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# The Concept of Deep Borehole Geological Disposal in Ukraine

Presented by Boris Faybishenko

Lawrence Berkeley National Laboratory

Compiled from publications and presentations provided by
V.Shestopalov, Iu.Rudenko, Iu.Shybetskyi

Radioenvironmetal Centre of National Academy of Sciences of Ukraine
55b Gonchar str., Kiev, 01054, Ukraine

# Outline

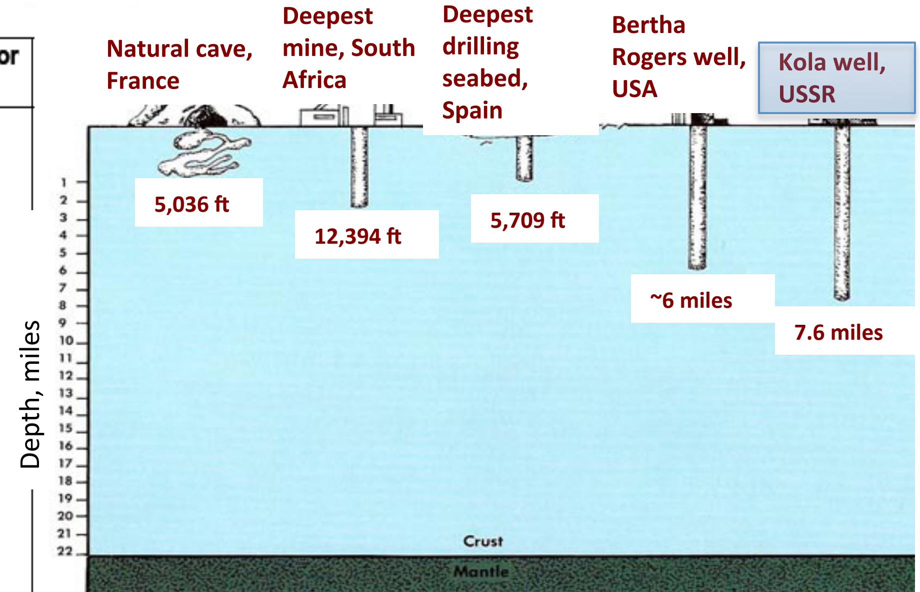
- Introduction: Summary of deep boreholes drilled into crystalline rock
- Sources and Inventory of Radioactive Waste in Ukraine
- Site Selection for Deep Boreholes
- Preliminary Numerical Modeling

# Summary of boreholes drilled into crystalline rock to > 1,500 m depths

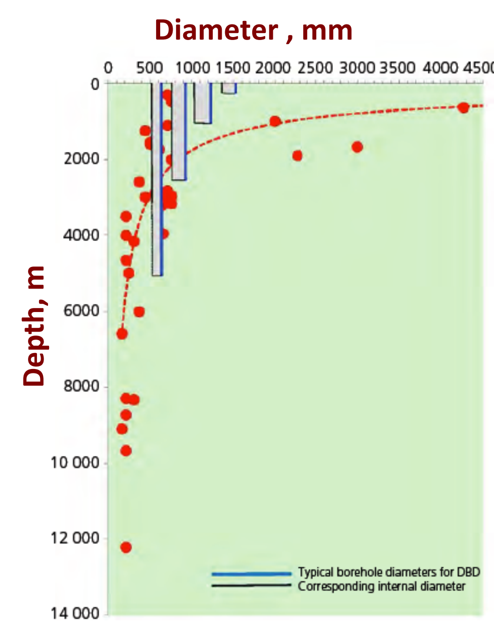
| Borehole Number | Name | Dated started | Depth (m) | Crystalline portion | Reason for drilling |
|---|---|---|---|---|---|
| USA-I | Mobil I-A, Nevada | 1979 | 5962 | 2440 | P |
| USA-2 | Nellie-I, Texas | 1983 | 5822 | 1748 | P |
| USA- 3 | Pinal County A-I, | 1980 | 5490 | 1180 | P |
| USA-4 | Arizona | 1983 | 5418 | 1980 | P |
| USA-5 | Paul-Gibbs-I, Montana | 1981 | 3810 | 520 | P |
| USA-6 | Haraway 1-27, | 1984 | 3506 | ? | P |
| USA-7 | Oklahoma | 1984 | 3366 | 1000? | P |
| USA-8 | 1-12 Boulder, Wyoming | 1979 | 4663 | 730 | H |
| USA-9 | TXO Henley F-I, | 1977 | 3854 | 174 | G |
| USA-I0 | Oklahoma | 1987 | 3472 | 500 | S |
| USA-II | Fenton Hill, New Mexico | ? | 3050 | 0 | ? |
| USA-12 | Roosevelt Hot Springs, | 1987 | 1829 | 0 | S |
| FRG-I | Utah | 1979 | 3334 | 1602 | H |
| FRG-2 | Cajon Pass, California | 1987 | 4001 | 0 | S |
| FRA-I | Wind River, Wyoming | ? | 3500 | 940 | S |
| SWT-I | South Hamilton, Mass | 1983 | 1501 | 315 | S |
| UK-I | Urach-3, Swabia | 1981 | 2800 | 0 | H |
| CAN-I | KTB, Bavaria | 1982 | 3500 | 0 | G |
| JAP-I | Sancerre-Couy | 1979 | 1804 | 1300 | G |
| URS-I | Nagra, Böttstein | 1970 | 12060 | 0 | S |
| URS-2 | Rosemanowes, CSM | ? | 3500 | 0 | S |
| URS-3 | Measer MT, BC | ? | 4008 | ? | S |
| URS-4 | Higrori, Tohoku | ? | 3508 | ? | S |
| URS-5 | SG-3, Kola | ? | 8300 | ? | S |
| URS-6 | DB-3000, Ukraine | ? | 4000 | ? | S |
| URS-7 | Ural SG-4 | ? | 3700 | ? | S |
| SWE-I | Krivoy Rog SG-8 | 1986 | 6600 | 6600 | P/S |
| IT A-I | Saatly | ? | 4094 | 1450 | G |
| | Central Asia | | | | |
| | Caucasus | | | | |
| | Gravberg-I, Orsa | | | | |
| | Sasso – 22, Lardello | | | | |

