The TAWARA_RTM project

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Outline

- Introduction: the problem of tap water radioactivity screening and the TAWARA_RTM project
- Short description of the TAWARA_RTM components and performances achieved
- The demonstration at Warsaw Waterworks
- Plans for the future

NARODOWE CENTRUM BADAŃ JĄDROWYCH Świerk
ENEA Italian National Agency for New Technologies, Energy and Sustainable Economic Development
CAEN Tools for discovery
MPWiK Warszawa
WAR DYN SKI• PAR TNE RS•
SCIONIX
Università degli Studi di Padova

A recent example of tap water contamination

Japan, March 11th 2011: the Fukushima Dai-ichi reactors got seriously damaged by the devastating earthquake and tsunami, and large quantities of radioactivity (mainly Cesium and Iodine isotopes) were released in the environment.

	①Iitate-mura (village)			②Date-shi (city)			③Kawamata-machi (town)		
Date	^{131}I	^{134}Cs	^{137}Cs	^{131}I	^{134}Cs	^{137}Cs	^{131}I	^{134}Cs	^{137}Cs
	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg
2011/3/17							308	ND	ND
2011/3/18							293	15	ND
2011/3/19							130	ND	ND
2011/3/20	965	ND	ND				127	ND	ND
2011/3/21	492	16	15	120	8	ND	174	ND	6
2011/3/22	344	ND	ND				69	ND	ND
2011/3/23	220	ND	ND	56	ND	ND	77	ND	ND
2011/3/24	94	ND	ND	53	ND	ND	50	ND	ND
2011/3/25	113	ND	ND	108	ND	ND	40	ND	ND
2011/3/26	179	ND	ND	29	ND	ND	37	ND	14
2011/3/27	159	ND	ND	42	ND	ND	67	ND	ND
2011/3/28	129	ND	8	45	ND	ND	34	ND	ND
2011/3/29	77	ND	ND	38	17	15	16	ND	ND
2011/3/30	71	ND	ND	18	ND	ND	17	ND	ND
2011/3/31	81	ND	12	83	69	53	35	ND	ND

Tap water samplings in the Fukushima's surroundings after 16/3/2011.

Regular monitoring started a few days after the disaster.

The danger threshold was set at 100 Bq/l for infants and 300 Bq/l for the rest of the population *Notice No. 0317 Article 3 of the Department of Food Safety, March 17, 2011*

A recent example of tap water contamination

The current tap water radioactivity screening procedures foresee **periodic samplings** followed by laboratory analysis, sometimes many months of each others...

- ***What could happen in case of not immediately evident contamination?***
- ***How to guarantee that the water distribution is stopped before reaching the population?***
- ***Are the current laboratory techniques suitable for a real-time monitoring of the water status?***

Some of the possible sources of RN threats considered in the project:

- **an emergency at a nuclear facility**, such as a nuclear power plant or a nuclear fuel reprocessing facility, in EU member states, or abroad;
- **a transportation accident** involving the shipment of radioactive material as nuclear waste from the power plants;
- **an emergency involving the loss, theft, or discovery of radioactive material** (as the so-called orphan sources);
- a contamination in the aquifer due to **illegal radioactive waste dump**
- a terrorist attack utilizing radioactive materials, such as a RDD (aka **"dirty bombs"**)

EU legislation survey (I)

EU legislation regarding radioactivity in water

EU legislation states that **the cumulative dose due to natural radioactivity in water cannot exceed the dose of 0.1 mSv/year for people**. This must be calculated without Tritium, ^{40}K, Radon and its decay products.

On the other hand, as stated by WHO in the Guidelines for Drinking Water Quality, the process of identifying individual radionuclide in drinking-water determining their concentration is time-consuming and expensive and is normally not justified for routine monitoring.

A more practical approach is to use **a screening procedure, where the total radioactivity present in the form of alpha and beta radiation is first determined**.

EU legislation survey (II)

The **2013/51/EURATOM Directive** defined the **recommended screening levels for gross alpha and beta activity in drinking-water**, below which no further action is required: **0.1 Bq/L for gross alpha activity** and **1 Bq/L for gross beta activity**. If neither of these values is exceeded, the cumulative dose of 0.1 mSv/year is not exceeded either. On the contrary, a further radioisotope-specific analysis is necessary.

