Implementing Geological Disposal of Radioactive Waste Technology Platform

7th Exchange Forum

Hotel Córdoba Centre, Córdoba, Spain, October 25-26th, 2016

R&D Activities in Ukraine towards Geological Disposal of Radioactive Waste

Presented by - I.Shybetskyi

Radioenvironmetal Centre of National Academy of Sciences of Ukraine

55b, Gonchara str., Kiev, 01054, Ukraine

Phone/fax:+38-044-486-35-98

e-mails: shybetsky@hydrosafe.kiev.ua

iurii.shybetskyi@gmail.com

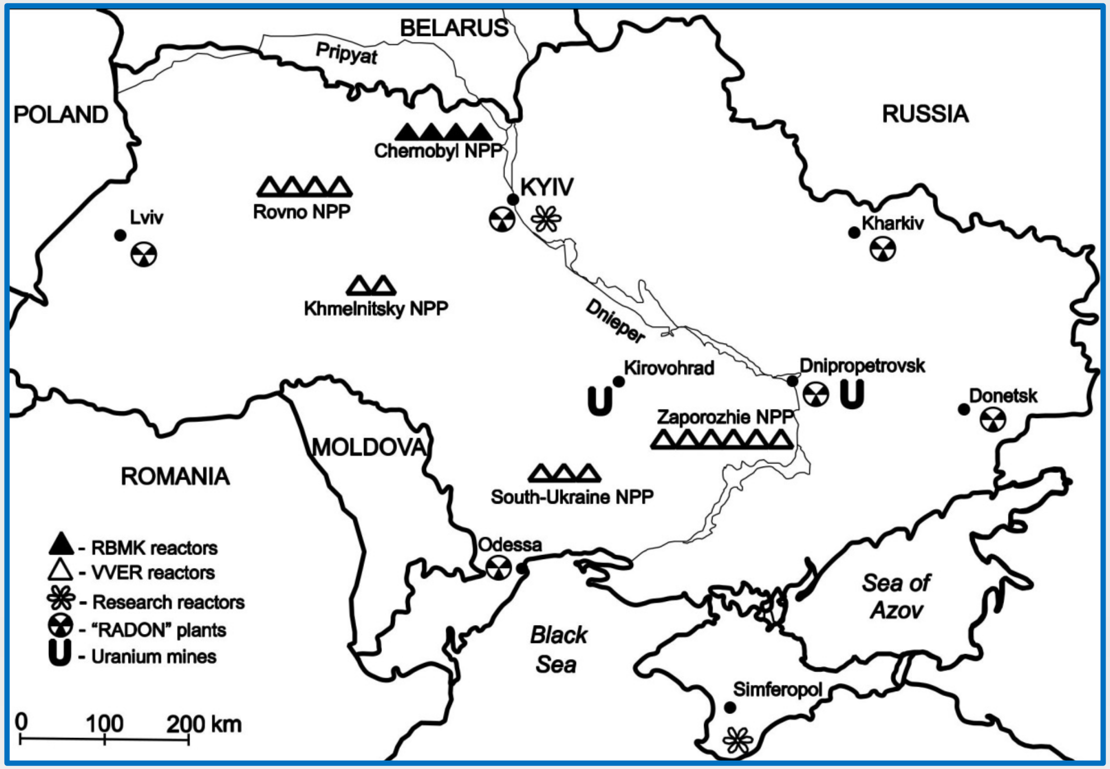
Content

1. Background
   - Ukrainian Nuclear Program and Waste Inventory
2. General Characteristics of R&D
   - Main projects & actors
3. Status of R&D Activities
   - Site Selection
   - Repository Concepts Development
   - EBS and Natural Barriers Studying
   - Safety Case Development
   - Natural Analogs
4. Conclusions

Contributors

Avila, Rodolfo	Facilia, Sweden
Bugai, Dmitrii	Institute of Geology, NASU, Ukraine
Felix, Bernard	ANDRA, France
Forsström, Hans	SKB, Sweden
Kireev, Sergiy	State Specialized Company “Ecocentre”, Ukraine
Koliabina, Iryna	Institute of Environmental Geochemistry, NASU, Ukraine
Krone, Jürgen	DBE Technology, Germany
Sayenko, Sergiy	National Science Centre “Kharkov Institute of Physics and Technology”, NASU, Ukraine
Shabalin, Borys	Institute of Environmental Geochemistry, NASU, Ukraine
Shestopalov, Vyacheslav	Radioenvironmental Centre, NASU, Ukraine
Shybetskyi, Iurii	Radioenvironmental Centre, NASU, Ukraine
Solente, Nicolas	ANDRA, France

Background (1): Nuclear Energy in Ukraine



Nuclear fuel cycle:
- U mining&miling
- NPP's operation
- NPP's decommissioning

Industry, medicine, science …

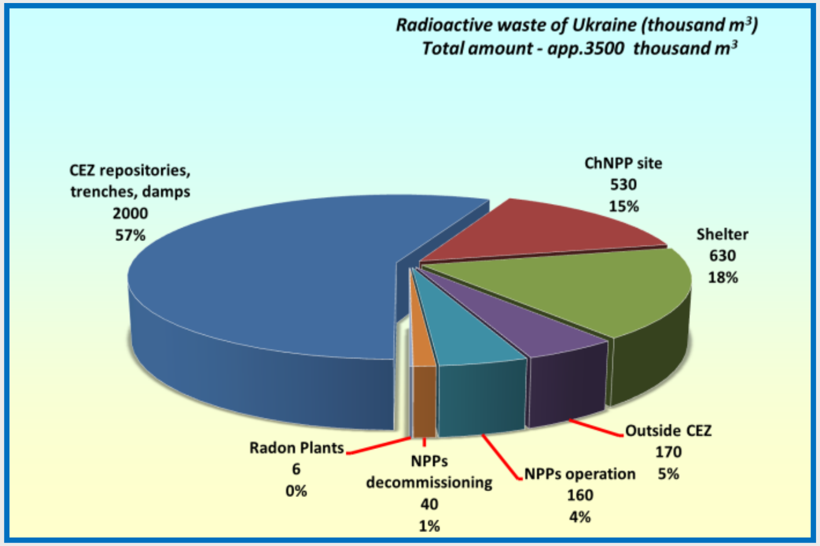
Research reactors

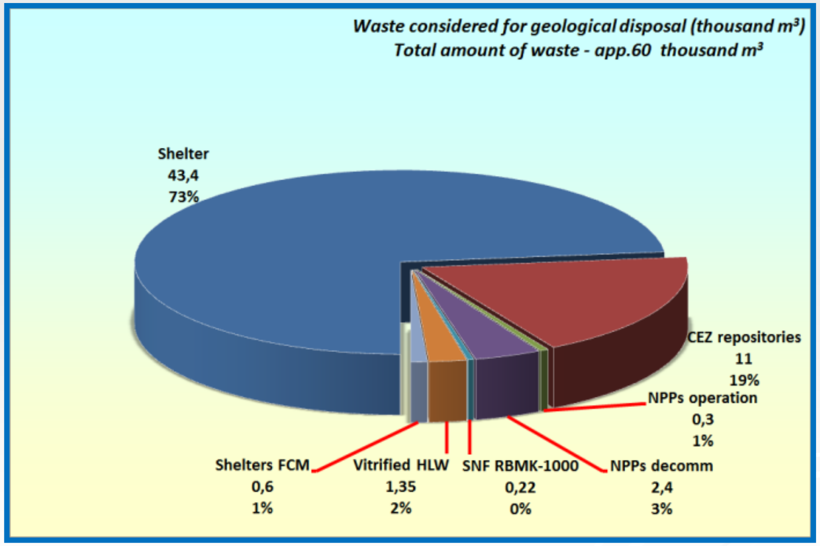
Military installation

Chernobyl accident:
- Shelter
- RWDS (engineered facilities)
- RWTSS (trenches)
- Contaminated landscapes

4 NPPs and 15 operating reactors (2 WWER-440 + 13 WWER-1000), **3 decommissioned reactors** (RBMK-1000). Total capacity is **13,8 GW.** NPPs produce **50%** of electricity. An intention to **build additional reactors.**

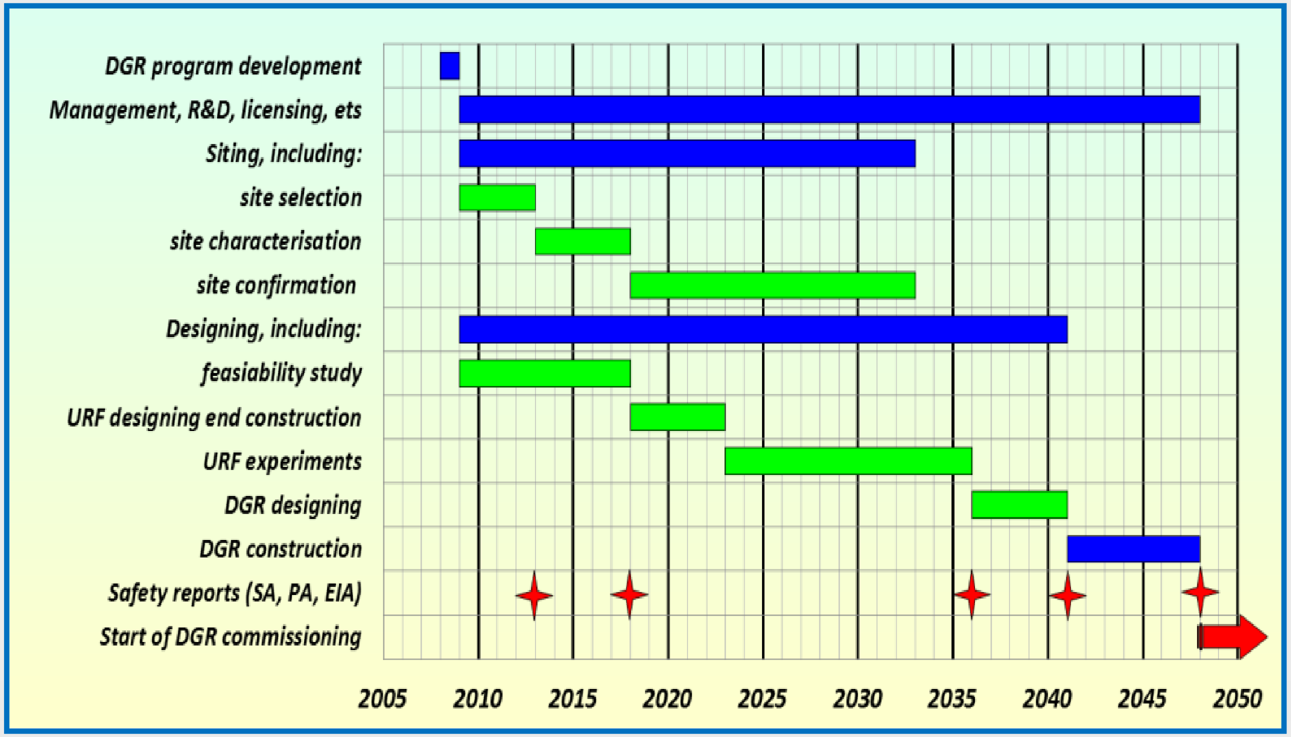
Background (2): Waste Inventory





- **A total volume** of radioactive waste in Ukraine is over **3.45 Million m^3**
- **App. 3.3 Million m^3 (96%)** of waste have the accidental origin
- **97 – 98 % of waste** is short lived and can be disposed in the near surface repositories
- **App. 59 000 m^3** of long-lived waste must be disposed in the geological repository
- **95 % of total volume** of long lived waste are localized in Chernobyl Exclusion Zone (CEZ)

Background (3): National Strategy and State Program



According to Strategy, DGR in Ukraine should be created by 2048.

