



Environmental spectrometry @JSI

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- Purpose of environmental spectrometry
- Off-site radiological monitoring around Krško NPP (NEK)
- Emergency preparedness and response (EPR)
- Conclusions

Purpose of environmental spectrometry

Assessment of any discharge/release of radioactivity to the environment is important for the protection of public health, especially if the released radioactivity can enter the food chain.

Assessment demands rapid, reliable and practical techniques for analysis (spectroscopic methods) of various radionuclides in different media (air, water, soil, food ...).

Purpose of environmental spectrometry

The information provided by spectroscopic methods is critical to

- determining radioactivity levels in air, water, soil, foods, and other media
- identifying pollutants
- Studying transport, process and other mechanisms of transverse in media to determine the effects on human and non-human biota
- ensuring compliance with national and international regulations and/or standards

Purpose of environmental spectrometry

What are spectroscopic techniques for environmental analysis?

Environmental samples are analysed using

- High-resolution gamma-ray spectrometry (HRGS)
- Liquid Scintillation Spectrometry (LSC)
- Radiochemical analysis (alpha, beta)
- Dosimetric techniques (TLD, OSL, dose-rate meters) – direct measurement of ionising radiation
- others

Radioactivity monitoring programs in Republic of Slovenia

- Article 35 of the EURATOM Treaty requires that each Member State shall establish the facilities necessary to carry out continuous monitoring of the levels of radioactivity in air, water and soil and to ensure compliance with the Basic Safety Standards.
- Article 35 also gives the European Commission (EC) the right of access to such facilities in order that it may verify their operation and efficiency.

Radioactivity monitoring programs in Republic of Slovenia

- Monitoring of radioactivity in the environment is intended for measuring the radioactivity levels due to nuclear or radiological activities and/or practices (discharges, releases) in the past, present or future.
- In the scope of the environmental radioactivity monitoring program, radioactivity of air, soil, precipitation and surface waters, as well as of drinking water, food, animal feed and non-human biota is measured.
- In the environmental radioactivity monitoring program, sampling locations, sampling strategy and frequency, measurement techniques, radionuclides, and measuring frequency are determined for every type of sample.
- Planned, existing and emergency exposure situation are considered in the assessment.

Radioactivity monitoring programs in Republic of Slovenia

- **Off-site radiological monitoring around Krško NPP (NEK)**
- ERM of living environment in Republic of Slovenia(URSJV)
- Monitoring of radioactivity in drinking water (URSVS)
- Independent verification of the operational ERM around Krško NPP(NEK + URSJV)
- Monitoring of radioactivity in fodder (MKGP)
- Central radioactive waste repository radiological monitoring (ARAO)
- Monitoring of liquid and atmospheric discharges from Krško NPP (NEK)
- **Emergency preparedness programme (NEK, URSZR - MORS)**
- *Monitoring of radioactivity in the environment of uranium mine Žirovski Vrh*
- TLD measurements of environmental doses

...

ERM=Environmental Radioactivity Monitoring
Authorized laboratories in Slovenia

Off-site radiological monitoring around Krško NPP (NEK)



Off-site radiological monitoring

- ❖ Commercial operation 1983
- ❖ Steam Generators replacement 2000
- ❖ Westinghouse two loop PWR
- ❖ Power 2000 MWt, 696 MWe



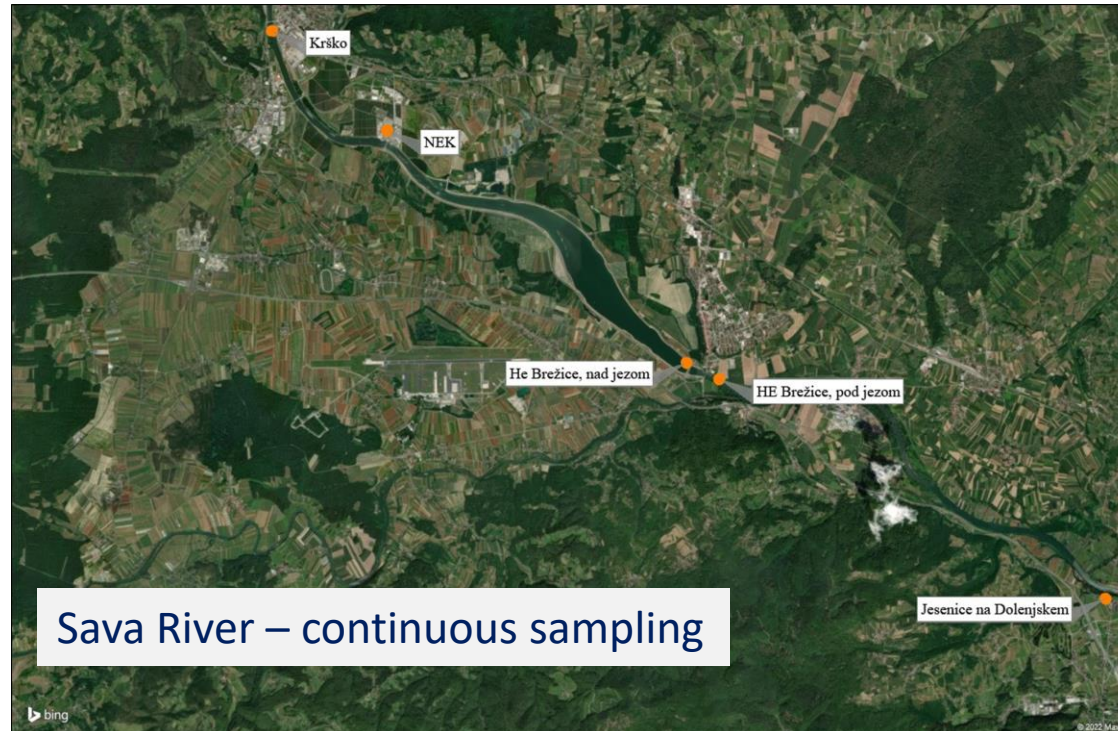
Off-site radiological monitoring around Krško NPP (NEK)