Moreover it provides indication on the **number of yearly measurements** that have to be performed, depending on the size of the water plant.

Volume of water distributed or produced each day within a supply zone m^3	Number of samples per year
volume ≤ 100	frequency can be decided by the Member State
100 < volume ≤ 1,000	1
1,000 < volume ≤ 10,000	1 + 1 for each 3,300 m^3/d and part thereof of total volume
10,000 < volume ≤ 100,000	3 + 1 for each 10,000 m^3/d and part thereof of total volume
volume > 100,000	10 + 1 for each 25,000 m^3/d and part thereof of total volume

Minimum sampling and analysis frequency for water intended for human consumption 2013/51/EURATOM Directive

Other guide lines from International Agencies

More recently the **EU Directive 2015/1787** (6/10/2015) reviewed the legislation related to quality of water intended for human consumption, but as far as radioactivity is concened it stated that “*monitoring programs for radioactive substances should exclusively be established under the directive 2013/51/ EURATOM*”

In addition to the radioactivity monitoring procedures in the everyday life, there are indications from national and international agencies regarding **the levels of radioactivity that require rapid actions in emergency situations** (like in Fukushima)

As an example, the IAEA “Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency” No. GSG-2 (2011), in the Operational Intervention Level 5 (OIL5), recommends a screening levels of **5 Bq/L for gross alpha activity** and **100 Bq/L for gross beta activity in an emergency situation**, above which a fast action should be taken within a week.

Baseline technology

The baseline technologies are represented by the **Liquid Scintillation Counters (LSC)** and **Proportional Counters (PC)**. These technologies offer good sensitivity and low detection limits but:

- the measurements are performed only on a sampling basis (periodical or occasional) and rely on the presence of a dedicated laboratory.
- Each sampling may need many hours from the collection of the water sample to the release of the results.
- The counting efficiency of the PC method is strongly affected by the total dissolved solids in water and the chemical composition of the sample as well.
- In the case of LSC, quenching (chemical, color and physical) can reduce the counting efficiency. Furthermore the alpha/beta separation can be difficult at all energies.

LSC and PC are not the best solution for <u>continuous real-time monitoring</u> of the radioactivity in tap water

Real-time radioactivity monitoring

Final considerations about legislation

- The current EU and National legislations define the gross alpha and beta detection limits for drinking water and the corresponding screening procedures (**periodic sampling**)
- No official requirements exist for the **real-time screening** scheme (the TAWARA_RTM scheme).
- Reasonable real-time monitoring requirements in terms of detection limits and technical specifications can be derived considering both the current legislation requirements and the End-user needs. TAWARA_RTM started from here.

➔ **A Real-Time radioactivity Monitoring system can improve the safety of our drinking water**

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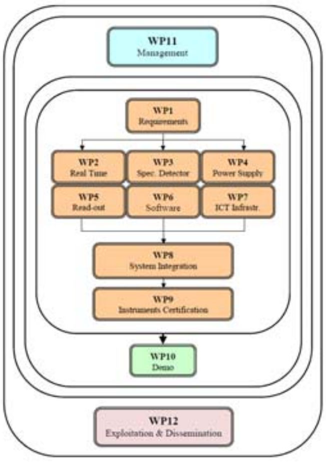
The TAWARA_RTM project

Title	**TAp WAter RAdioactivity Real Time Monitor**		
Acronym	TAWARA_RTM		
Project ID	312713	Call	FP7-SEC-2012-1
Programme	FP7	Rdg	ENTR
Keywords	Water radioactivity, Water contamination, Water plants, Alpha-Beta discrimination, Gamma spectroscopy, CBRN, RTM, Sensor Network		
Activity Codes	SEC-2012.1.5-2 Improving drinking water security management and mitigation in large municipalities against major deliberate, accidental or natural CBRN-related contaminations - Capability Project		



The TAWARA_RTM project aimed at **designing, building and testing a prototype of real-time monitoring system for the radioactivity level in the tap water plants.**