Juhlin and Sandstedt, 1989.

P = petroleum exploration;
G = geothermal;
H = hot dry rock;
S = scientific




http://www-icdp.icdp-online.org/front_content.php?idcat=695




Beswick et al, 2014

# Data are available from super-deep boreholes in crystalline rocks

CHARACTERIZATION OF
CRYSTALLINE ROCKS
IN
DEEP BOREHOLES

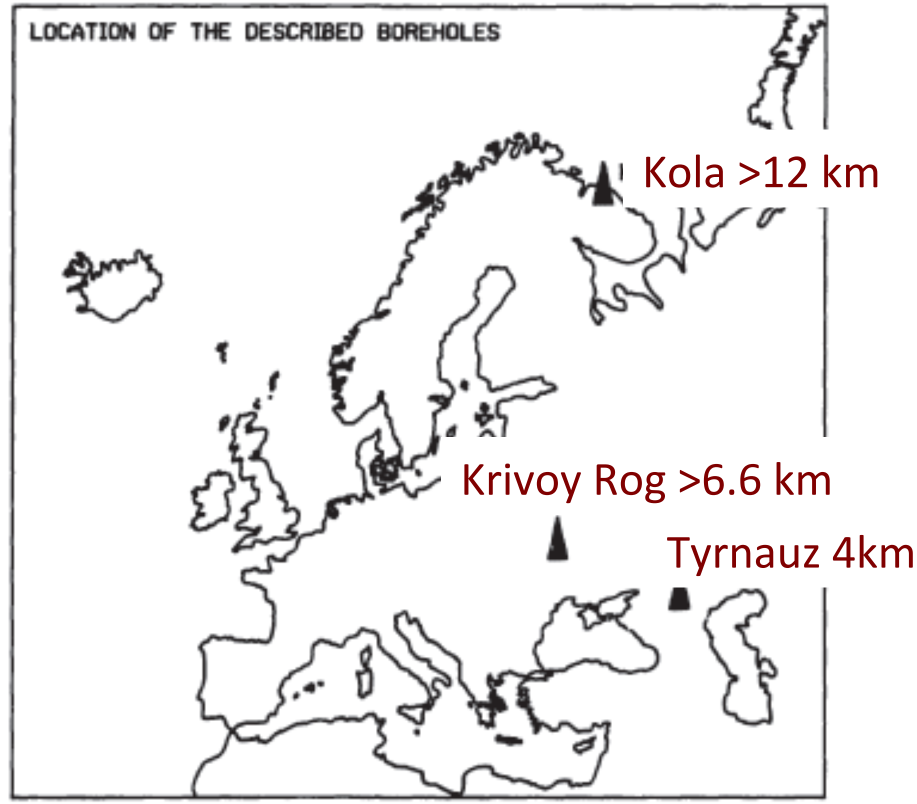
THE KOLA, KRIVOY ROG AND TYRNAUZ
BOREHOLES

NEDRA

Scientific Industrial Company on Superdeep Drilling and Comprehensive
Investigation of the Earth's Interior