Off-site radiological monitoring

- Emissions (at the source) – sampling + model to **estimate** environmental concentrations and effective doses
 - *Liquid effluents (new model based on 3D simulation of transport and dispersion of liquid effluents into river Sava has been developed (2023))*
 - *Atmospheric discharges (Lagrangian dispersion modelling)*
- Environmental samples - sampling, **measurement** of environmental concentrations → effective doses
 - *River Sava (water, sediments, biota)*
 - *Drinking water (pumping stations, water system)*
 - *Precipitations & dry residue*
 - *Aerosols and charcoal filters*
 - *Soil*
 - *foodstuff*

Off-site radiological monitoring around Krško NPP (NEK)

In 2017 the environment downstream from the NPP drastically changed due to the construction of the Brežice hydroelectric power plant (Brežice HPP) dam, additional radiological monitoring sampling locations were introduced in the reservoir.



Off-site radiological monitoring around Krško NPP (NEK)

Liquid discharges – source monitoring & ERM



liquid effluents (WMT, SGBD) discharges to river Sava

Sampling station for monitoring liquid effluents in Brežice

- monthly composite
- ~ 50 L
- Analysed by HRGS, LSC and radiochemical separation for Sr-90

Off-site radiological monitoring around Krško NPP (NEK)

Liquid discharges – ERM (drinking water)



Automatic sampler for drinking water in the area of Krško NPP:

- 190 mL per 3 hours
- monthly composite
- ~ 50 L
- Analysed by HRGS, LSC and radiochemical separation for Sr-90



Off-site radiological monitoring around Krško NPP (NEK)

Atmospheric discharges – ERM (precipitation)



Precipitation samplers:

- Krško, Brege, Dobova, and Ljubljana
- a stainless funnel of an effective area of $0,25 \text{ m}^2$ is placed 1 m over the ground and it is equipped by the 50 L replaceable plastic container
- Amount of the sample – amount of the precipitations
- Analysed by HRGS, LSC and radiochemical separation for Sr-90

Off-site radiological monitoring around Krško NPP (NEK)

Atmospheric discharges – ERM (aerosol, charcoal)

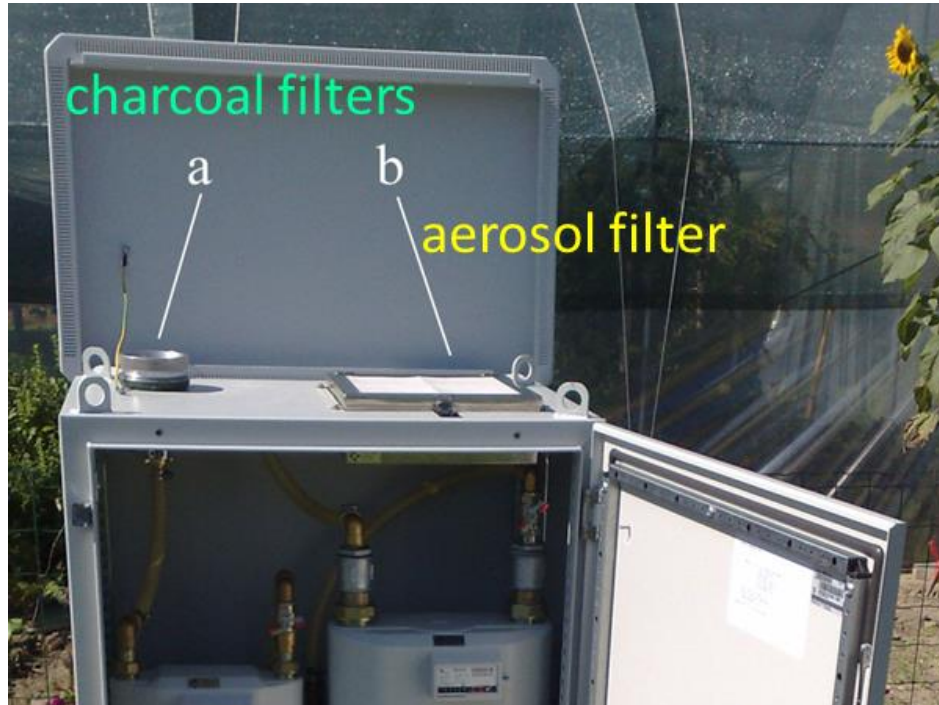


High volume flow rate aerosol pumps

- 2 locations: Dobova (off the NPP) and Ljubljana
- The single-branch sampler uses a concertinaed fiberglass filter of an area of 0.9 m^2
- Air flow-rate of $150\text{-}200 \text{ m}^3/\text{h}$ the retention efficiency of the filter is 99.99 % for the particles larger than $0.3 \mu\text{m}$
- The air samplers are in-house built devices (continuous operation)
- Sampling period: one month
- Filters are folded, pressed and packed into plastic containers
- Analysed by HRGS
- Measurement results of detected radionuclides are reported as the activity concentration in the units of Bq/m^3 .