Structure of the project

33 Months, **12** Work Pacakges, **8** Partners

UNIPD CAEN SCIONIX NCBJ ENEA MPWIK UNIPI WIW

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The TAWARA_RTM project

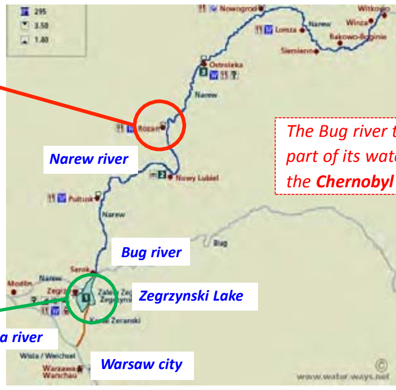
The Demonstration Site

The TAWARA_RTM prototype has been installed at the **Northern Water Treatment Plant of the Warsaw Waterwork Company (MPWiK)**

Located 30 km north from Warsaw, was launched in 1986. It can supply up to 240.000 m³/d

Polish National Radioactive Waste Disposal Site (NRWD)
During the almost 50 years of activity of the site, about ***3300 m³ of nuclear wastes*** *have been accumulated, with a total activity of almost* ***34 TBq***

DEMONSTRATION SITE



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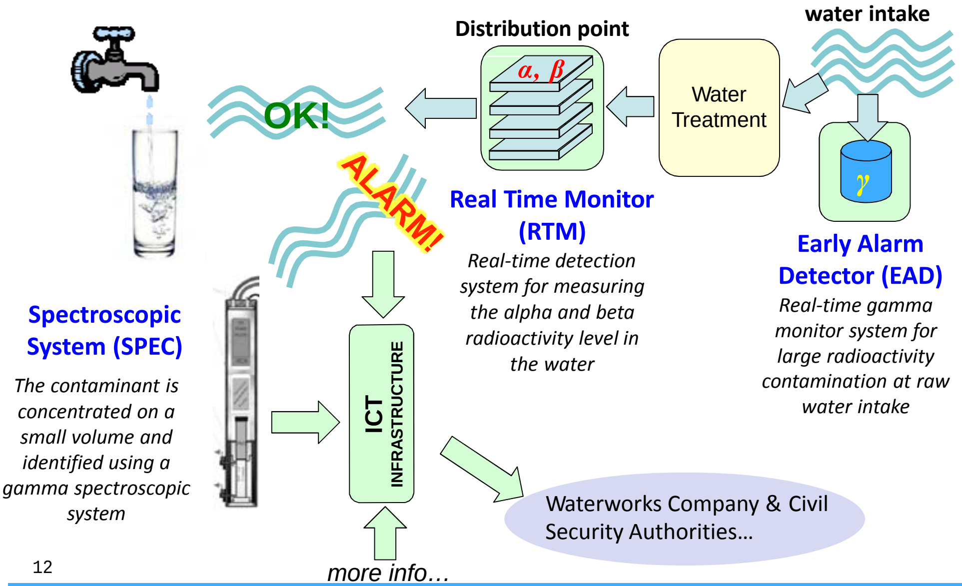
The TAWARA_RTM platform concept



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The Early Alarm Detector (EAD)

The Early Detection System (EAD)
The gamma spectroscopy system placed at the pumping station to rise a fast alarm in case of important water contamination

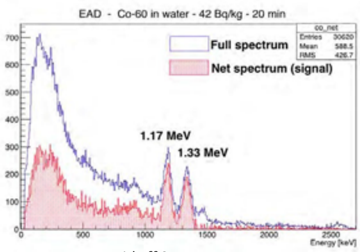
105 Bq/kg of ^{40}**K**: Net Rate @ ENEA = 3.72 +- 0.25 s^{-1}
Minimum Detectable Activity
1.71 / 3.72 * 105 Bq/kg => 48 Bq/kg in 5 minutes
1.25 / 3.72 * 105 Bq/kg => **35 Bq/kg in 10 minutes**

42 Bq/kg of ^{60}**Co**: Net Rate @ ENEA = 25.40 +- 0.28 s^{-1}
Minimum Detectable Activity
1.71 / 25.40 * 42 Bq/kg => 2.8 Bq/kg in 5 minutes
1.25 / 25.40 * 42 Bq/kg => **2.1 Bq/kg in 10 minutes**

139 Bq/kg of ^{241}**Am**: Net Rate @ ENEA = 2.10 +- 0.05 s^{-1}
Minimum Detectable Activity
0.40 / 2.10 * 139 Bq/kg => 26 Bq/kg in 5 minutes
0.29 / 2.10 * 139 Bq/kg => **19 Bq/kg in 10 minutes**