The Program details the activities for 2008-2017.

Key tasks of the Program in the field of DGR development are:

- R&D program
- site investigations
- DGR concepts
- preliminary safety assessments
- development of decision about site selection

General Characteristics of R&D activities (1)

R&D activities started **since 1993**

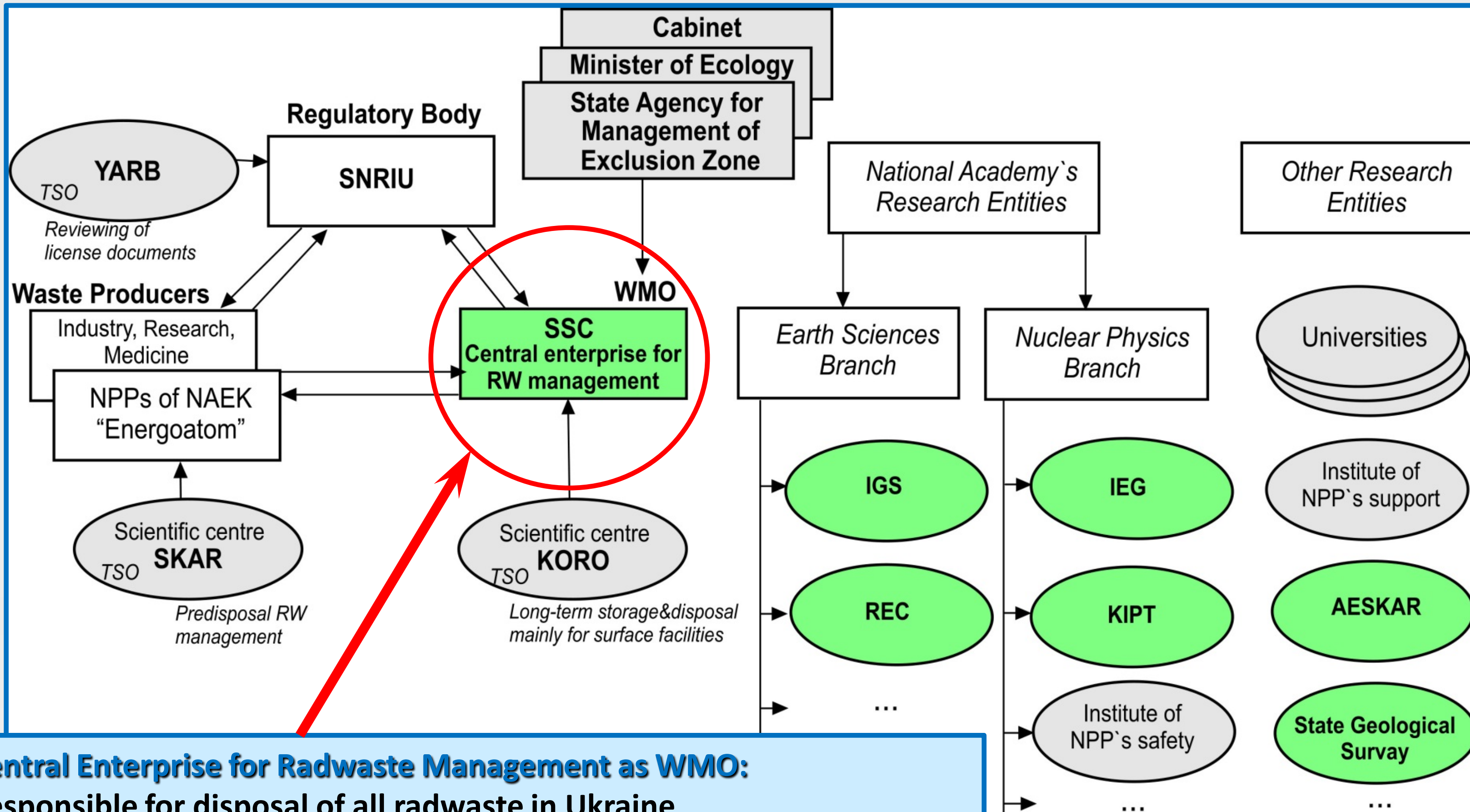
Participants: Institutes of the NASU, Universities, State Specialized Enterprises of SAMEZ, the enterprises of the State Geological Survey, and International organizations and Consortia.

Funding: the European Commission and IAEA technical assistance, as well as international organizations grants (first of all, by Scientific and Technological Centre of Ukraine or STCU) and – state budget of Ukraine.

Areas:

- Siting
- Disposal concepts
- EBS and Natural barriers study
- Safety assessments
- Analogs

General Characteristics of R&D Activities (2): Main Actors



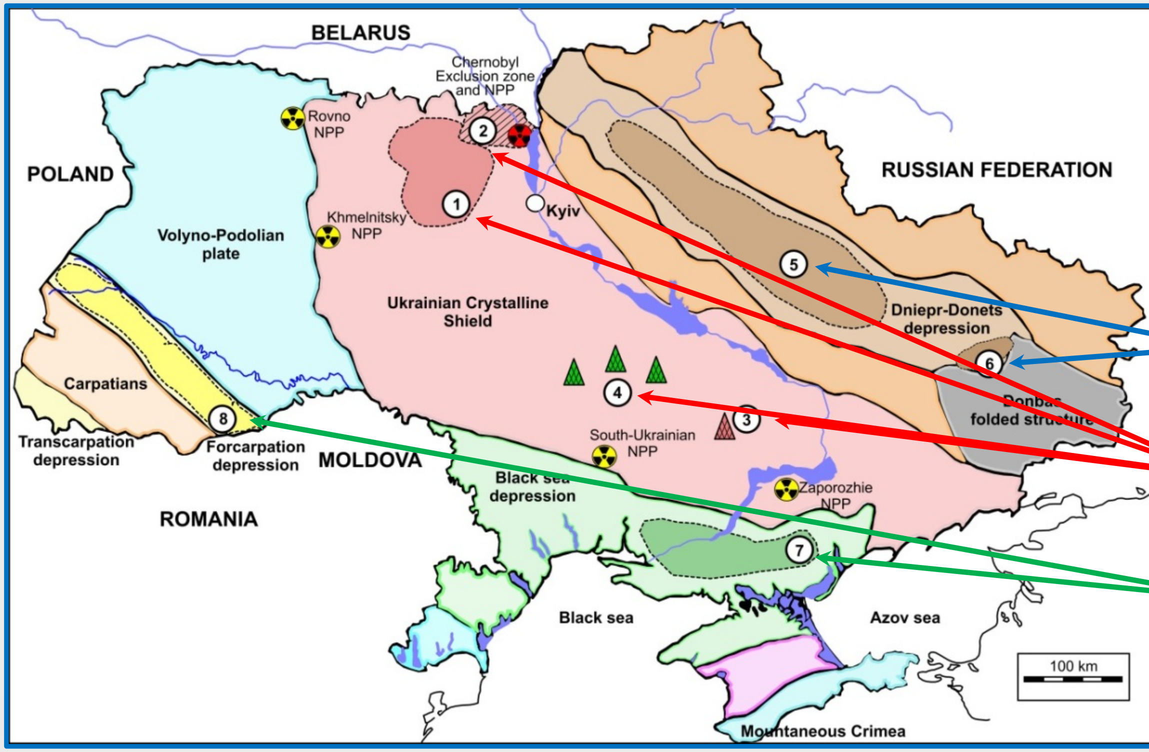
SSC Central Enterprise for Radwaste Management as WMO:

- Is responsible for disposal of all radwaste in Ukraine
- Is responsible for DGR development (including necessary R&D program)
- Has to coordinate R&D program in Ukraine

General Characteristics of R&D Activities (3): Examples of Performed Projects

R&D Projects	Type	Who
EC (2013): U.04.01/08-C 'Improvement of new radwaste classification…'	Concepts	ICD
EC (2013-now): U.04.01/09-B 'Disposal concepts for Radwaste in Ukraine'	Concepts, EBS, SA	ICD
IAEA (2010): CRP T21024 'The use of numerical models in support of … DGR'	SA	REC
IAEA (2012-now): CRP T21027 'Processing Technologies for HLW… and Characterization of Waste Forms'	EBS	IEG
STCU (2003): # 1580 'RBMK reactor spent fuel encapsulation technology'	EBS	NSC KIPT
STCU (2006): # 3187 'Grounds for Radwaste Disposal in Korosten Pluton'	Siting, SA	REC, SGS
STCU (2010): # 4568 'Investigation … of … protective layer of … repositories'	EBS, SA	IEG
IRSN (2011): Project EPIC 'Experimental Platform in Chernobyl'	Migration	IGS
SAMEZ (2008): # 34/1k-08 'The … program for DGR siting'	Siting	REC
ENERGOATOM (2010): # SOU-N-YaEK 1.027.2010 'Calculation of … activity of HLW from reprocessing of SF of WWER-440 reactors'	EBS, SA	AESKAR
NASU (2011): 'Investigation of Korosten Plutone and its Prospects for Geological Disposal of Radwaste'	Siting, SA	REC, SGS
NASU (2003): 'Possibility for radwaste disposal in the mines of Ukraine'	Siting	IEG
NASU (2015): 'RN geochemistry in natural and technogenic systems'	EBS, SA	IEG

Siting (1): Considered options (1993-2000)



There are all types of formations in Ukraine suitable for geological disposal of waste:

Salts

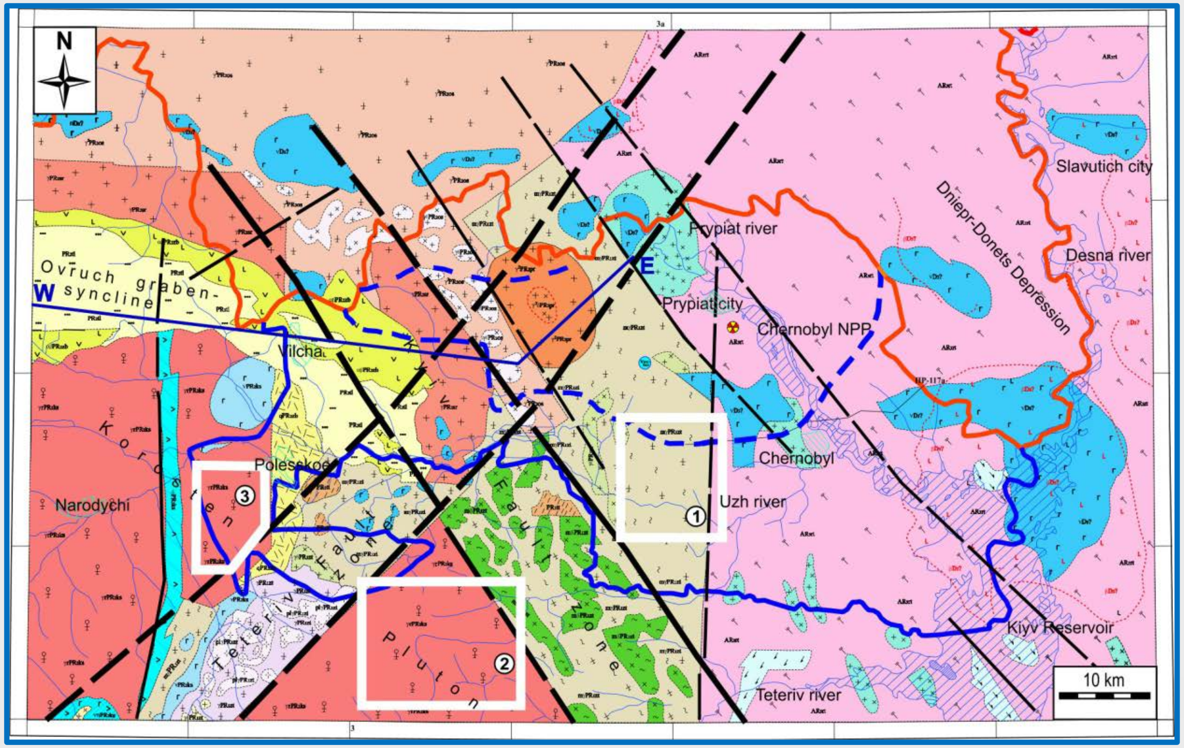
Crystalline rocks

Clays

1	Korosten Pluton (Proterozoic granitoids)
2	CEZ areas within Korosten pluton (Proterozoic granitoids and Archaean gneisses)
3	Iron ore mine Saksagan (Archaean granitoids)
4	Uranium mines (Proterozoic crystalline formations)
5	Salt-dome structures of the Dnieper-Donets depression
6	Permian bedded salts of folded structure
7	Black Sea depression (Paleogene and Neogene clays)
8	Forcarpathian depression (potash salts and Neogene clays)

Contact: I.Shybetskyi
(shybetsky@hydrosafe.kiev.ua)

Siting (2): Results of 2000-2015



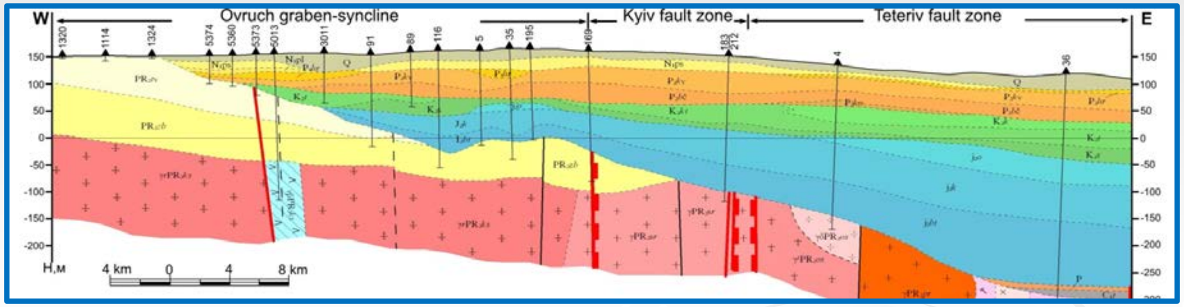
The regional geological scheme of the CEZ and adjacent territories and location of prospective areas

SEDIMENTS

Thickness: 50 to 500 m
Age: J, K, P, N, Q
Lithology: sandstone , aleurites, marls, loam, clays,

CRYSTALLINE BASEMENT

Rocks: rapakivi-like granites, gneisses
Age: from 1640 to 2050 Million years



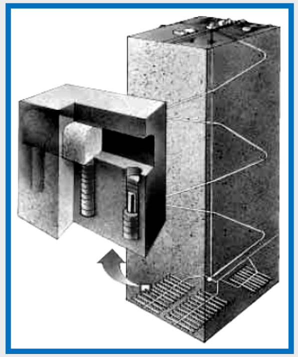
PROMISING AREAS

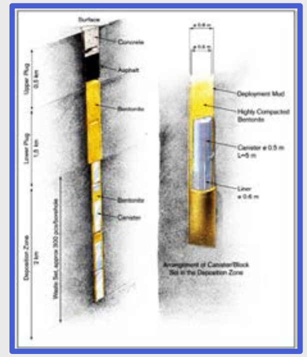
	Name	Area, km²	Sediments, m
1	Novosilky	130	350-500
2	Veresnia	210	160-200
3	Zhovtneva	80	50-100

Contact: I.Shybetskyi
(shybetsky@hydrosafe.kiev.ua)

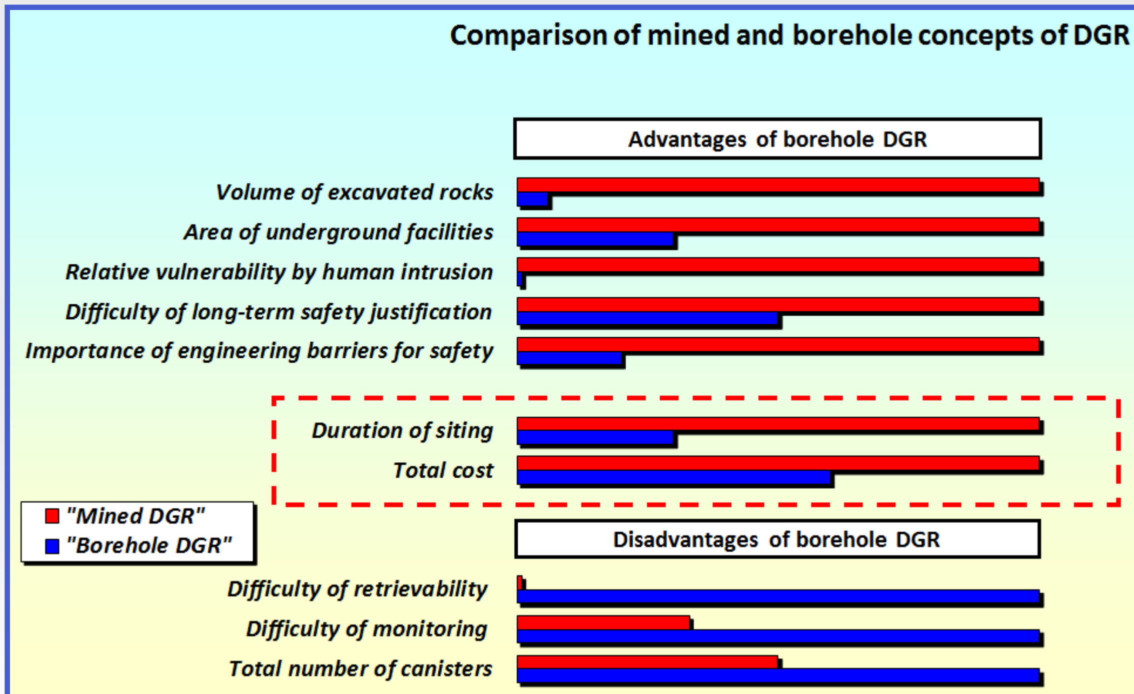
Concepts (1): Comparison of mined and borehole concepts

Mined repository (KBS-3V)
- Depth 500-1000 m
- For all types of waste





Very deep borehole (VDH)
- Depth 2000-4000 m
- Only for SF&HLW



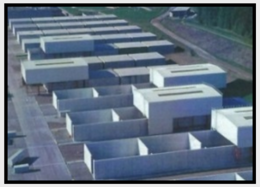
Contact: I.Shybetskyi
(shybetsky@hydrosafe.kiev.ua)

Concepts (2): New Waste Classification

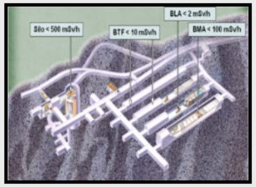
Current Classification

Category	*Description*	*Disposal option*
Short-lived waste	Clearance after 300 years of regulatory control	Surface (near-surface) repositories (first type)
Long-lived waste	Clearance is impossible	Deep geological repository (second type)

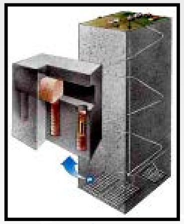
First type: landfill repository for VLLW, Sweden (In Ukraine Buriakovka)



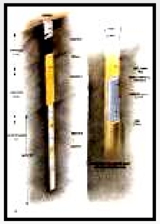
Second type: surface repository for LLW, France (in Ukraine – Vector)



Third type: GR at intermediate depth for disposal of ILW (SFR, Sweden)