Off-site radiological monitoring around Krško NPP (NEK)

Atmospheric discharges – ERM (aerosol, charcoal)



Combined Iodine I-131 and aerosol sampler

- The combined-branch sampler is made up of two suction branches with intake ports
- 7 locations
- Two flow-rate meters
- At the intake port of the first suction branch
 - Fiberglass filter
 - The aerosol filter with the dimension of 30 x 30 cm
 - 99,96 % retention efficiency for the particles of sizes larger than 0.3 μm
 - Air flow-rate through the aerosol filter of 16.2 m^3/h .
- At the intake port of the second branch
 - Charcoal filter (to catch short-lived iodine radionuclides)
 - The air flow-rate through the charcoal filter is 3.6 m^3/h
- Analysed by HRGS and radiochemical separation for Sr-90

Off-site radiological monitoring around Krško NPP (NEK)

External radiation– ERM



TLD in environment

- 124 locations: 50 in Slovenia, 74: NPP
- $\text{CaF}_2:\text{Mn}$ material
- Accreditation 17025:2017



Soil sampling

- 3 locations in the area NPP
- Uncultivated soil
- Analysed by HRGS and radiochemical separation for Sr-90

Off-site radiological monitoring around Krško NPP (NEK)

Sample preparation



Sample preparation room



homogenized cylindrical
sample ready for the
measurement

Off-site radiological monitoring around Krško NPP (NEK)

Environmental spectrometry



High resolution γ -ray spectrometry - counting room with 9 HPGe detectors

- γ -ray emitters (Cs-137, Co-58, Co-60, Ag-110m)
- Accreditation 17025:2017



Liquid scintillation spectrometry laboratory – counting room with 3 Quantulus spectrometers

- H-3, C-14, OBT, Ra
- Accreditation 17025:2017

Off-site radiological monitoring around Krško NPP (NEK)

Environmental spectrometry

High resolution gamma-ray spectrometry

- Energy range from 4 to 2700 keV
- Sensitivity for Cs-137
 - **high volume flow-rate aerosol pumps** $0.2 \mu\text{Bq}/\text{m}^3$ (air)
 - **low volume flow-rate aerosol pumps** $1.0 \mu\text{Bq}/\text{m}^3$ (air)
 - **Water samples:** $0.1 \text{ Bq}/\text{m}^3$
- During the measurement the N_2 is introduced inside the shield, which is aged for 2 weeks; overpressure; blanks are checked ...
- Stable conditions in the counting room are controlled, and (p, T, RH) data are used for Rn progeny activity concentration correction



Natural radionuclides in water samples:
 $A(\text{U-238}) \rightarrow A(\text{Th-234})$ and $A(\text{Pa-234m})$
 $A(\text{Ra-228}) \rightarrow A(\text{Ac-228})$
 $A(\text{Ra-226}) \rightarrow A(\text{Pb-214})$ and $A(\text{Bi-214})$ +
correction for the exhalation of the Rn-222
from the sample

Off-site radiological monitoring around Krško NPP (NEK)

Environmental spectrometry

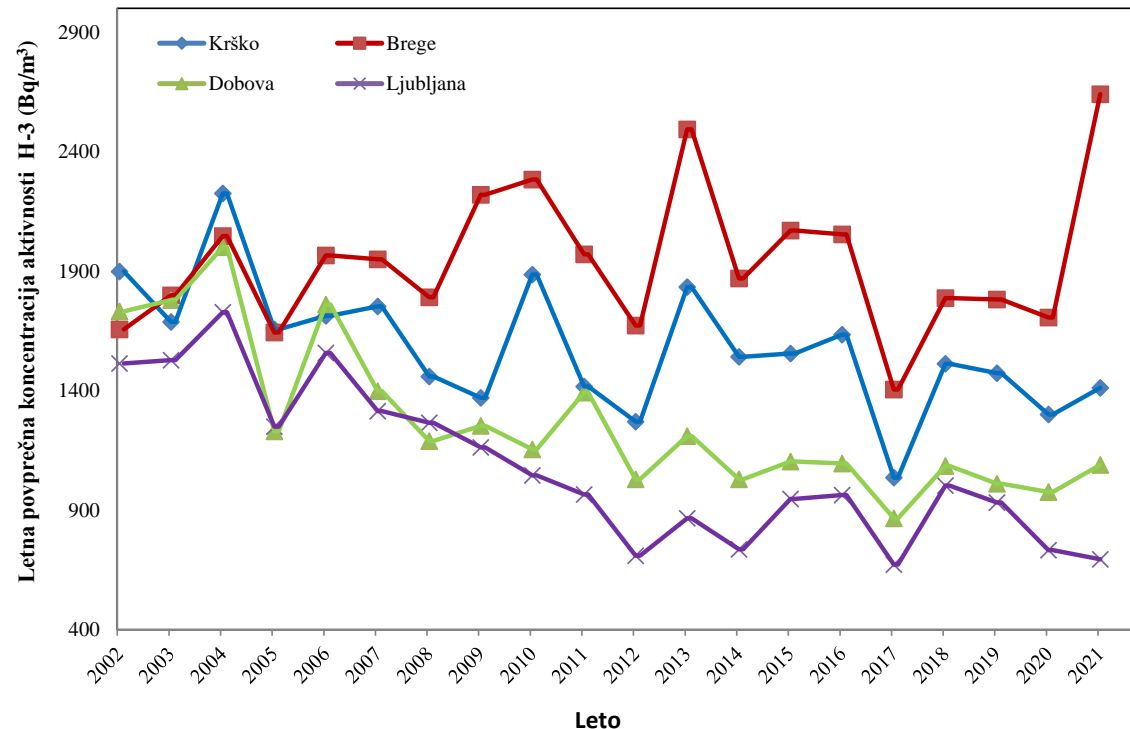
Statistical analysis of the results

- Results of the analysis of every sample measured are stored in a relational database (RAD-DATA)
- The database contains measurements' results since 1983
- Before current analysis' results are fed into the database, they are statistically compared to the average and a warning to the operator is issued in case of discrepancy – practical value for the monitoring programmes (the same sampling location for years)
- Participation in intercomparison measurements and proficiency tests presents an opportunity to assess the overall performance of the sample measurement and spectrum analysis used

Off-site radiological monitoring around Krško NPP (NEK)

