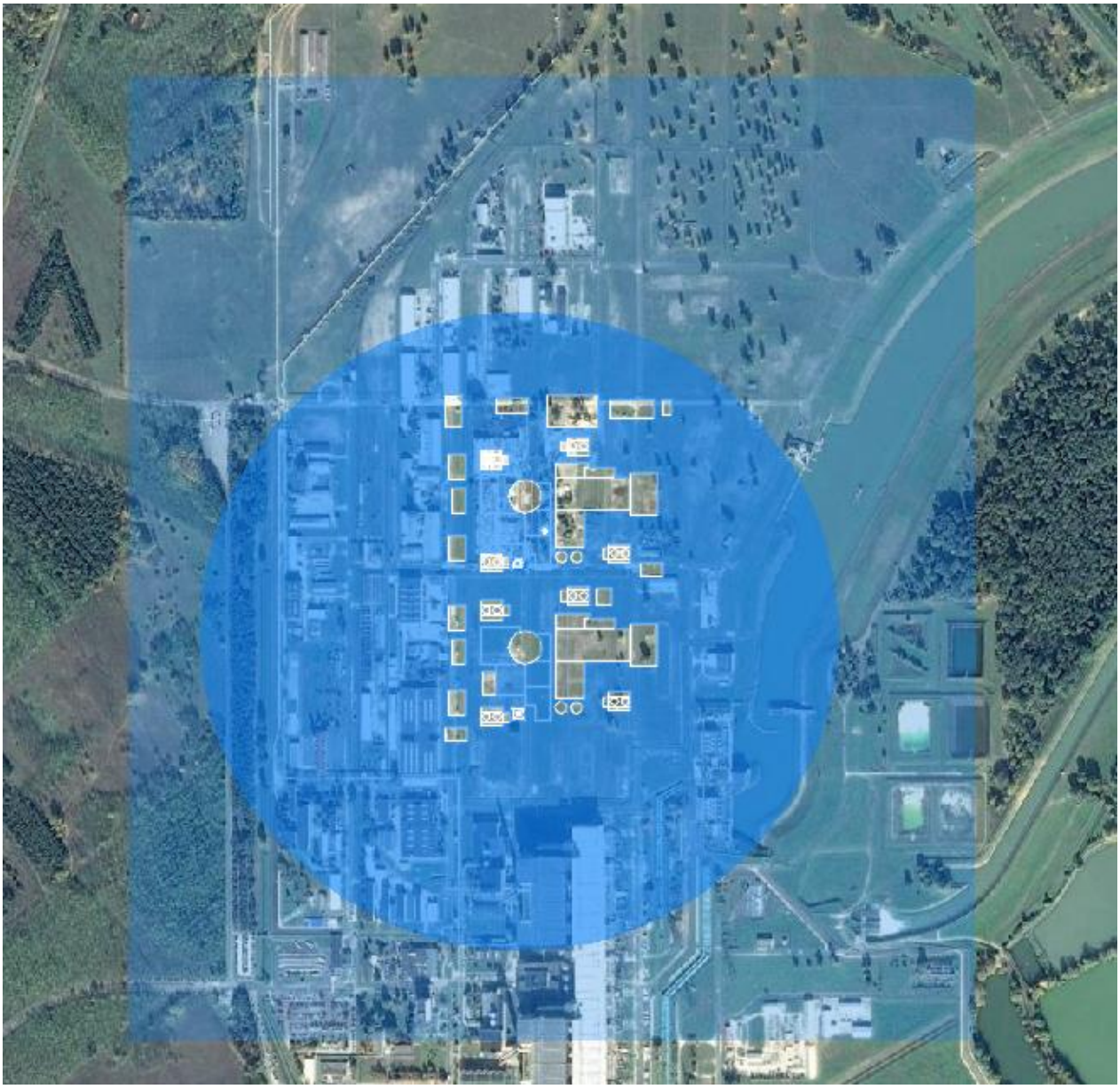


Figure 20.6.5-1: Impact area of Paks II normal operations: 500 m radius circle within the 500 m safety zone.

(The impact area was determined and is displayed on the basis of the respective central points of both chimneys (smokestacks) and the impact is indicated in a circle around these central points (a circle of a diameter of 500 m). Clearly, this area is within the 500 m safety zone.)

Based on the design basis accident (DBC4) event calculations in Chapter 20.6.2, the radiological impact is: below the dose restriction level, and the maximum is to be found at a circle of a 400 m radius. In regard to a ***design basis accident*** the boundary of the circuit of a 400 m radius may be taken as the area of impact but in reality the boundary of the 500 m safety zone should be regarded as the boundary of the actual impact area (Figure 20.6.5-2).