Fourth type: DGR (KBS-3V, Sweden) for co-disposal of ILW and HLW



Fourth type: DGR (VDH, Sweden) for disposal of HLW

New Classification

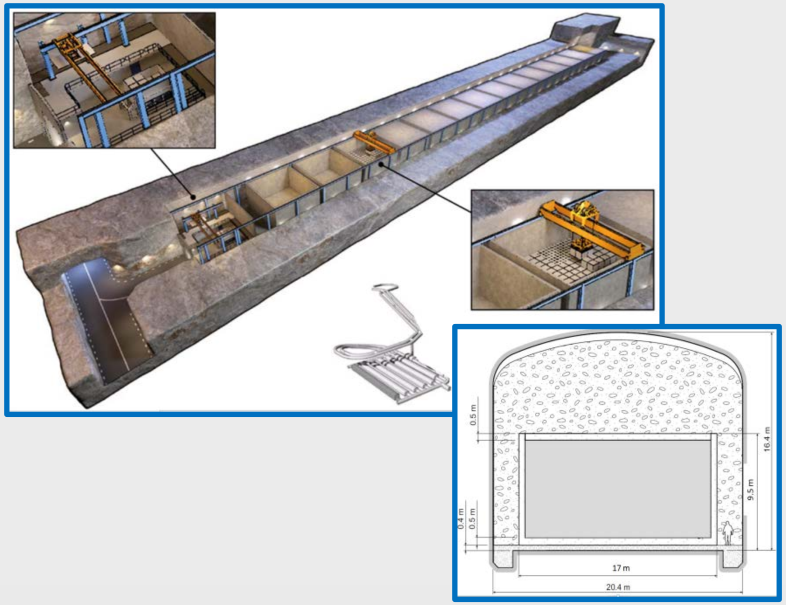
Class	*Description*	*Disposal option*
Very Low Level Waste (VLLW)	not determined in Ukraine - large volumes of waste in Ukraine can be classified as VLLW	Landfill repositories (first type)
Low Level Waste (LLW)	corresponds to existing short-lived waste	Surface (near-surface) repositories (second type)
Intermed. Level Waste (ILW)	corresponds to existing long-lived waste	Repository at interm. depth (third type)
High Level Waste (HLW)	corresponds to existing heat-generating HLW	Deep geological repository (fourth type)

ANDRA DBE TEC DBE TECHNOLOGY GmbH enresa COVRA SKB

[Project U4.01/08-C, 2012]

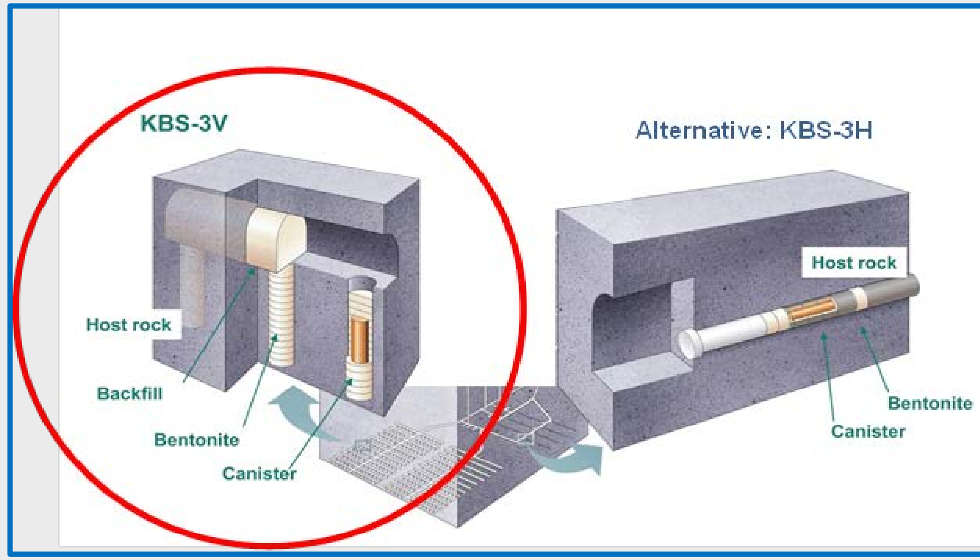
Contact: J.Krone
Krone@dbe.de

Concepts (3): Recent recommendations for Ukraine



ILW disposal concept

The SKB concept 2BMA developed for the extension of the SFR facility in Forsmark



HLW disposal concept

The KBS-3V reference concept for spent fuel and vitrified HLW and KBS-3H as an alternative presently studied by SKB (Sweden) and Posiva-Oy (Finland)

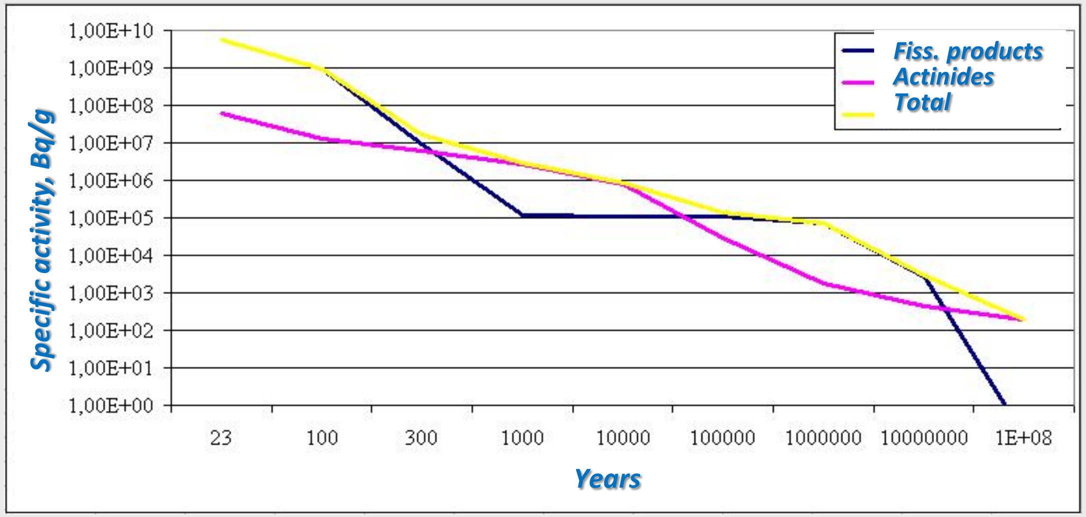
[Project U4.01/09-B, 2016]
Contact: B.Felix
Bernard.Felix@andra.fr

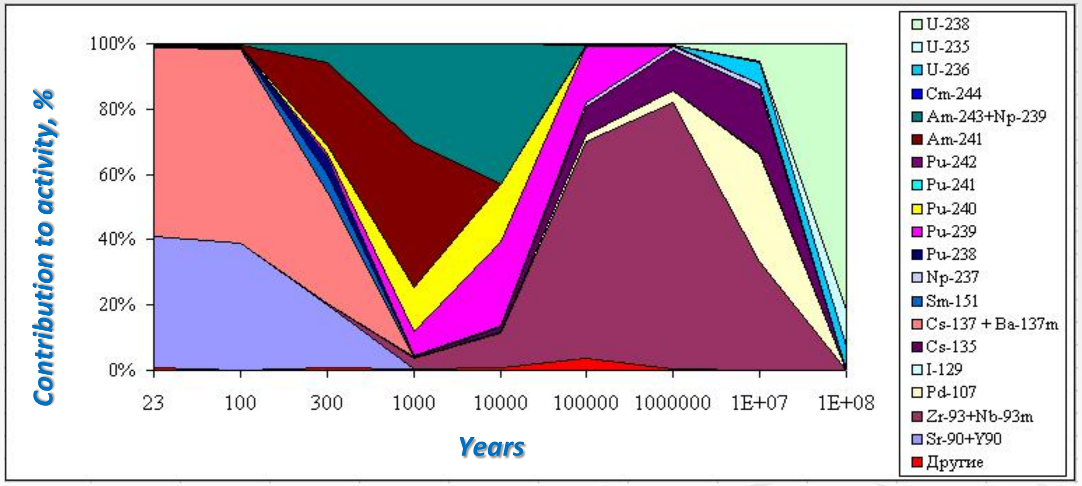
Concepts (4):
Action plan – main milestones

	Geological Repository for ILW	*Deep Geological Repository SNF/HLW*
2016 – 2025	**Characterize the ILW. Develop disposal concept and WAC. Start conditioning and storage. Geological investigations.**	**Define preferred disposal concept. Preliminary siting activities. Safety assessment and R&D programme. Long-term safety of storage.**
2026 – 2035	**Detailed site investigations and choice of site. Licensing, construction and start of operation of disposal facility**	**Study alternative concepts. Investigate co-location with ILW. Further geological screening. Decide on concept and geological area.**
2036 – 2045	**Continued operation. Continue supporting R&D programme.**	**Choose area and concept for disposal. Detailed site investigations and decide on site. Design, license, and start construction of disposal facility and encapsulation plant.**
2046 – 2055	**Continued operation.**	**Start operation. Continue supporting R&D programme.**

[Project U4.01/09-B, 2016]
Contact: H.Forsstrom
hans.forsstrom@skb.se

EBS (1): Radionuclide composition of HLW





Task: to identify the essential radionuclides in HLW after SNF (WWER-440) reprocessing

Method: analysis of radionuclide contributions to specific activity, per-oral and inhalation doses and total toxicity depending of decay time

Result: The list of radionuclides was decreased from 42 to 9 ones namely: Sr-90, Cs-137, Pu-238, Pu-239, Pu-240, Pu-241, Am-241, Am-243, Cm-244

Contact: L.Litvinsky
ludvig.litvinsky@gmail.com

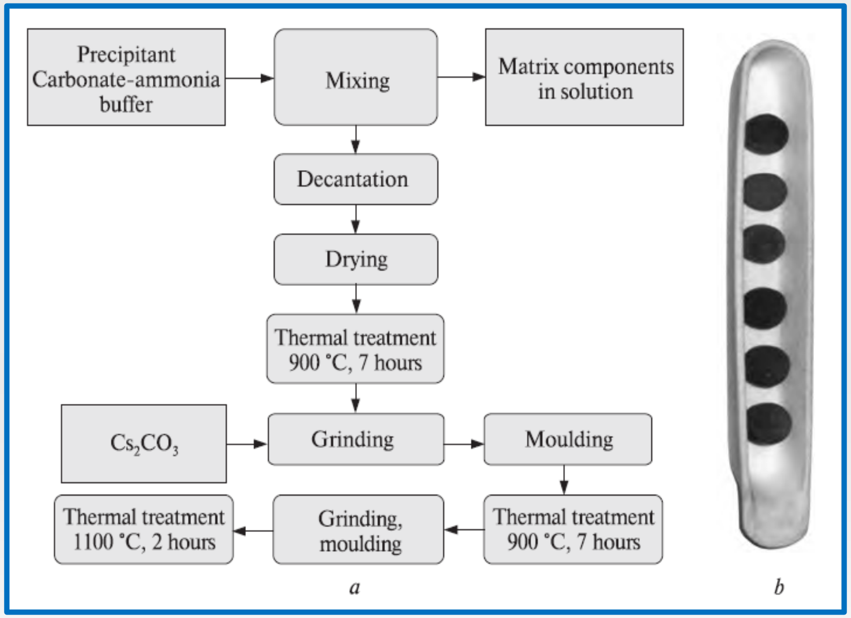
EBS (2): Synthesis of Ceramic Matrix

Task: Synthesis of ceramics matrices for immobilization of HLW

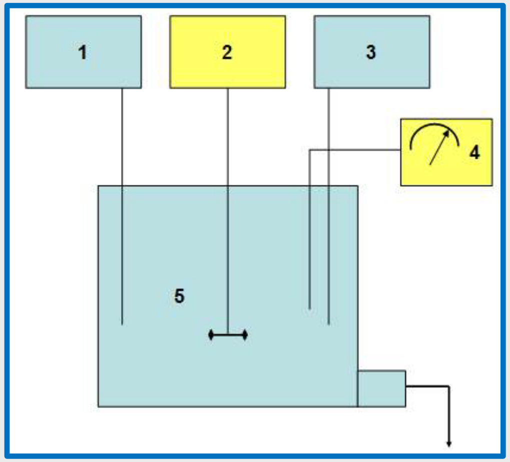
Materials: crystalline ceramics on the base of ZrO_2, Al_2O_3... (Zirconolite, Perovskite, Garnet And Hollandite)