Outcomes from Environmental spectrometry & dose assessment

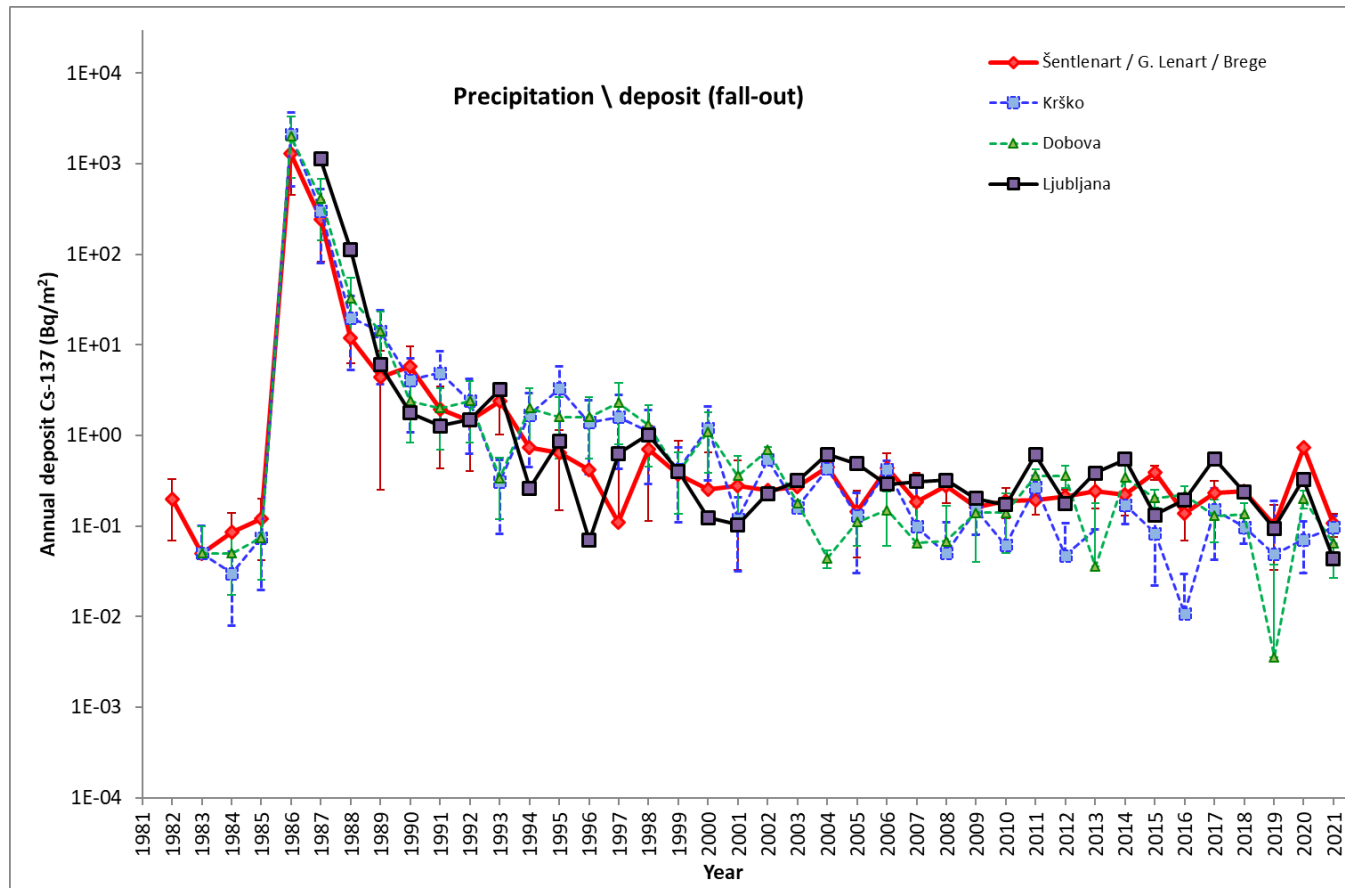
Annual activity concentration of H-3 in precipitation for the last decade (2002 - 2021)



Excerpt from
Ovrednotenje meritev radioaktivnosti in
ocena učinkov izpustov NEK na okolje
ISBN 978-961-264-227-3

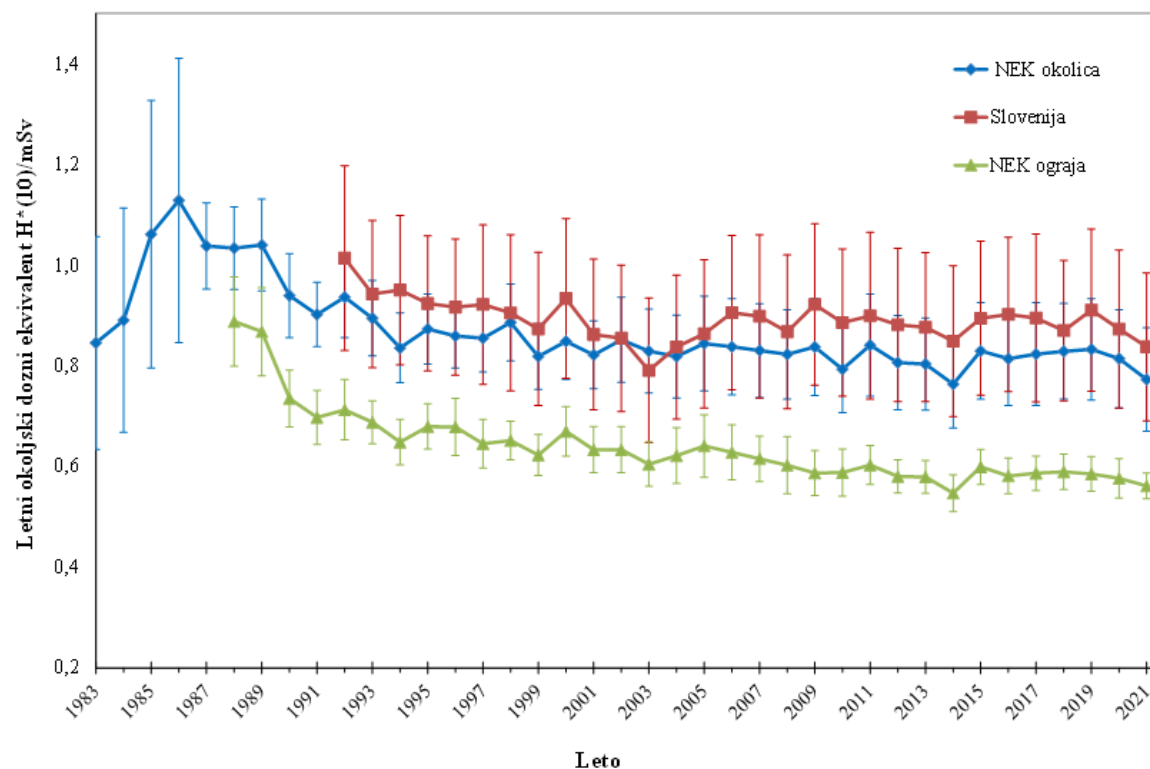
Off-site radiological monitoring around Krško NPP (NEK)