December 1992

Keywords: Deep boreholes, Crystalline rock, Salinity, Rock characterization



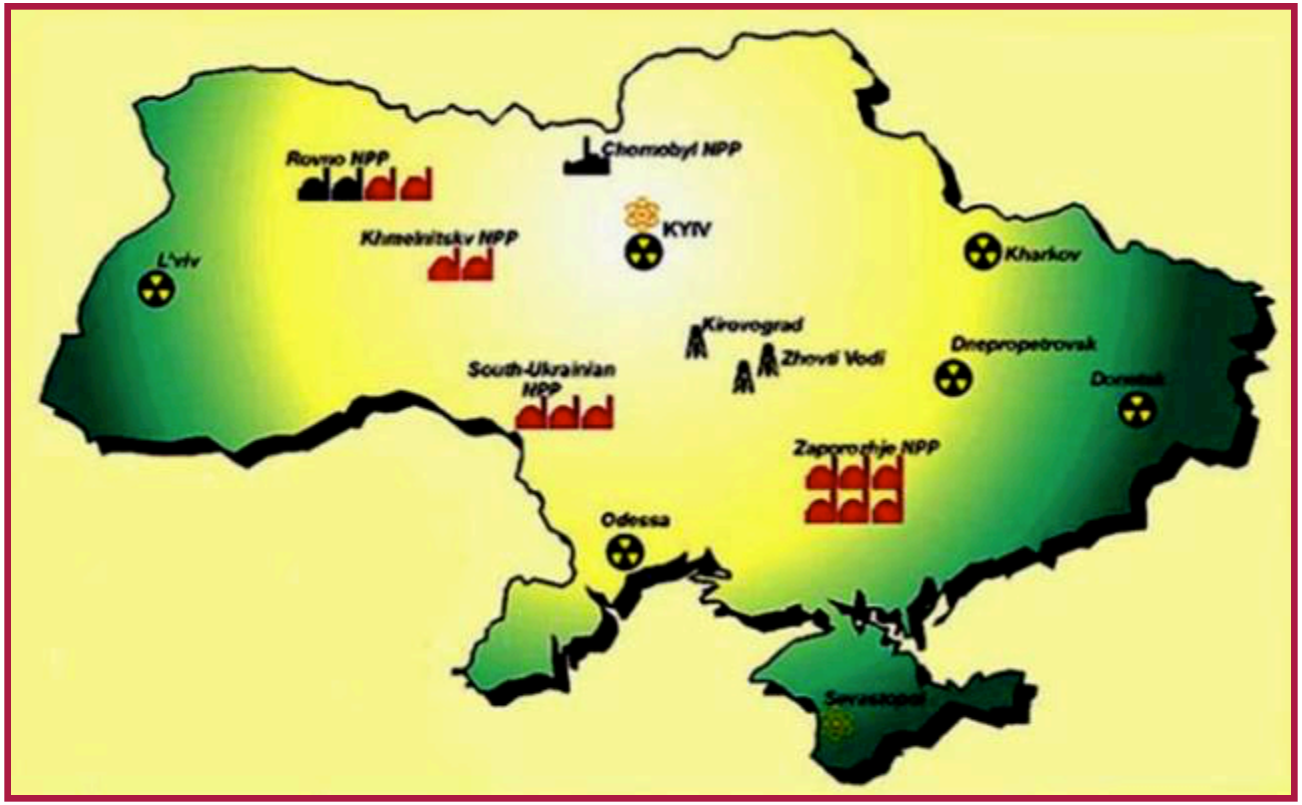

- The Kola and Krivoy Rog boreholes penetrate ancient (2.3 billion years) Lower Proterozoic and Archaean complexes.
- Testing geophysical seismic and magnetic methods
- The Tyrnauz borehole is located at the junction of the young (Cenozoic) Caucasian fold belt and the ancient Skif-Turansky plate, and penetrates young (2 million years) granite.

https://www.youtube.com/watch?v=xy5LNWrWYsQ

# Scientific Findings of Kola Superdeep Borehole

- No transition from granite to basalt was found at the depth of about 7 km, where the velocity of seismic waves has a discontinuity.
- The change in the seismic wave velocity is caused by a metamorphic transition in the granite rock.
- The rock at that depth had been thoroughly fractured and was saturated with water. This water, unlike surface water, must have come from deep-crust minerals and had been unable to reach the surface because of a layer of impermeable rock.
- A large quantity of hydrogen gas. The mud that flowed out of the hole was described as "boiling" with hydrogen.
- The temperature gradient suddenly began to increase at the depth of 10,000 feet.
- Microscopic plankton fossils at depths of 4 miles.
- http://www.mnn.com/lifestyle/eco-tourism/stories/the-worlds-deepest-hole-lies-hidden-beneath-this-rusty-metal-cap#ixzz3cdGWhqqw
- http://en.wikipedia.org/wiki/Kola_Superdeep_Borehole