Equipment: High temperature sintering furnace, Hot isostatic pressing facility

Tests: corrosion resistance, radiation stability

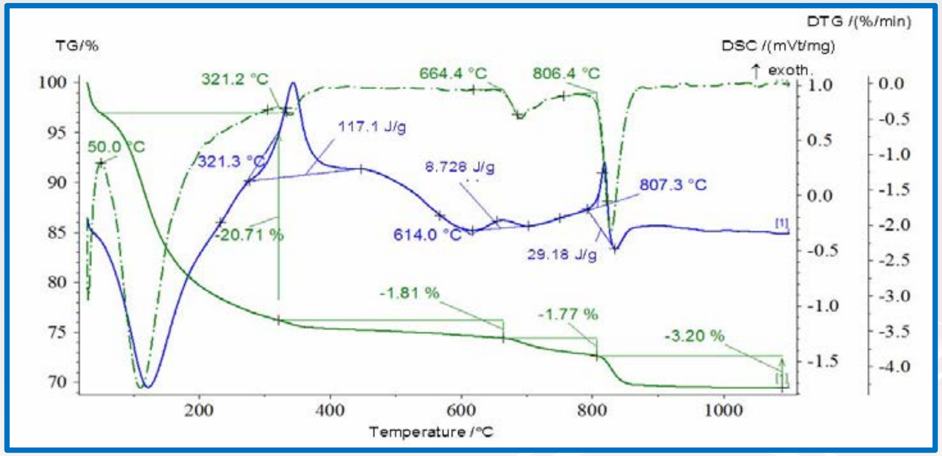


Scheme of synthesis of Cs-containing Ba, Fe, Ti-ceramics (a) and visual appearance of pellets after sintering on air at temperature of 1100 °C during 2 hours (b)



Apparatus for continuous deposition:

(1) - coprecipitated components,
(2) - mixer,
(3) – mixtures of inorganic salts and precipitator,
(4) - pH-meter,
(5) – reactor



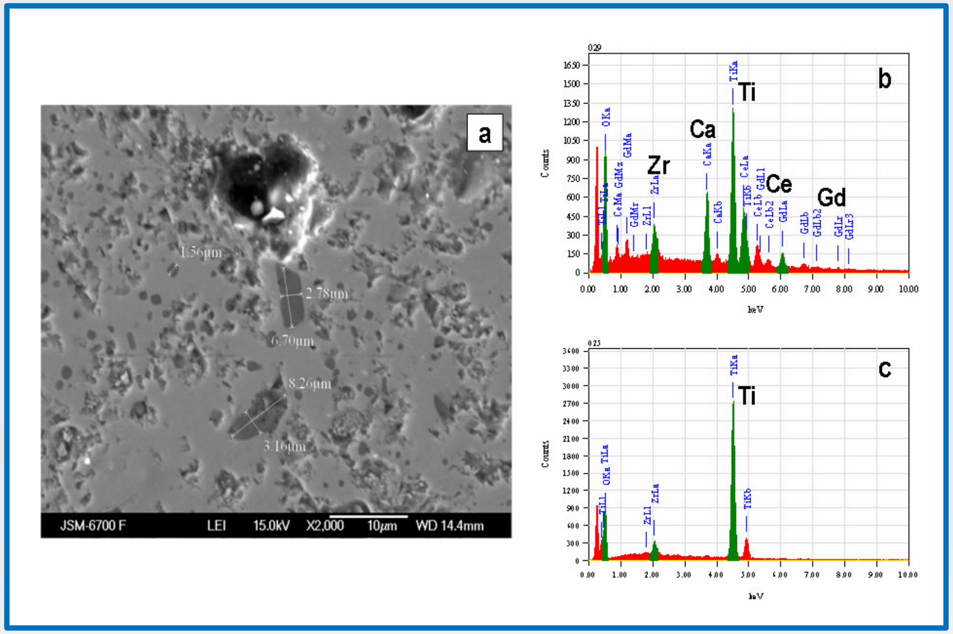
DTG record of air-dry charge of coprecipitated hydroxycarbonates with ratio of Ba:Fe:Ti = 1,0:2,0:6,0

Contact: **B.Shabalin**
(b_shabalin@ukr.net)

EBS (3): Leaching of Cs from Ceramic Matrix

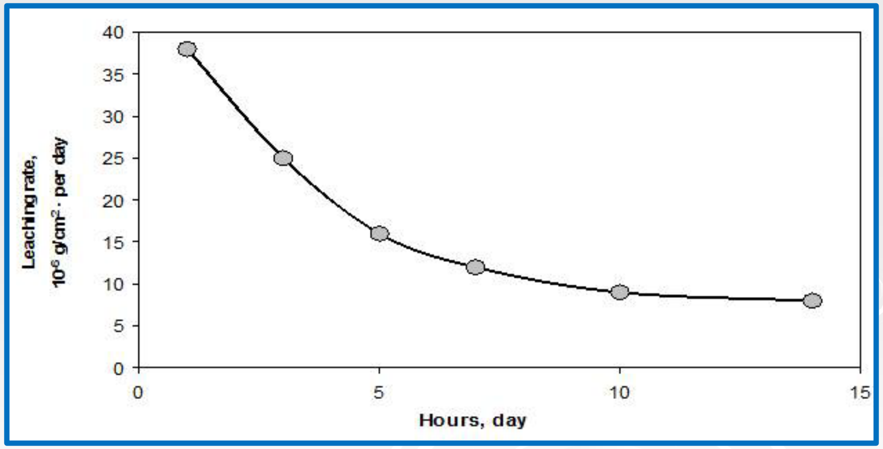
Task: Studying of Cs leaching from ceramics matrices for immobilization of HLW

Materials: crystalline ceramics on the base of ZrO_2, Al_2O_3… (Zirconolite, Perovskite, Garnet And Hollandite)



The SEM images of pyrochlore based ceramics (sample III-P-$GdCe_4$ and EDS spectra of pyrochlore phase (b) and TiO_2-based phase (c)

Design of the leaching experiment



Cs leaching rate in deionized water at 150° C from ceramics of $Ba_{0.9}Cs_{0.2}Fe_{2.0}Ti_{6.0}O_{16}$ composition

Contact: B.Shabalin
b_shabalin@ukr.net

EBS (4): Containers

Design: Concept based on KBS-3, adapted to Ukrainian SNF dimensions and geometries. Common Cu shell, specific cast iron insert

	VVER-1000	VVER-440	RBMK-1000	Vitrified HLW
Assemblies	4	10	19	1-3 canisters
U (tHM)	1,7	1,2	2,2	-
Length (m)	5,0	3,55	4,0	1,5 – 4,5

[Project U4.01/09-B, 2016]
Contact: N.Solente
Nicolas.Solente@andra.fr

EBS (5): Sorption Properties of Buffer

Task: Modeling of U, Pu, Ra, Sr, Cs, Co distribution in clay / sand layer

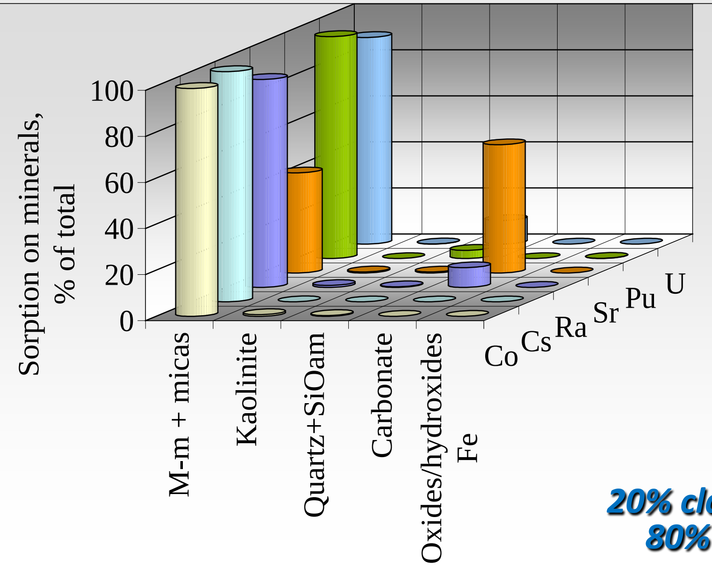
Code: GEM http://gems.web.psi.ch/overview.html)

System: U, Pu, Ra, Sr, Cs, Co + concrete pore water + clays + sand

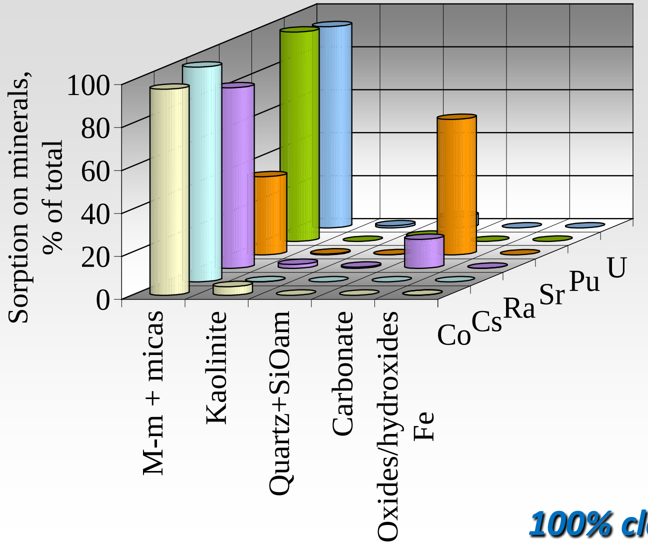
Result: pH changed from 13,44 to 9,1; all radionuclides are almost completely uptaken by polimineral clay-sand mixture (up to 99,98 %) by different mechanisms.