Outcomes from Environmental spectrometry & dose assessment



Off-site radiological monitoring around Krško NPP (NEK)

Outcomes from Environmental spectrometry & dose assessment

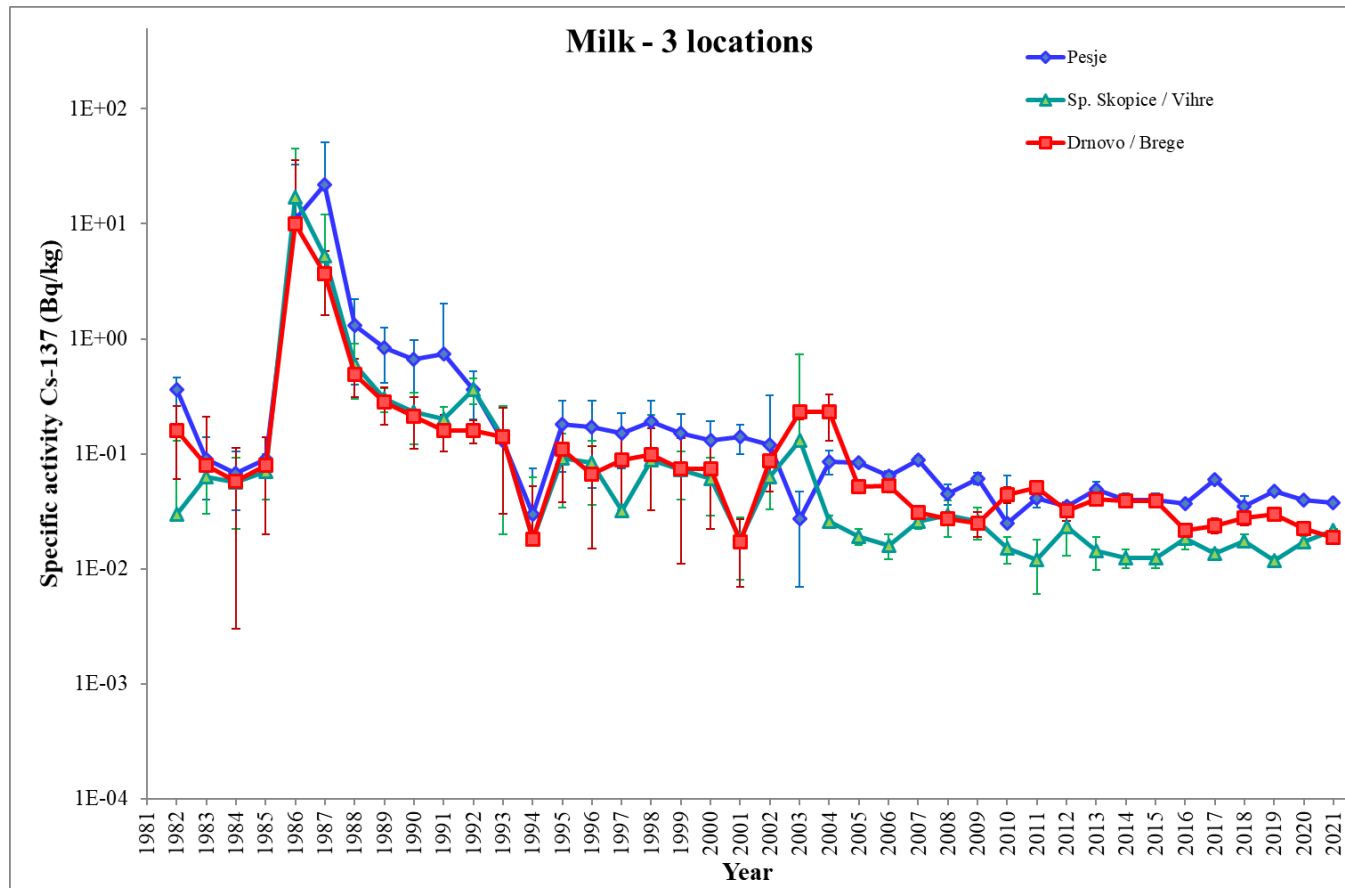


Average annual ambient dose equivalent $H^*(10)$ around NPP, at the fence perimeter of the NPP, and in Slovenia from 1982 to 2021

Excerpt from
Ovrednotenje meritev radioaktivnosti in
ocena učinkov izpustov NEK na okolje
ISBN 978-961-264-227-3