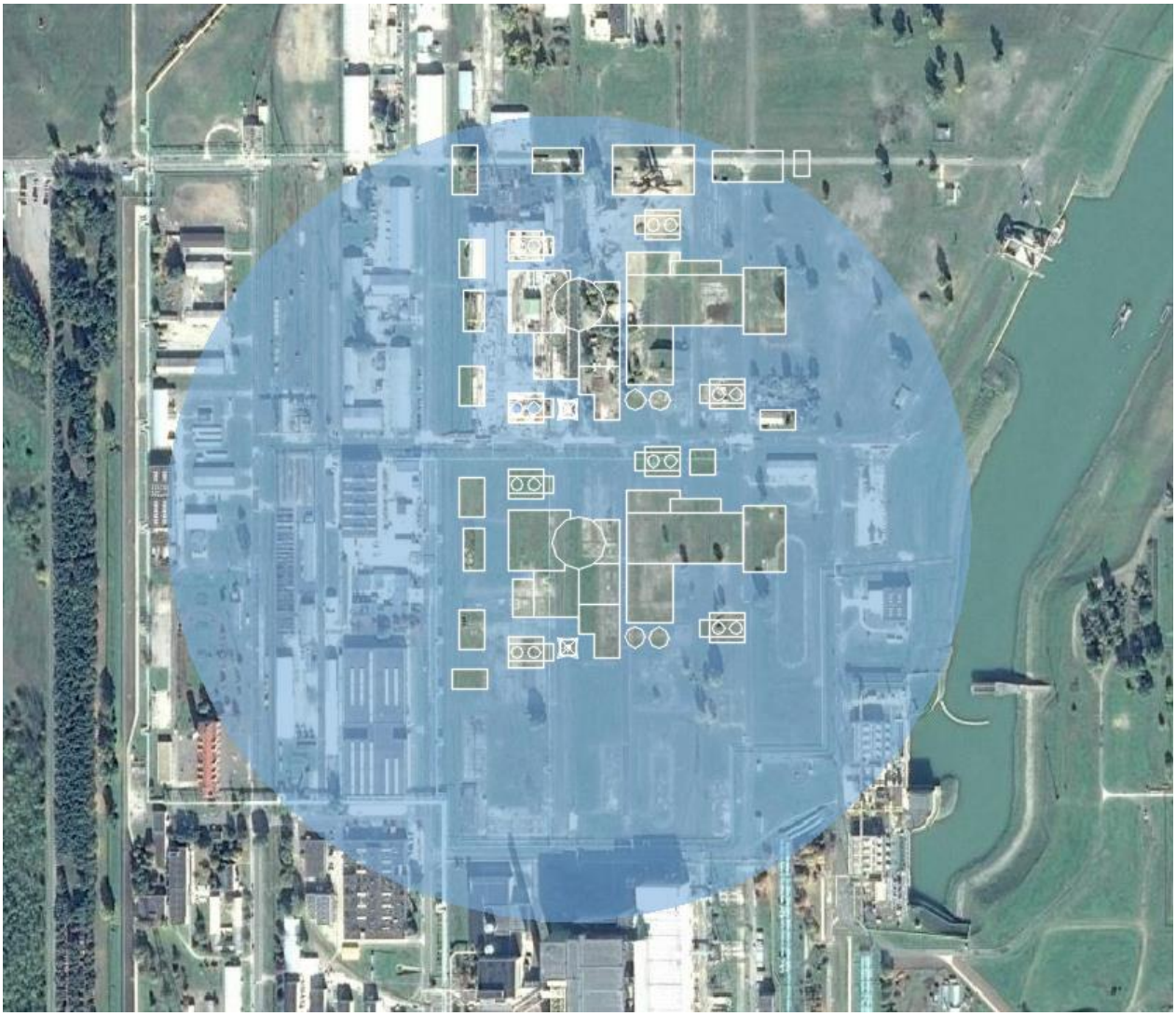


Figure 20.6.5-2: 400 m impact area for a Paks II design basis accident (DBC4).

20.6.5.3 Transboundary impacts

In case of a hypothetical occurrence of a design basis accident, the impact area of indirect impacts was identified as the same area as that falling within the 500 m safety zone boundary, from which it follows that no transboundary impacts need to be taken into account.

20.6.6 COMBINED IMPACT AND IMPACT AREA OF PAKS II, PAKS NPP AND ISFS FACILITY OPERATIONS

20.6.6.1 Combined impact of Paks II, Paks NPP and ISFS Facility operations

The combined impact of normal operation airborne emissions can be determined on the basis of Chapters 20.4.2, 20.6.1 and 20.6.3.