[Project STCU # 4568]
Contact: I.Koliabina
kolira_igns@i.ua

U, Pu, Ra, Sr, Cs, Co distribution during sorption by polymineral clay D-1 (Cherkasy deposit of bentonite clay, first horizon)



20% clay D-1 + 80% sand



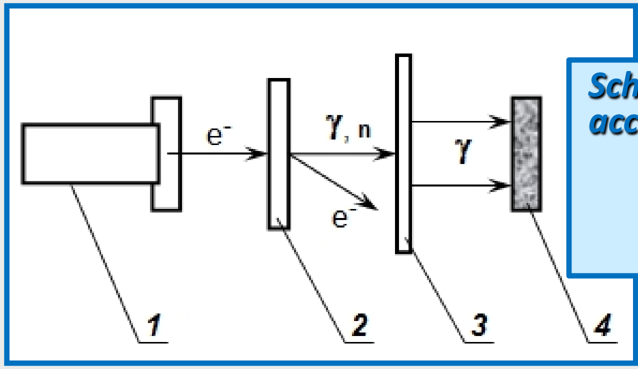
100% clay D-1

Natural Barriers (1): Nuclides Migration in Irradiated Granites

Task: Study of the tracer elements penetration (as volatile and actinide simulators) in depth of rocks (in pristine and irradiated state)

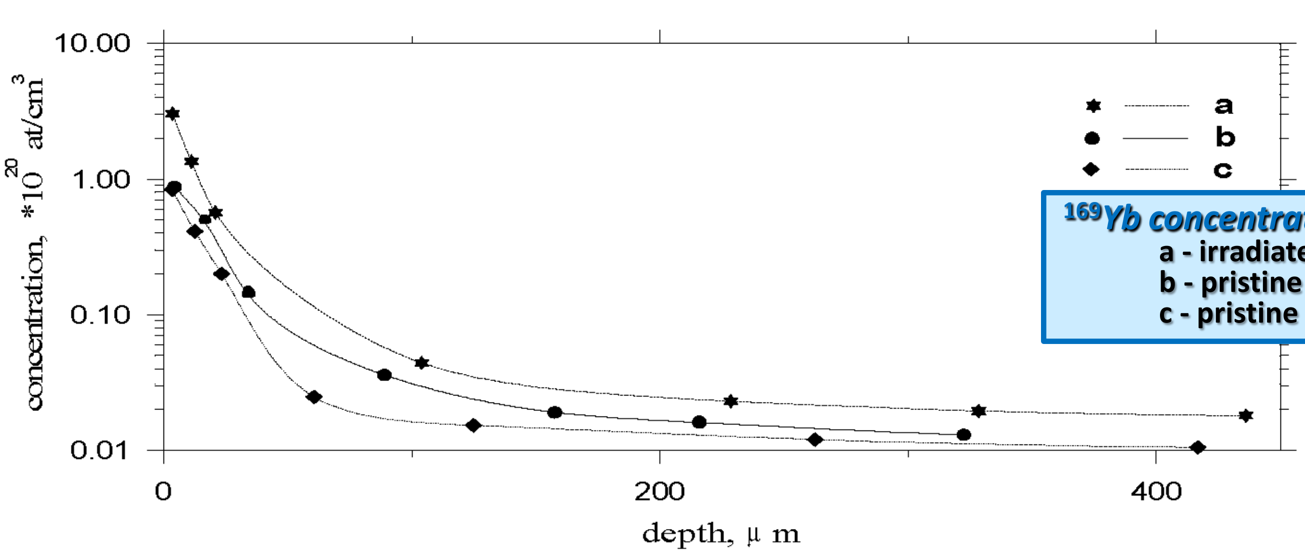
Analytical methods: ceramography, XRD, TG-DTA and SEM.

Result: Penetration profile of the ^{169}Yb in granites (as tracer simulating the actinides)



Scheme of gamma-irradiation in electron accelerator:

1 - electron accelerator,
2 - Ta-converter,
3 - filter for electrons and neutrons,
4 - specimen.



^{169}Yb concentration in specimens of granite:

a - irradiated by dose of $3{,}0\cdot10^7$ Gy,
b - pristine state with pegmatite structure,
c - pristine state with uniform grain structure

Contact: S.Sayenko
(sayenko@kipt.kharkov.ua)

Natural Barriers (2): Kinetics of ^{137}Cs Absorption in Granites

Tasks: **Theoretical and experimental study of cesium absorption kinetics in granitic rocks of Ukrainian Shield**

Experimental conditions:

- **Plagiogranite of Korosten pluton**
- **model chemical composition of fractured water**

Semiempirical model

$$C_{sorb} = \sum_i a_i \cdot e^{-k^i_{sorb} \cdot t} - \sum_i a_i \cdot e^{-k^i_{des} \cdot t}$$

C_{sorb} – Cs sorbed at time t; a_i – factor corresponds to the highest possible cesium absorption on the i-th type of reaction centers;

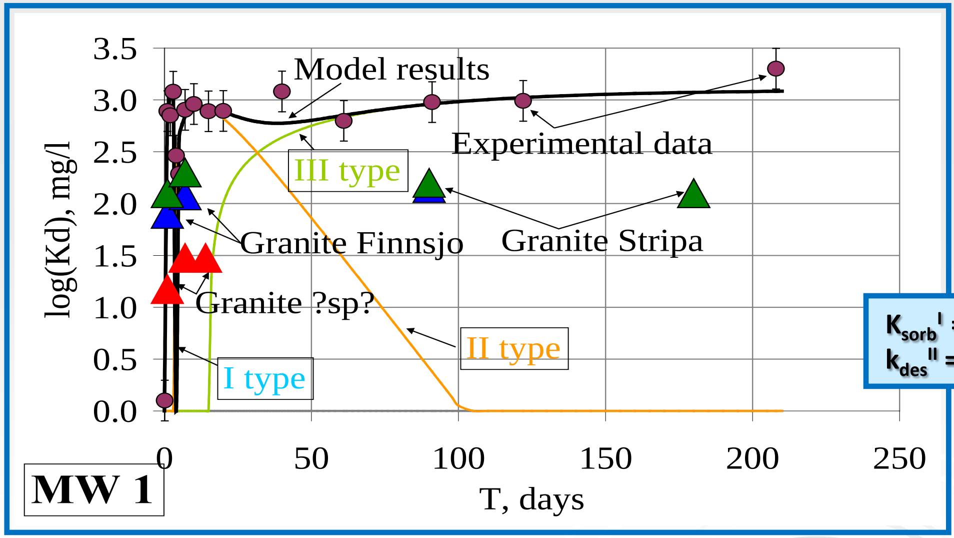
k^i_{des} k^i_{sorb} – kinetic sorption/desorption parameters for i-th type of reaction centers

Mineral composition

Potassium feldspar	12%
Plagioclase	18%
Micas	5%
Sericite	37%
Quartz	28%

Main cations in model water (MW 1)

pH	7,3
Ca^{2+}, mg/l	49,7
Na^{+}, mg/l	15,43



Some results:

hydrocarbonate-chloride-calcium water

K_{sorb}^{I} = 1,229 1/day, k_{des}^{I} = 7,975·10^{-1} 1/day, k_{sorb}^{II} = 1,579·10^{-1} 1/day, k_{des}^{II} = 8,395·10^{-2} 1/day, k_{sorb}^{III} = 1,697·10^{-2} 1/day.

Contact: I.Koliabina
kolira_igns@i.ua

Safety Case Development (1): Methodology of Safety Calculation

Tasks: To develop the methodology of absorbed dose calculation for geological disposal of HLW

Initial suggestions:
- *the depth of repository: 300 m*
- *the length of repository: 1350 m*
- *flux is shown per one container of vitrified waste with volume of 200 l*
- *a steel wall has through-the-thickness cracks*

The one-dimensional differential equation of non-stationary diffusions for a multi-layer cylinder:

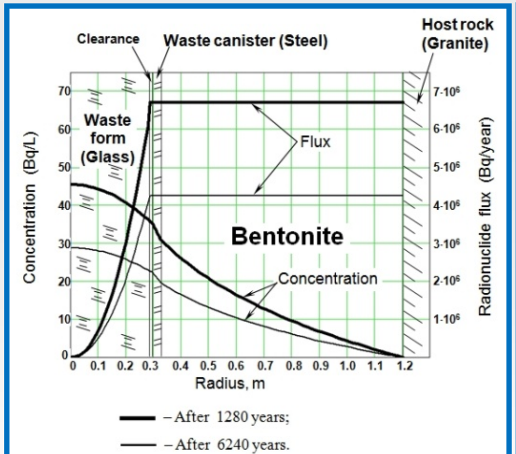
$$\varepsilon \cdot R \cdot \frac{\partial c_W}{\partial \tau} = \frac{1}{r}\frac{\partial}{\partial r}\left[r \cdot (\varepsilon \cdot k_F \cdot D_W) \frac{\partial c_W}{\partial r} \right] - \lambda \cdot \varepsilon \cdot R \cdot c_W + q_V$$

Contact: S.Sayenko
(sayenko@kipt.kharkov.ua)

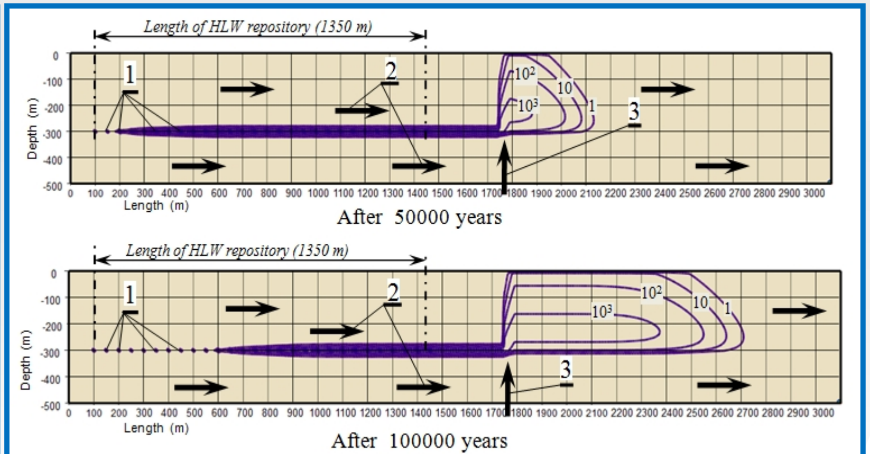
Three-dimensional equation of non-stationary mass transfer of the radionuclide in a porous medium:

$$\frac{dc_W}{d\tau} = \frac{D_W}{R}\left(\frac{\partial^2 c_W}{\partial x^2} + \frac{\partial^2 c_W}{\partial y^2} + \frac{\partial^2 c_W}{\partial z^2} \right) - \frac{W_X}{R} \cdot \frac{\partial c_W}{\partial x} - \frac{W_Y}{R} \cdot \frac{\partial c_W}{\partial y} - \lambda \cdot c_W + \frac{q_V}{\varepsilon R}$$