# Nuclear Energy and Sources of Nuclear Waste In Ukraine




**Industrial and research sources**

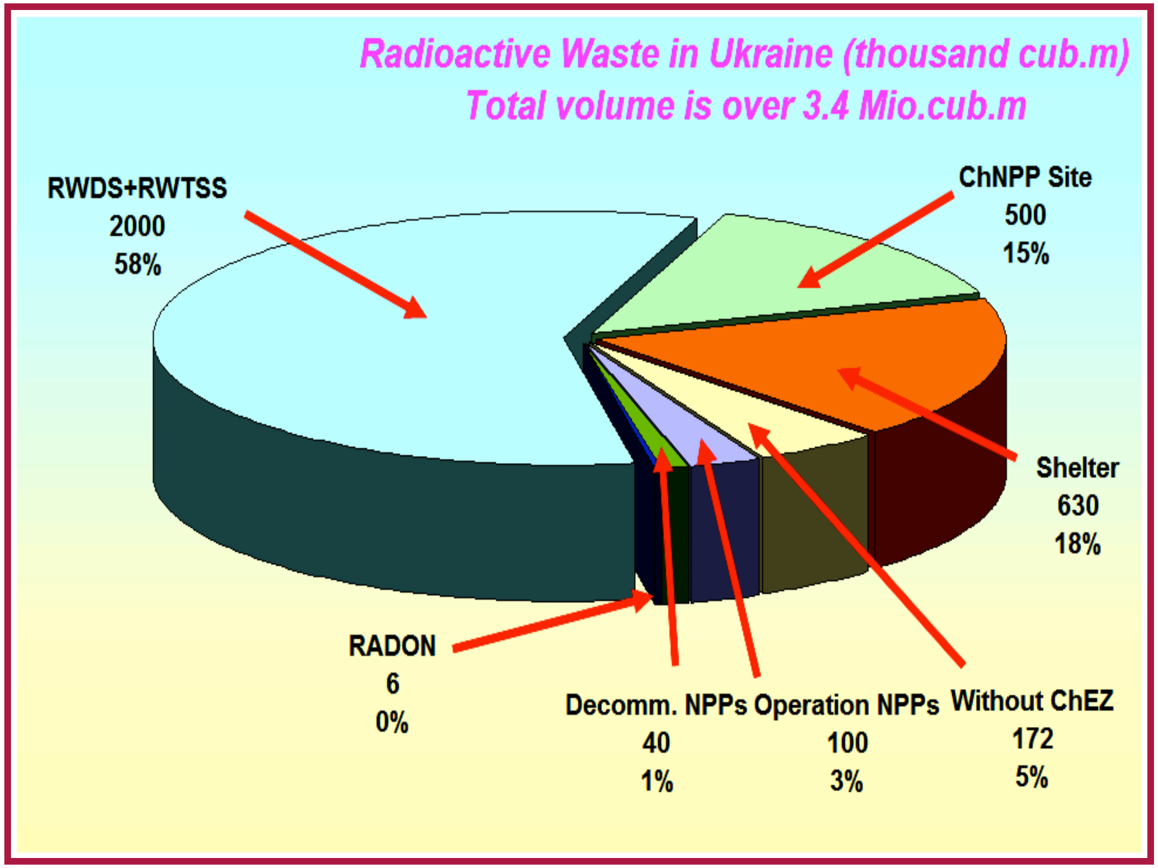
- U mining & milling
- NPP's operation
- NPP's decommissioning
- Industry, medicine, science
- Research reactors
- Military installation

**Chernobyl accident:**

- Abandoned ChNPP
- Contaminated soils
- Temporary storage facilities

- 4 NPPs with 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.
- Plan to build additional reactors.

# Nuclear Waste Inventory in Ukraine




Total volume of waste in Ukraine is >3.4 million $m^3$

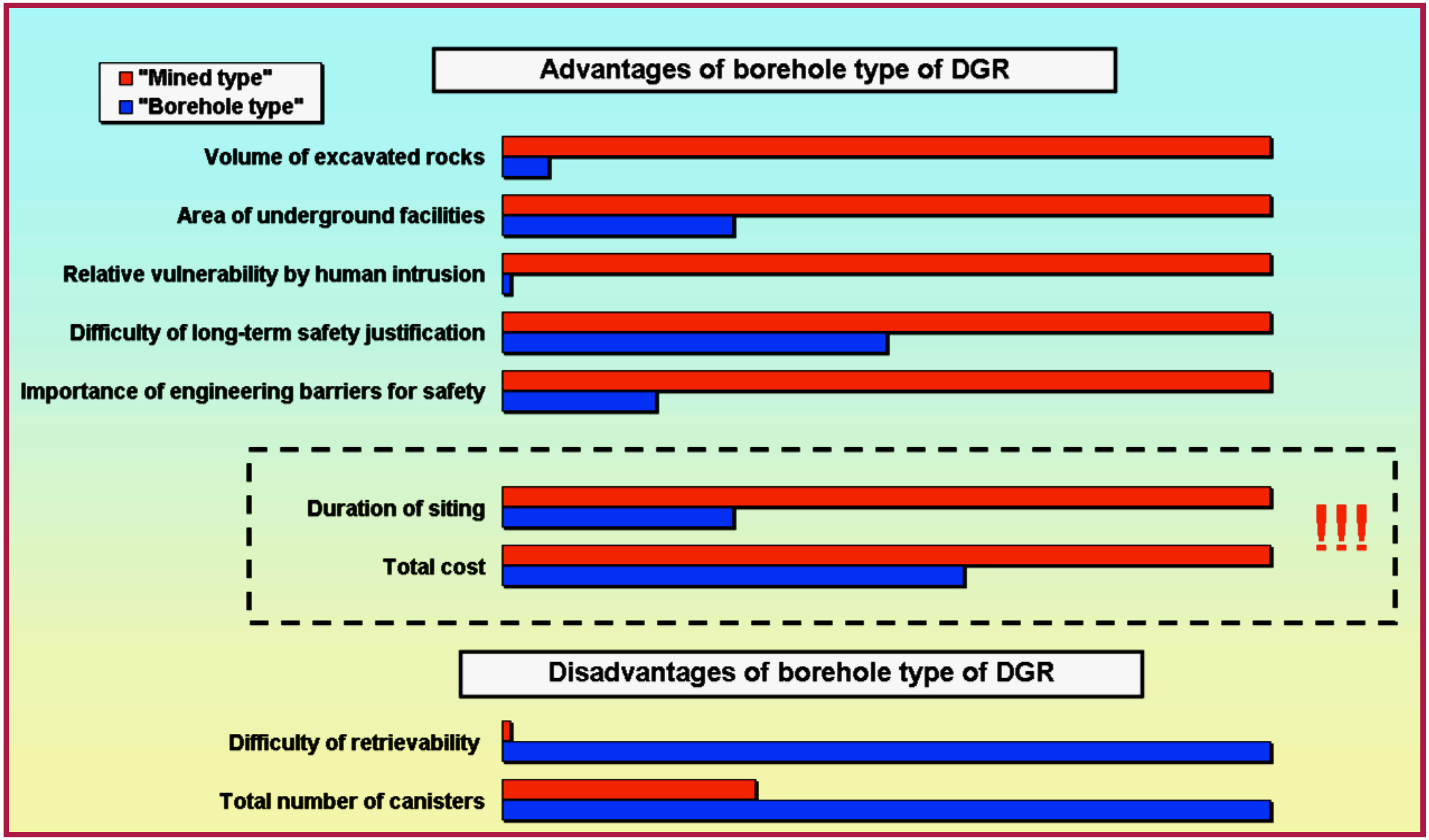
~ 3.3 million $m^3$ (96%) of waste are from the accidents