Off-site radiological monitoring around Krško NPP (NEK)

Outcomes from Environmental spectrometry & dose assessment



Off-site radiological monitoring around Krško NPP (NEK)

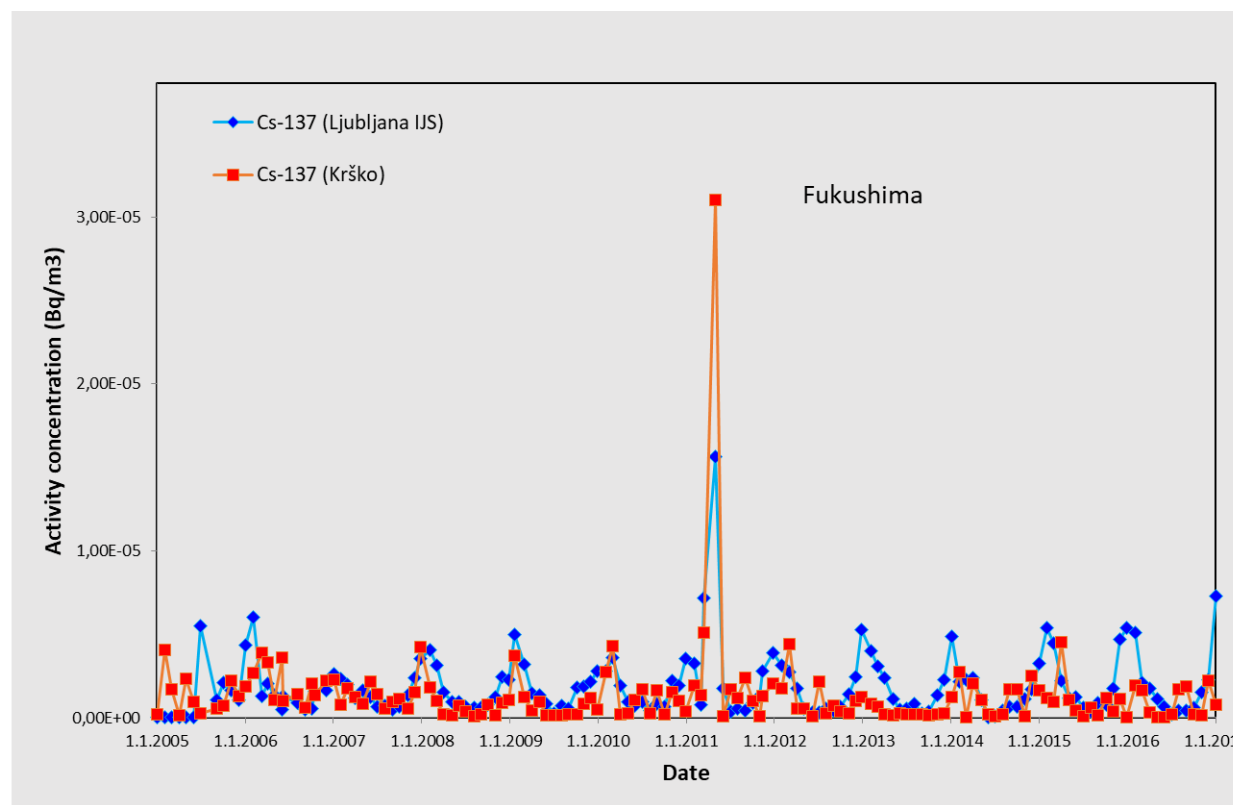
Summary of annual exposures of the representative person in the vicinity of Krško NPP for 2021– compliance with the regulation

Excerpt from
Ovrednotenje meritev radioaktivnosti in
ocena učinkov izpustov NEK na okolje
ISBN 978-961-264-227-3

Source	Exposure pathway	Annual effective dose (mSv)
Natural radiation	– gamma radiation and the directly ionizing component of cosmic radiation	0.65 ^{**}
	– neutron component of cosmic radiation	0.06
	– ingestion (K, U, Th)	0.26
	– inhalation (Rn-222 short-lived daughters)	1.30
	Total natural radiation in the vicinity of the Krško NPP	2.30
Krško NPP - direct radiation at the fence of the Krško NPP	– direct irradiation from the Krško NPP buildings	indeterminable
Krško NPP atmospheric discharges (representative person at the Krško NPP fence ^{****})	– external dose (air immersion)	5.8 E–7
	– groundshine (Co-60, Cs-137)	7.4 E–11
	– inhalation (H-3, C-14)	1.9 E–5
	– ingestion (C-14)	1.4 E–4
Krško NPP Liquid effluent (Sava)	– adult representative person at 350 m downstream from the Krško NPP dam	1.6 E–5
	– adult representative person in Brežice	7.3 E–6
	Total radiation effects of the Krško NPP*	1.8 E–4
Chernobyl accident, nuclear-weapons tests	– external dose ^{**}	< 1.4 E–2 ^{***}
	– ingestion of vegetable and animal food (without C-14) ^{*****}	5.0 E–4
	– ingestion of vegetable food (C-14)	1.45 E–2
	– ingestion of fish	9.2 E–5
	Total global contamination	2.9 E–2

Off-site radiological monitoring around Krško NPP (NEK)