The cumulated maximum total doses of the three entities (Paks II., Paks NPP and ISFS) operating in the area are shown in Table 20.6.6-1 and Table 20.6.6-2 for the two age groups and the individual distances. It can be seen that the cumulative dose is two orders of magnitude smaller than the neutral limit.

Plant/Area	Csámpa	<5km	5-10km	10-30km
Paks NPP (2009)	8,40E-08	4,00E-08	6,50E-09	1,00E-09
Paks II (2009)	6,90E-08	3,90E-08	9,00E-09	1,50E-09
ISFS (2011)	1,40E-09	4,00E-10	6,60E-11	1,00E-11
Total	**1,54E-07**	**7,94E-08**	**1,56E-08**	**2,51E-09**

Table 20.6.6-1: Total doses of Paks II, Paks NPP and ISFS from peak year for children aged 1-2 years, Sv.

Plant/Area	Csámpa	<5km	5-10km	10-30km
Paks NPP (2009)	6,00E-08	2,90E-08	4,70E-09	7,30E-10
Paks II (2009)	5,90E-08	3,30E-08	7,50E-09	1,30E-09
ISFS (2011)	7,00E-10	2,10E-10	3,40E-11	6,60E-12
Total	**1,20E-07**	**6,22E-08**	**1,22E-08**	**2,04E-09**

Table 20.6.6-2: Total doses of Paks II, Paks NPP and ISFS from peak year for adults, Sv.

Children aged 1-2 (nSv/yr)	Adult (nSv/yr)
1,54E+02	2,04E+02

Table 20.6.6-3: Maximum combined impact of liquid discharges on annual level in Gerjen.

20.6.6.2 Impact areas of Paks II, Paks NPP and ISFS Facility combined operations

The radiation exposures arising from normal operations must be summed up to estimate the combined radiological impact according to the quality categorization presented in the first part of Chapter 20.6.5. This impact area will be the perimeter of the combined safety zones of Paks II, the Paks NPP and the ISFS Facility.

20.6.6.2.1 Direct impacts

Considering the similar calculations of Chapter 20.4.2, it is possible to determine the direct impacts. Similar events occur in both facilities, therefore based on the results one may say that the combined impact area never exceeds the dose restriction value at the boundary (200 m) of the safety zone(s). For the purpose of normal operations, the boundary of the impact area can be taken as the boundary of the safety zone(s).

20.6.6.2.2 Indirect impacts

Based on Chapters 20.4.2 and 20.6.1 - 20.6.3, the release figures show that the boundary of the impact area of combined effects can be taken as the boundary (500 m) of the safety zone(s).

20.6.6.2.3 Transboundary impacts

The impact area of direct and indirect impacts can also be taken as an area equal to that within the boundaries of the safety zone(s), therefore no transboundary (cross-border) impacts should be considered.

20.6.7 PROPOSED RADIATION PROTECTION MONITORING SYSTEM

The currently operating environmental radiation protection system can be regarded as comprehensive, it meets al applicable international standards.

Liquid and airborne releases are measured with a two-tier control system: continuous measurements by remote measuring systems, and sampling.

The remote measuring system includes remote measuring stations: Type A (9 pcs), G (11 pcs), C (15 pcs) and B (1 pc, control) stations (already presented in Subchapter Monitoring systems in the neigbourhood of the Paks Nuclear Power Plant).

In the Paks NPP, liquid discharges are monitored:

- In tanks: gross-beta, isotope composition, tritium, radiostrontium, radiocarbon, gross-alpha
- In canal waters (V1, V2, V3)

While airborne emissions are monitored in chimneys (stacks):

- on-line: alpha and beta-emitters, radioiodine, noble gas, gamma-emitters
- off-line: aerosol, radioiodine, noble gas, tritium, radiocarbon, radiostrontium.

Using the samples taken by the Environmental Monitoring Laboratory, the following environmental measurements are made:

(Abbreviations used: gross-beta = gb, gamma-spectrometry = gs, liquid scintillation = ls, alpha spectrometry = as, gross-alpha = ga)

Liquid discharge testing

Water samples:

- canal waters (gs, ls, ga)
- groundwater (gb, gs, ls)
- fish ponds (gb, gs, ls)
- diversion ditch (gb, gs, ls)
- Danube water (gs, ls)

Mud samples:

- Danube mud (gb, gs)
- fish ponds (gb, gs, ls)
- diversion ditch (gs,)
- defecated mud (gs)

Airborne emission testing

At sample collection stations:

- aerosol, radioiodine (gs)
- elemental iodine (gs)
- organic iodine (iodine-remote, active carbon), (gs)
- aerosol (high volume), (gb, gs)
- elemental iodine (high volume), (gs)
- organic iodine (act. c., high volume), (gs)
- radiostrontium (ls)
- tritium (HTO/HT)(ls)
- radiocarbon (C_nH_m, CO_2) (gb)
- fall-out (gs,)

Environmental mentoring testing in power plant environs:

- soil sample (gs, as, gb)
- grass sample (gs, gb)
- milk sample (gs)
- fish sample (gs)
- dose (TLD)
- on-site measurements (in-situ gamma-spectrometry, dose rate)

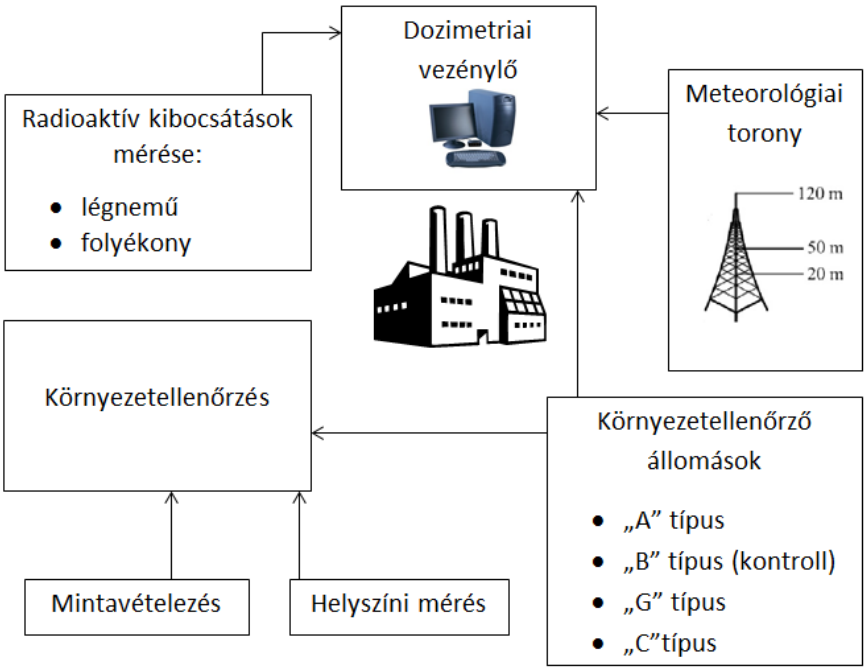
The Paks II units will globally be placed within the current environmental monitoring system, with a few exceptions.

- Thus the extension of the currently operating environmental radiation protection monitoring system of the Paks NPP is proposed to surround the area around the Paks II site.
- The number of type ”A” and ”G” measuring stations should be augmented.
- The expansion of type ”V” stations can be justified as function of the applied release technology.
- It is proposed to extend the sampling and measuring of the Environmental Monitoring Laboratory to encompass the Paks II site for the current environmental elements, which is important to ensure continuity and comparability (reference level), too.
- New groundwater monitoring wells must be constructed, as it was described in detail in Chapter Geological medium and underground water on the site and in the immediate vicintiy.

In order to establish the two-tier monitoring system of airborne and liquid releases of the Paks II units, in the new chimneys and at the points of liquid discharge continuously operating sampling and remote measuring systems similar to the current ones must be installed.

For laboratory measurements, it is recommended to priorities selective isotope measurements and to procure instruments with lower detection limits.

The conceptual structure of the proposed Paks II radiation protection monitoring system is sketched in Figure 20.6.7-1.



Dozimetriai vezénylő - Dosimetry control
Radioaktív kibocsátások mérése - Measuring radioactive releases
légnemű - airborne folyékony - liquid
Meteorológiai torony - Meteorological tower
Környezetellenőrzés - Environmental monitoring
Mintavételezés – Sampling
Helyszíni mérés - On-site measurement
Környezetellenőrző állomások - Environmental monitoring stations
“A” típus - Type ”A”
“B” típus (kontroll) - Type ”B” (control)
“G” típus - Type ”G
“C” típus - Type ”C”

Figure 20.6.7-1: Conceptual structure of the proposed Paks II radiation protection monitoring system.

20.7 IMPACT OF PAKS II DECOMMISSIONING ON THE RADIATION EXPOSURE OF THE POPULATION NEAR THE SITE

In respect of decommissioning, based on international experience it is safe to conclude that no increased impact can be expected as compared to normal operation, the impact will be similar to the analyses in section 20.4.2, 20.6.1 and 20.6.3, only the release points and the amount of waste may vary.

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