97–98% of waste is short-lived, which can be disposed in the surface/near surface repositories

**~59 000 $m^3$ of long-lived waste must be disposed in the geological repository**

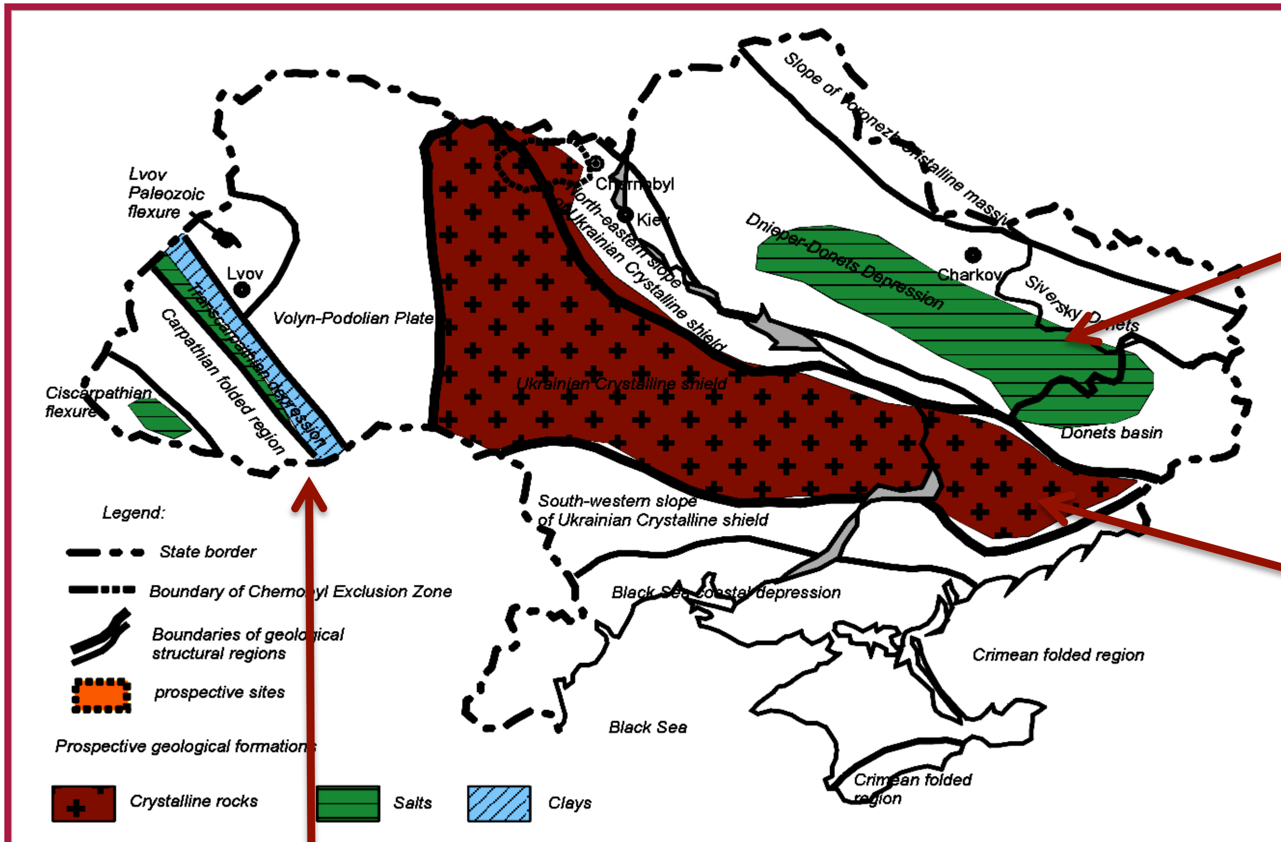
95% of total volume of long-lived waste are stored at the Chernobyl Exclusion Zone