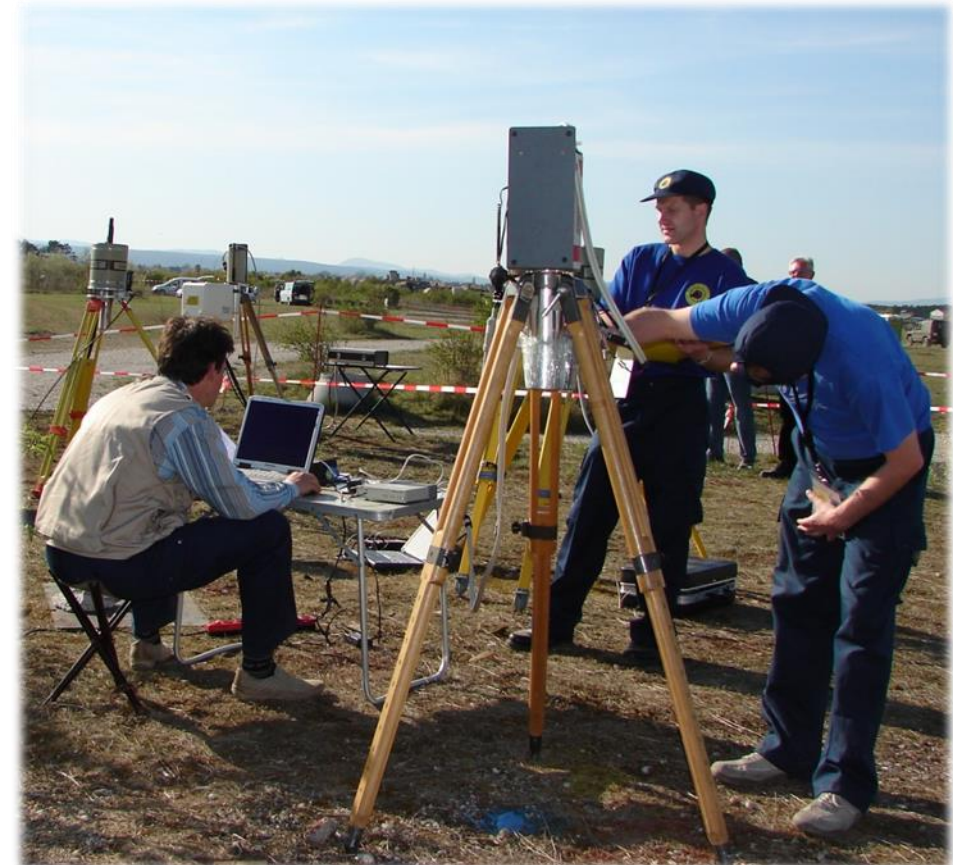
Example of good practices of the ERM



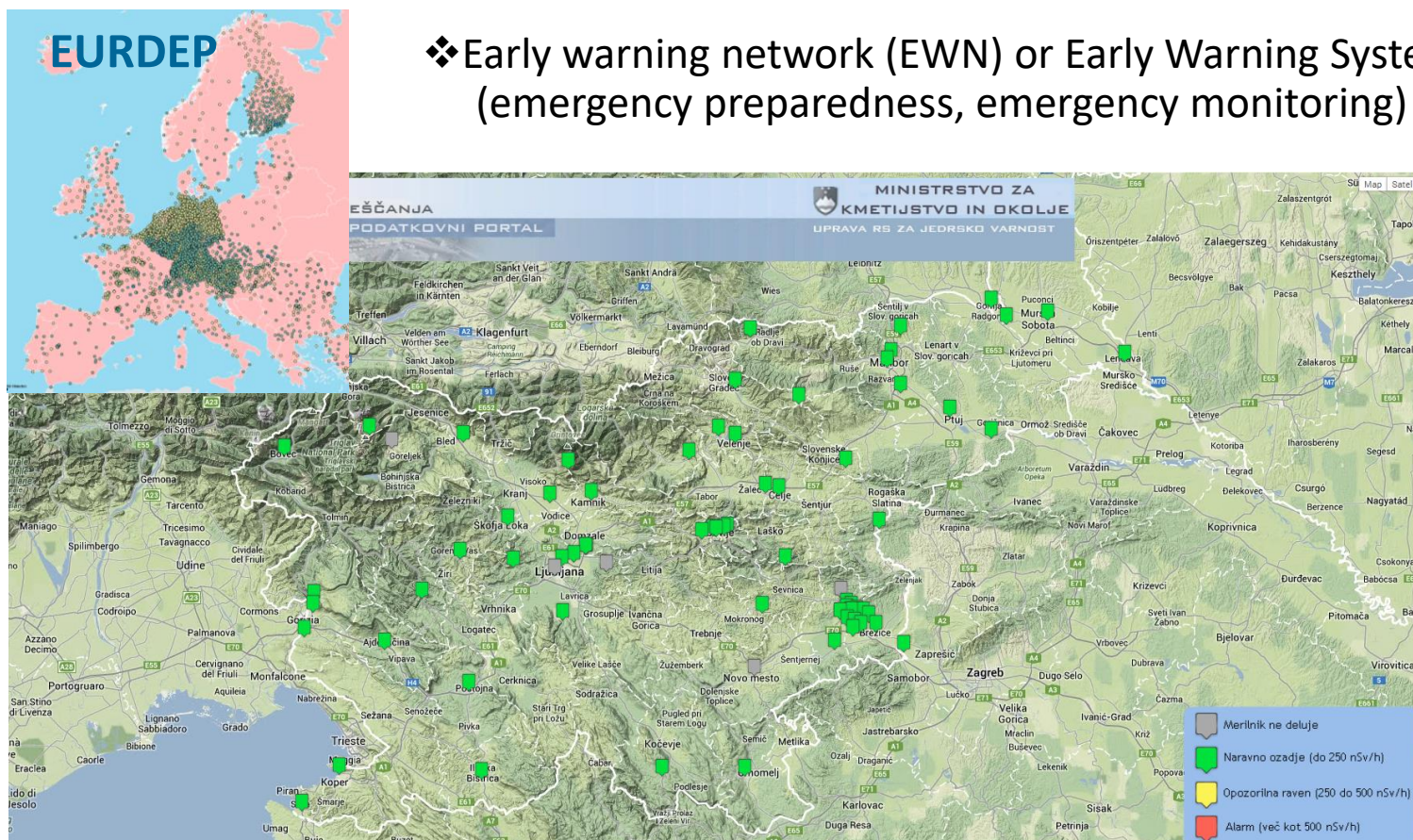
Emergency preparedness and response programme