Calculated MDA for a False Alarm Rate of 1 FA/month and Probability of Detection PD = 90% (using the whole spectrum)

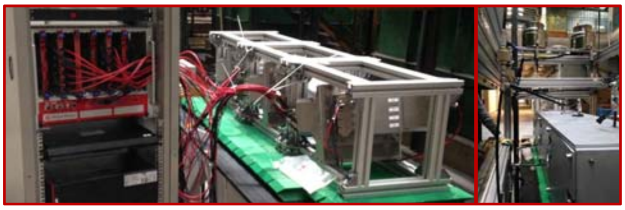
the EAD system during the assembly at the demo site



Test with ^{60}Co source at ENEA

The Real Time Monitor (RTM)

The Real-Time Monitor (RTM)
The high sensitivity gross alpha and beta detection system placed at the water distribution point



the RTM system during the assembly at the demo site

Decision threshold y* and Detection limit y# for the three RMT chambers calculated @ENEA for a counting time T=240 s and expressed in Bq/kg

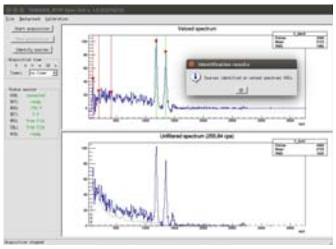
y* (Am-241)	32.11	34.71	33.69
y# (Am-241)	40.0	81.7	120.0
y* (Co-60)	4.12	9.05	7.20
y# (Co-60)	8.3	18.2	14.5
y* (K-40)	6.81	17.97	9.52
y# (K-40)	13.7	36.0	19.1
y* (Sr-90)	2.20	7.71	3.43
y# (Sr-90)	4.4	15.5	6.9
y* (F-18)	5.78	13.87	9.48
y# (F-18)	11.6	27.8	19.0

The SPECtroscopy System (SPEC)

The SPECtroscopy System (SPEC)

The high-resolution gamma spectroscopy system to identify the radioactive contaminant after an RTM alarm is raised

the SPEC system during the assembly at NCBJ



Example of Co-60 identification

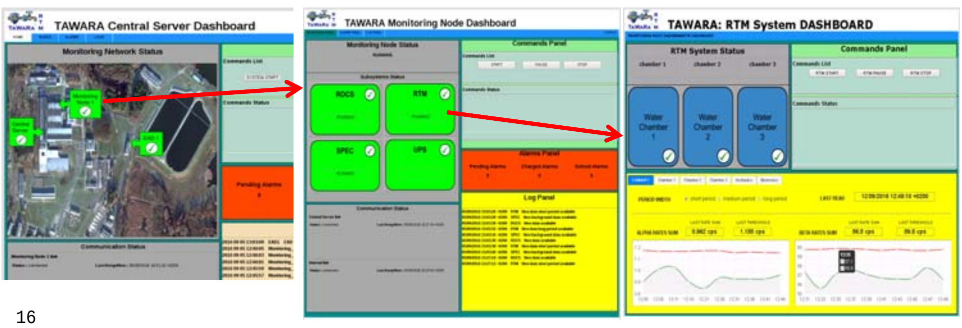
Time (s) needed to identify a given activity of contaminant @ENEA
value of significance > 5 (99.9999% c.l.)

Source	0.5 Bq	1 Bq	2 Bq	5 Bq	10 Bq
^{137}Cs		3000	1000	300	100
^{139}Ce	2300	1200	600	200	60
^{109}Cd	700	300	100	60	60
^{88}Y		2000	600	60	60
^{60}Co			1500	300	100

ICT infrastructure

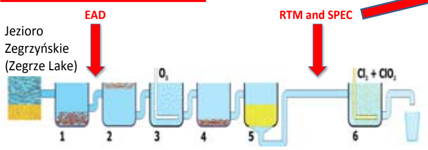
Global User Interface Central Server

- Map-based home page with the global status of all monitoring nodes (DCCs)
- Global commands for all DCCs
- List of alarms with the status (pending, accepted, cleared)
  Possibility to access a DCC specific control panel with the status, the visualization of aggregate data, alarms and commands console



Field Demonstration

Location of the TAWARA_RTM subsystems installation along the water treatment line



1 – Sedimentation in tanks
2 – Dissolved Air Flotation
3 – Ozonation
4 – Coagulation
5 – Rapid Sand Filtration
6 – Disinfection Cl2 and ClO2

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Plans for the future

End-User Feedback

During the two months of operation at the demonstration site, the End-User point of view was collected in order to improve the system usability in real-life conditions on a water treatment plant.