# Evaluation of efficacy of deep borehole repositories




If ILW and HLW are disposed of separately in different repositories, the costs will decrease by 40 times (DBE, 2012).

# Preliminary investigations of different formations for geological NW disposal (1993-2000)



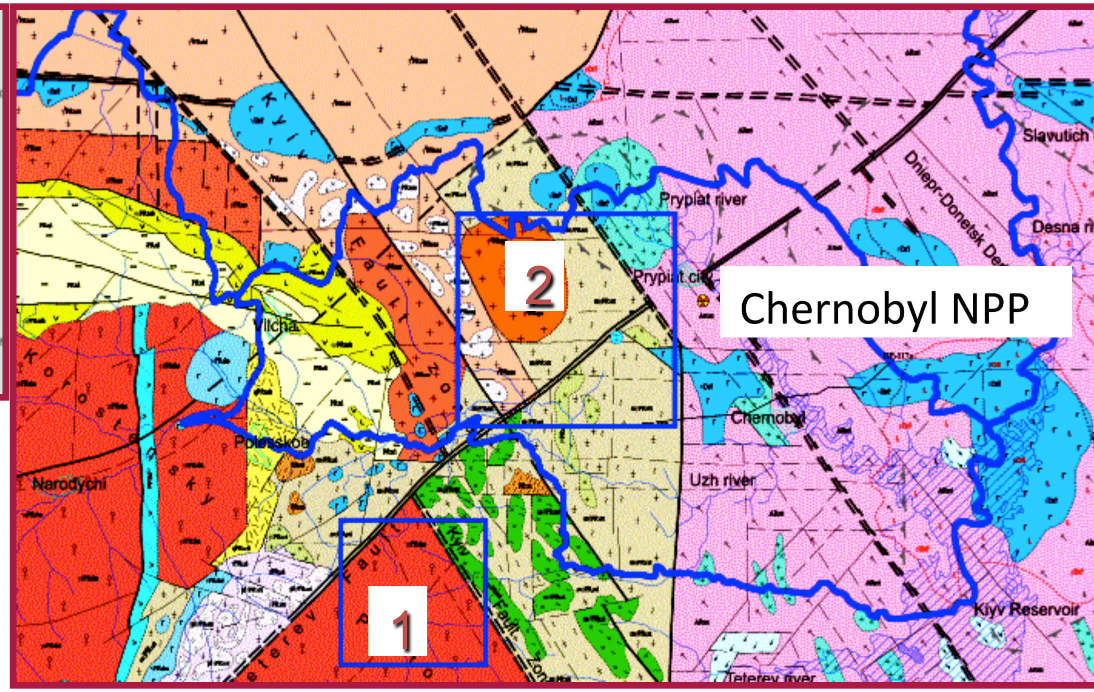

**Salts** – Dnieper-Donetsk depression, Donetsk basin, Precarpatian and Trans-Carpatian regions

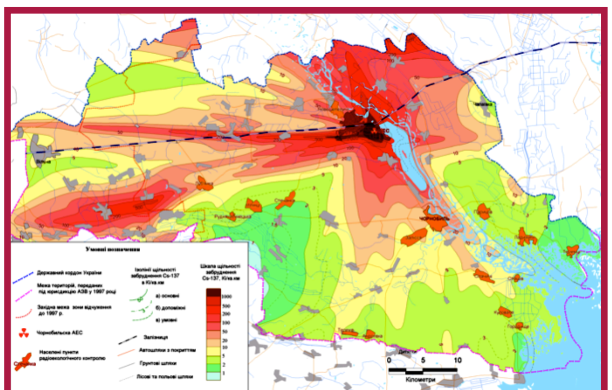
**Crystalline rocks** – Ukrainian Shield

**Clays** – Precarpatian region

[TACIS U 4.02/93, 1996]

# Based on geological and geophysical investigations (2001-2003), two areas within the Ukrainian Shield were selected for deep boreholes