In emergency, the ELME can be send to the location

- To perform dose rate and contamination measurements
- To perform rapid radionuclide specific measurements (γ -rays, α/β)
- To collect samples for prompt measurements and analyses, and to dispatch them to the stationary laboratories
- To advise appropriate steps to the authorities responsible for implementation of protective measures to minimize consequences



Emergency preparedness and response programme



Emergency preparedness and response programme

Radiological Mobile Laboratory



Emergency preparedness and response programme

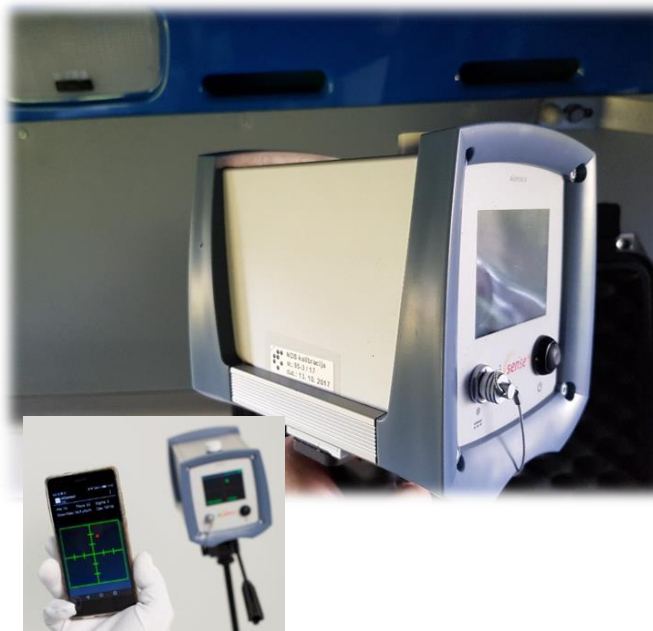
Environmental spectrometry – radionuclide identification



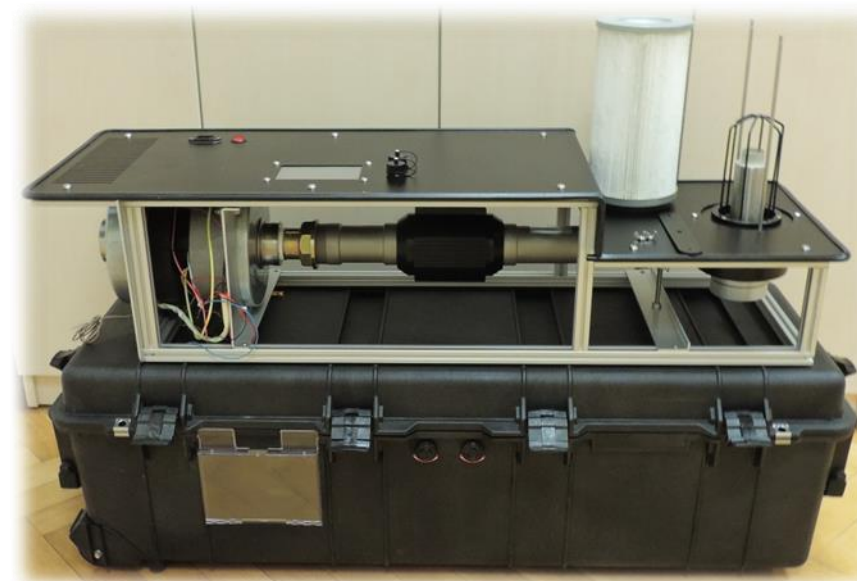
Hand-held
Spectrometer



HPGe



Radiation identification
and spectrometer



On-line aerosol particulate
spectrometer (CeBr₃) with high
volume aerosol pump was developed
and designed

Emergency preparedness and response programme

Environmental spectrometry – direct radiation, radiation identification, contamination



Hand-held dose-rate meter



telescopic dose-rate meter



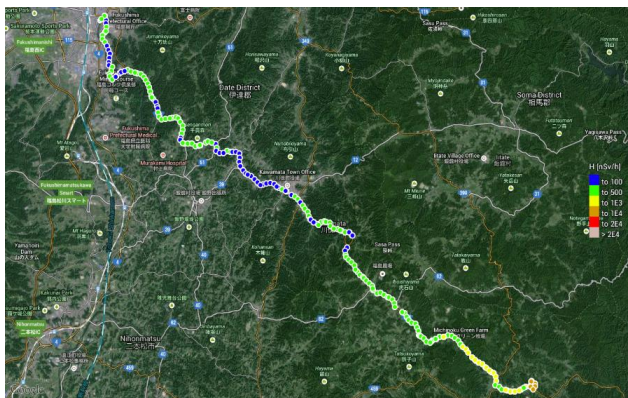
Neutron dose-rate
and dose meter



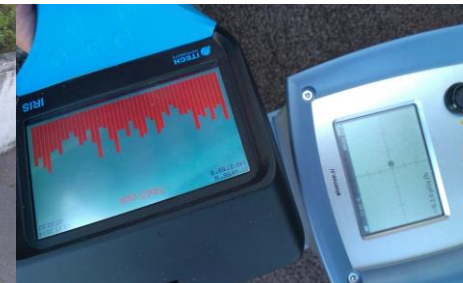
Radiation
contamination

Emergency preparedness and response programme

Environmental spectrometry – international cooperation (RANET-IAEA)



SI-FAT-1
Date: 2014-11-18
Dose rate mapping
(carborne)
Device: Automess
(6150AD-b/H)
Units: $H^*(10)$ [nSv/h]





Thank you for your attention!