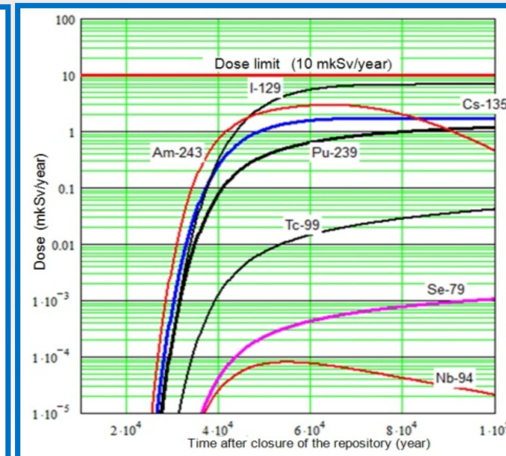
Results:



^{239}Pu concentration and flux through the engineered barriers



^{135}Cs release in geological barriers



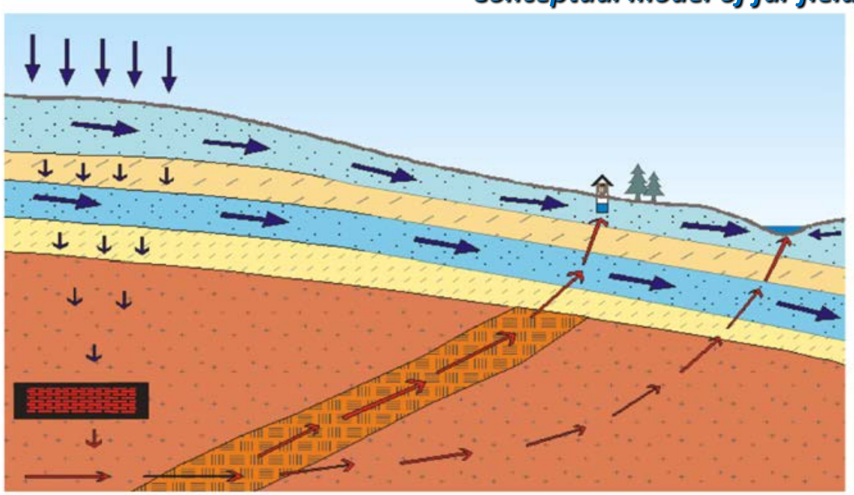
Absorbed dose for population (scenario of contaminated water consumption)

Safety Case Development (2): Initial RN transport modeling

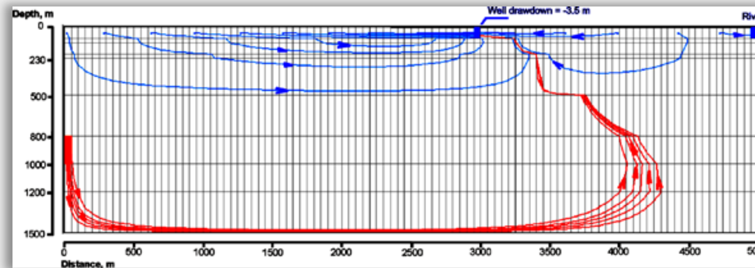
Tasks: groundwater flow and radionuclide transport modelling to characterize the influence of hydrogeological conditions of Ukrainian sites

Tool: PMWin Groundwater modelling system (http://www.pmwin.net/pmwin5.htm)

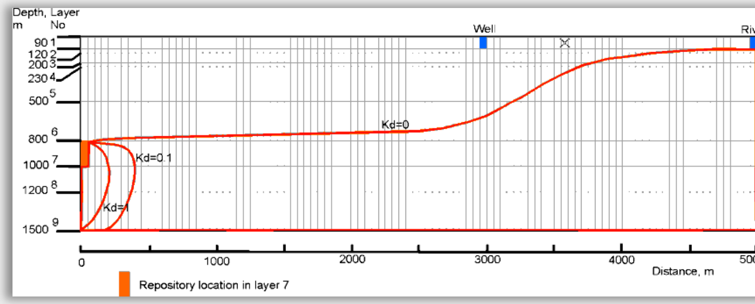
Conceptual model of far field



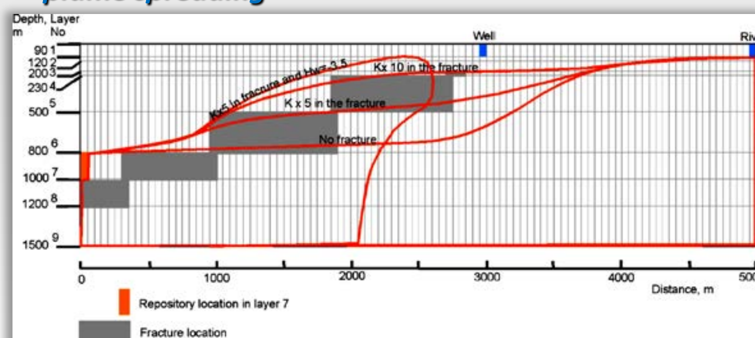
Results:



Contaminant pathways and travel time



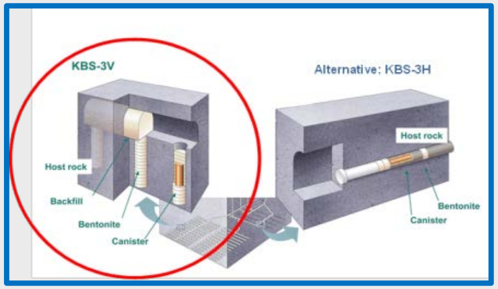
Influence of sorption on the contamination plume spreading



Influence of the fracture on the contamination plume spreading

[IAEA Project CRP T21024]
Contact: I.Shybetskyi
(shybetsky@hydrosafe.kiev.ua)

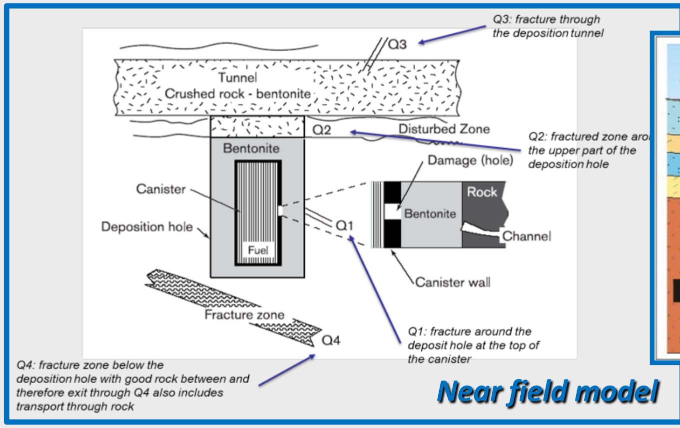
Safety Case Development (3): Deep Geological Repository for HLW



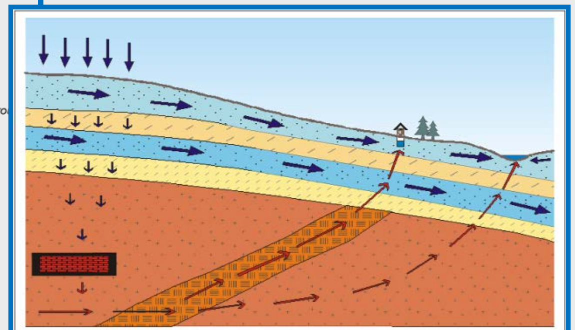
DGR Concept

[Project U4.01/09-B, 2016]

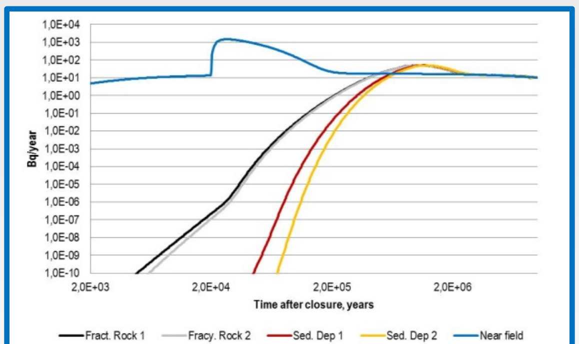
Contact: R.Avila
rodolfo@facilia.se



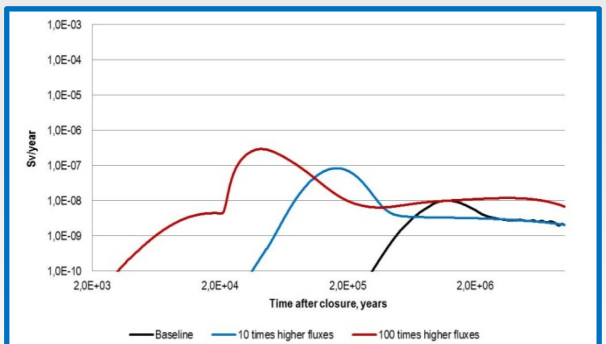
Near field model



Far field model



Nuclide flux



Doses for different GW fluxes

- the doses are below the dose constraint in Ukraine (10 μSv/year)
- DGR has to be placed at the depth where the groundwater fluxes are sufficiently low
- sedimentary deposits have a significant effect on retardation of radionuclides
- more realistic assumptions (e.g. concerning K_d) would lead to much lower doses
- few radionuclides I-129, Cl-36, C-14, Ni-59 and Se-79 have a potential significant to the doses

Natural Analogues (1): Chernobyl Exclusion Zone

Main characteristics:

- Area – 2 600 km ^{2}, contaminated after accident
- No population
- Dangerous object – Shelter, ChNPP, RWDS, RWTSS, RAW management facilities
- Personnel – 6 000 persons (Chernobyl town, ChNPP)

Basic activities:

- ChNPP decommissioning
- RAW management
  - Conditioning
  - Storage
  - Disposal
- Water protection measures
- Fire safety implementation
- Forestry measures