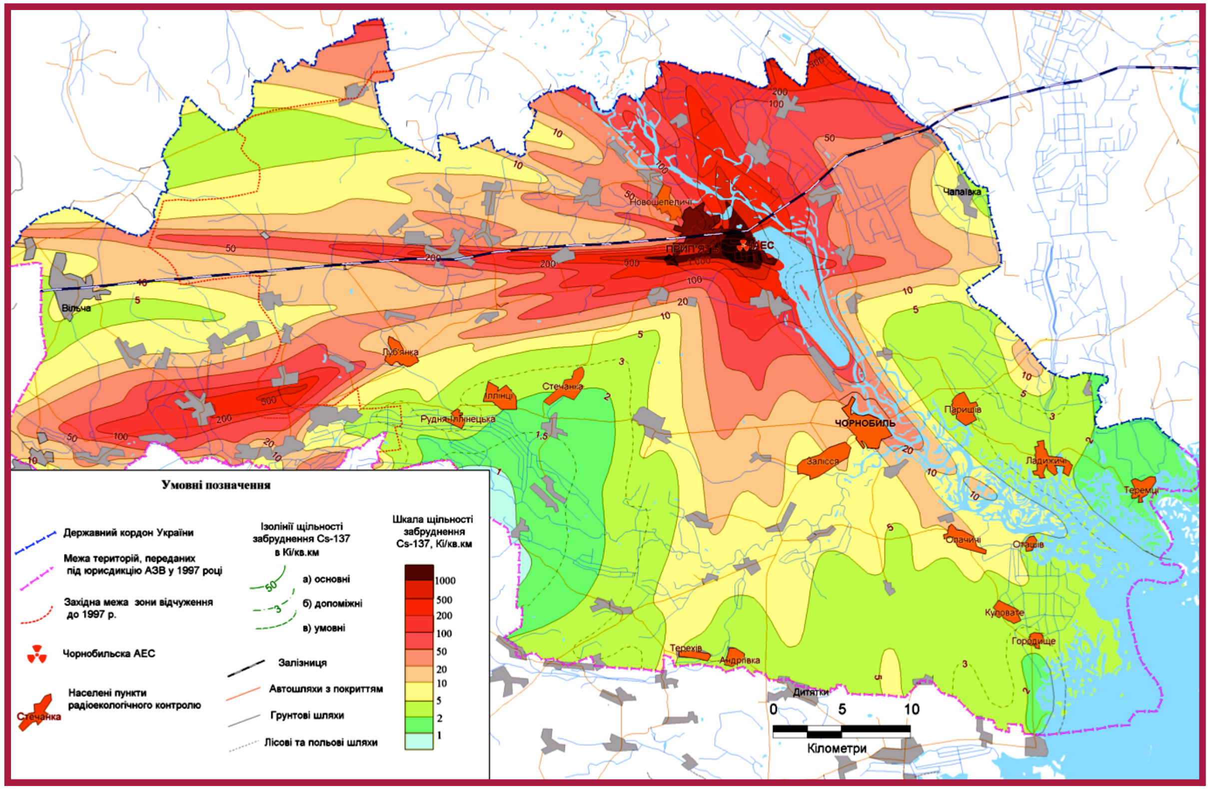



**1 – Veresnia    2 – Tovsty Lis**

**Chernobyl Exclusion Zone**

# Advantages of Chernobyl Exclusion Zone

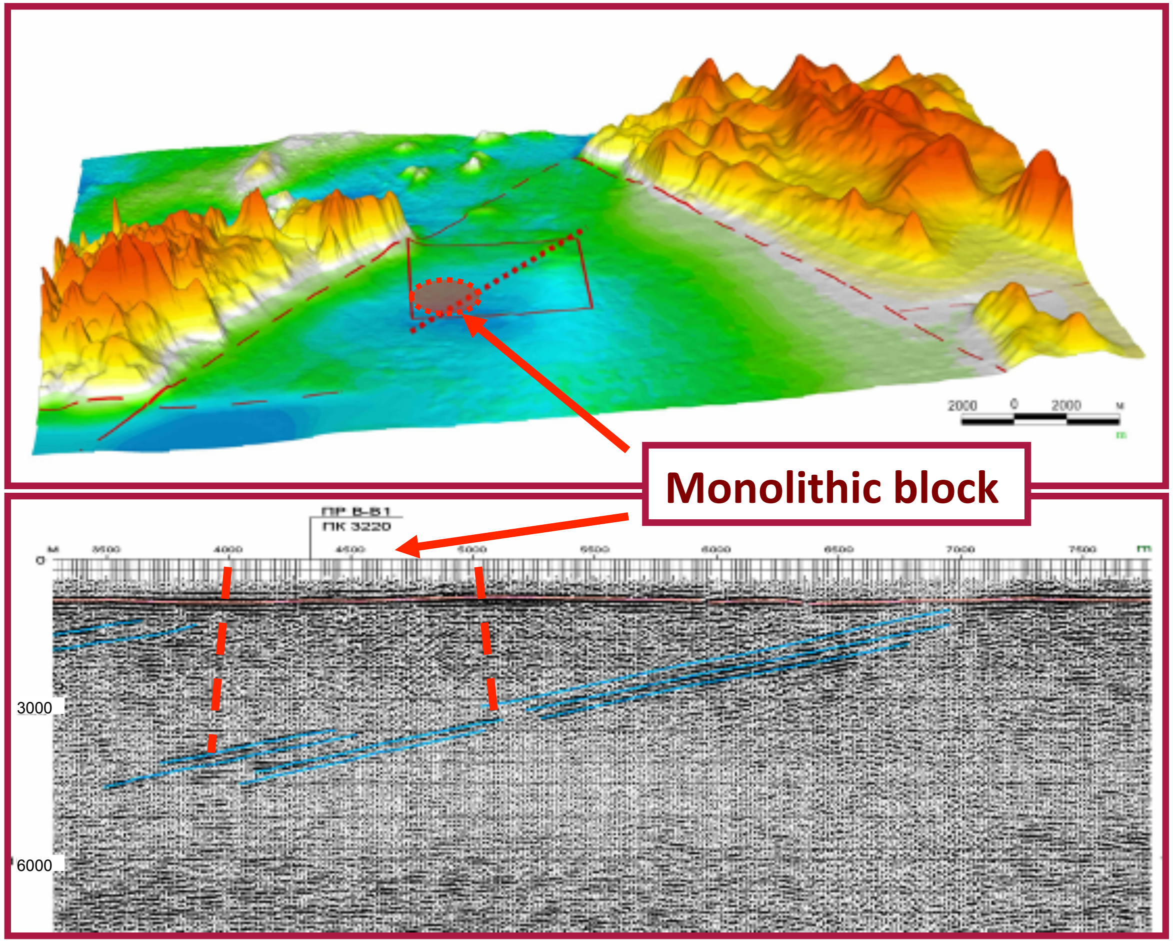



**Available data:**

- Airborne and space images
- Geology
- Hydrogeology
- Drilling
- Geophysical surveys:
  - seismic
  - magnetics
  - gravimetry
  - petrophysics

- No population
- Suitable geology
- Radioactively contaminated area
- Short transport routes