In particular they suggested to:

- improve the **access and visualization** of the archived detectors measurements;
- further **simplify the alarm displays** (e.g. adding better acoustic, graphical or written warnings);
- turn on and off, clean and rinse the equipment remotely from the control room (→ *already present, but not enabled*);
- initiate validation and calibration procedures

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TAWARA RTM

Plans for the future

Exploitation and transferability (I)

For the exploitation of the TAWARA_RTM technology developed under the project, three typical scenarios have been considered:

- **a fixed installation system** for water suppliers RN water quality monitoring
- **a mobile system** for waterworks RN water safety monitoring and emergency response
- **a low-cost device** for users' tap-water monitoring

The EU Environmental Technology Verification (ETV) Programme as exploitation driver was also condiered for this technology.

TAWARA RTM

Plans for the future

Exploitation and transferability (II)

Fixed installation system for water suppliers RN water quality monitoring

It's the current instrument scheme, to be improved from several points of view.

- Ion concentrator subsystem design requires some modification in order to achieve the expected performances.
- Development of software libraries to integrate the DCC in a SCADA control software
- Cost optimization
- Usability optimization
- Increase maintainability by simplifying the exchange of subparts of the system
- Perform long test runs and/or accelerated ageing runs to analyze ageing effects
- Involve certification authorities & policy makers to support technologically for the inclusion of RN real-time monitoring technology in the EU water legislation.
- Involve other end-users interested in the inclusion of RN real-time monitoring technologies in their respective water safety plan.

Expected price for an installation: 500.000 Euro – 1.000.000 Euro depending by the size and the specific requirements of the infrastructure.

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Plans for the future

Exploitation and transferability (III)

Mobile system for waterworks RN water safety monitoring and emergency response

It's a down-scaled version of the fixed installation that can be deployed in a mobile installation.

This product should targets two different users:

- **Water suppliers** interested in monitoring the real-time content of RN contaminants for the safety of the water distribution in case of severe contaminations.
- **Emergency responders** which require to add to their mobile intervention van a tool for the real-time measurement of the RN content in water.

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Plans for the future

Exploitation and transferability (IV)

Mobile system for waterworks RN water safety monitoring and emergency response

Recommended work to make it ready for the market:

- Development of a scaled-down RTM sensor with 10-time less sensitivity (miniRTM)
- Development of a simplified SPEC sensor with 10-time less sensitivity (miniSPEC)
- Test and laboratory characterization of miniRTM and miniSPEC with different radionuclides to assess the performances of the instrument
- Development of battery system for autonomous operation (> 8hrs at full use)
- Development of a rugged integration structure for van-mounted operations
- Cost optimization
- ... (as before)

Expected price for an installation: 80.000 Euro – 150.000 Euro depending by the specific operational requirements.

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Plans for the future

Exploitation and transferability (V)

Low-cost device for users' tap-water monitoring

The technology developed for the RTM sensor of the TAWARA_RTM system could be also a starting point for the development of **a low cost sensor for monitoring the RN content** (mainly ^{222}Rn, ^{220}Rn and other alpha emitters) in the tap-water.

This low-cost sensor could become in principle a commercial product for the consumer market.

Recommended work to make it ready for the market:

- Development of a scaled-down RTM sensor with **100-time less sensitivity** (microRTM)
- Test and laboratory characterization of microRTM with different radionuclides to assess the performances of the instrument
- Development of battery system and a water-flux power generator for autonomous operation (24/7 operation)
- Development & integration in a IP68 water-proof case
- Cost optimization
- ... (as before)

Expected price:
300 Euro – 500 Euro per sensor for small-medium volumes (1.000 < x < 10.000 pcs/year)
200 Euro – 300 Euro per sensor for big volumes (> 10.000 pcs/year)

The TAWARA_RTM Project

Thank you for your attention