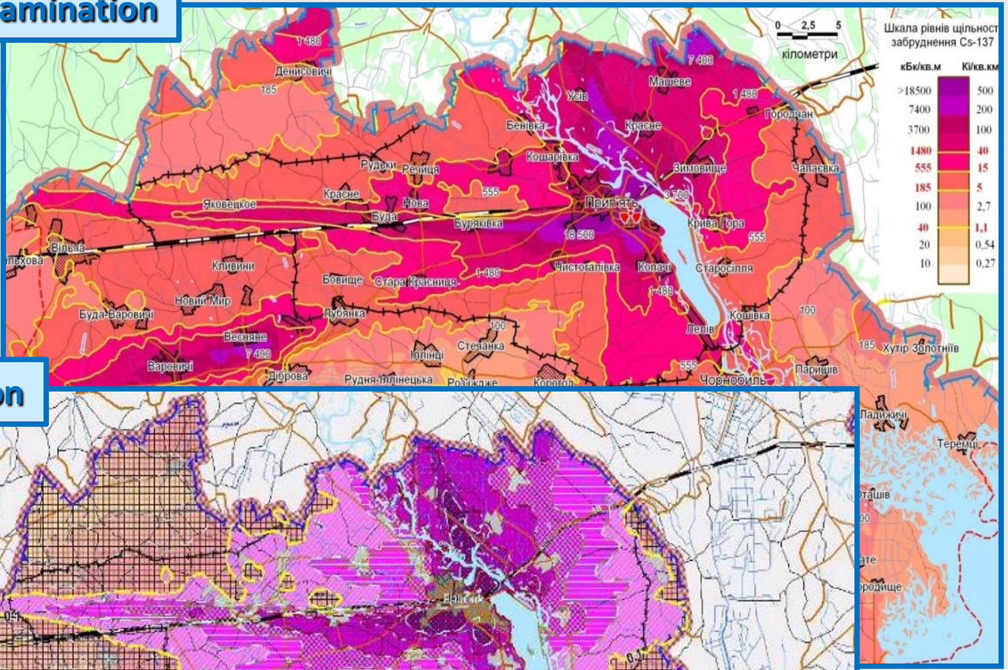
Key attribute:

CEZ is a unique natural analogue, which allows to study radionuclide migration in natural conditions

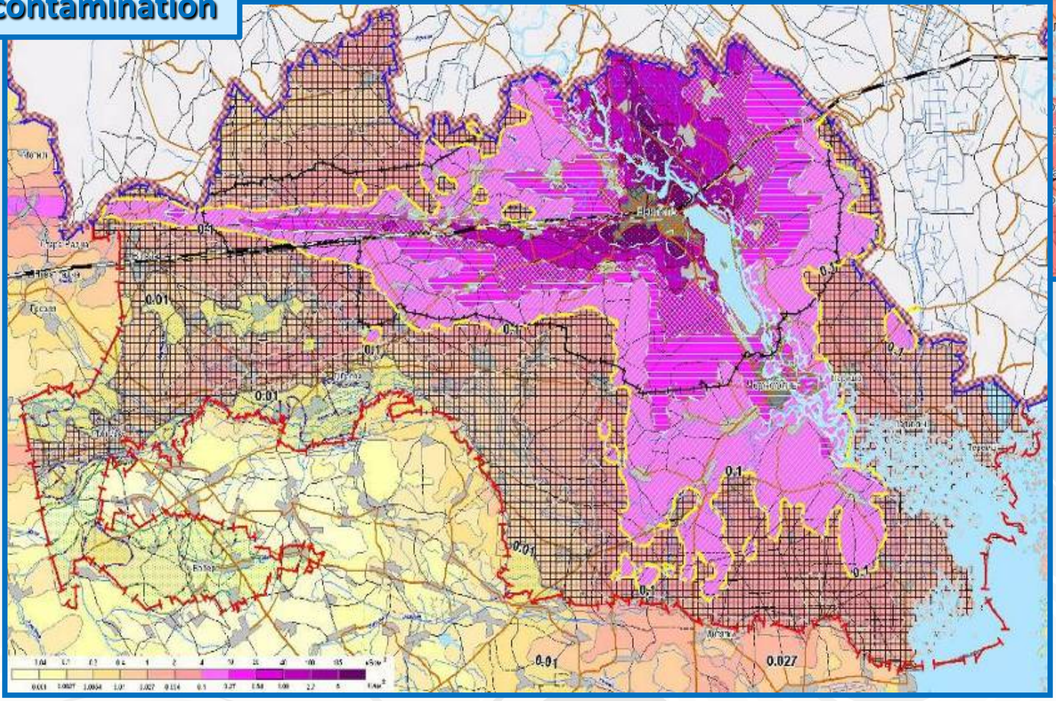
And

to validate the biosphere models

^{137}Cs contamination



Pu isotopes contamination



Contact: **S.Kireev**
s.kireev@ukr.net

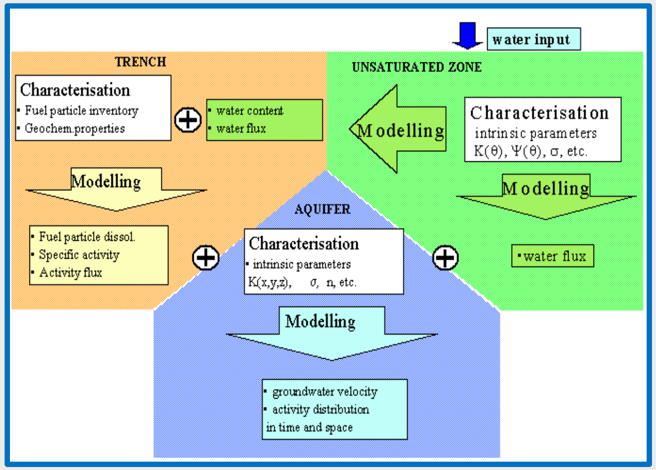
Natural Analogues (2): ^{90}Sr Transport in Chernobyl Landscapes

Task: Groundwater transport modeling for ^{90}Sr from the waste trench in the "Red Forest" site in Chernobyl zone

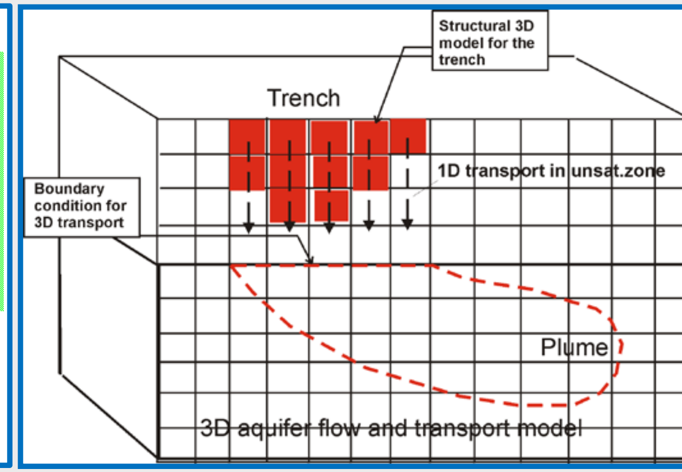
Tool: Modflow – MT3D (http://www.pmwin.net/pmwin5.htm)

Result: Predicted long-term ^{90}Sr transport in the aquifer (steady-state conditions)

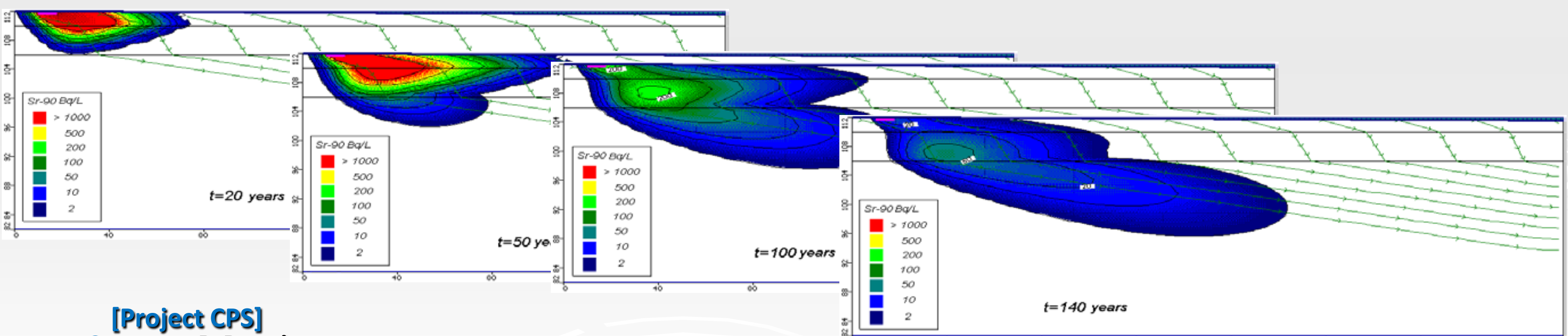
Conceptual model of the waste trench



Numerical schematization



Radionuclide transport modeling results



[Project CPS]
Contact: **D.Bugai**
dmitri.bugay@gmail.com

Natural Analogues (3): Opportunities – Central Analytical Lab

The Central Analytical Laboratory (CAL) was commissioned as a part of the EC project "Improvement of the Infrastructure for the Radioactive Waste Management in the Chernobyl Exclusion Zone. Phase II".

[Project U4.01/08-B, 2015]
Contact: S.Kireev
s.kireev@ukr.net

The CAL is included to the structure of the State Specialised Company "Ecocentre" and placed in Chernobyl town. "Ecocentre" is responsible for radioenvironmental monitoring within CEZ

CAL capabilities:

- full-scale characterization of RAW samples from CEZ according to WAC of disposal facilities (physical, chemical and radiological criteria)
- development of necessary analytical methods and methodologies

"Ecocentre" capabilities (per year):

- 350 000 measurements of exposure rate
- 4 000 – 5 000 samples of aerosols, surface and ground water, soils and biological objects
- 8 000 – 12 000 measurements of nuclide activity in collected samples

Conclusions (1)

- Ukraine has a national program of deep geological repository development (including the R&D program)
- The main funding source - international technical assistance. It is necessary to provide adequate funding at the national level
- Many research institutions are involved in R & D activities. Their actions are often not coordinated. It is necessary to have a single coordination centre.
- Current R&D activities in Ukraine belong to the generic phase of DGR development:
  - early stages of site selection
  - conceptual studying of the disposal system
  - generic safety assessments

Conclusions (2)

- Three promising areas for DGR were determined within Chernobyl Exclusion Zone and in adjacent territories: Zhovtneva, Veresnia and Novosilky areas
- The concepts of ILW and HLW repositories were proposed for conditions of the Chernobyl Exclusion Zone
- Results of generic safety assessments for proposed concepts demonstrate the suitability of crystalline rocks within the Chernobyl Exclusion Zone
- There is urgent necessity of detail field investigations (including drilling) within the promising areas
- In Ukraine there is a unique opportunity for experimental study of radionuclide migration in natural conditions. The laboratory infrastructure has been created

Ukraine is interested in learning the international best practices and in broad collaboration!

Thank you for attention!