- Security (physical protection)
- Advanced infrastructure

# Geological and geophysical studies of Veresnia site (2004-2006)




- **Seismic**
- **Magnetics**
- **Gravimetry**
- **Geoelectrics**
- **Gases survey (He, Rn)**
- **Airborne imaging**

- **Monolithic block 3×3 km in the crystalline rock has been chosen for drilling**

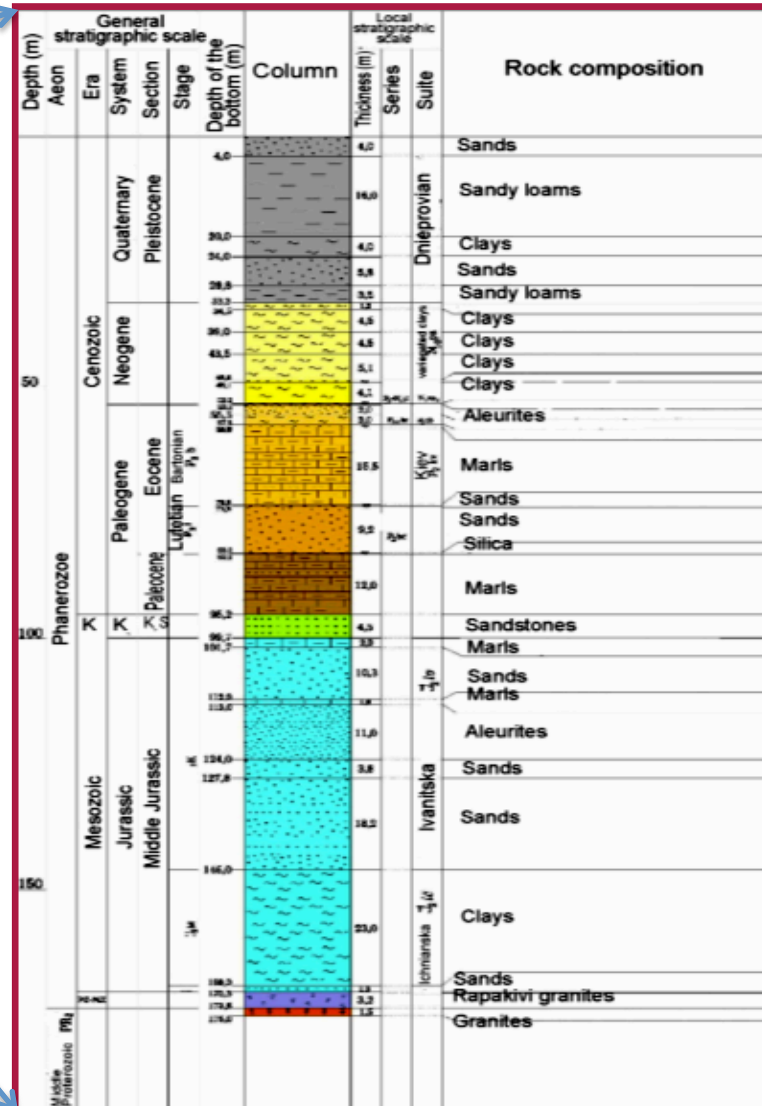
Core logging produces uncertain results.

[STCU 3187, 2006]

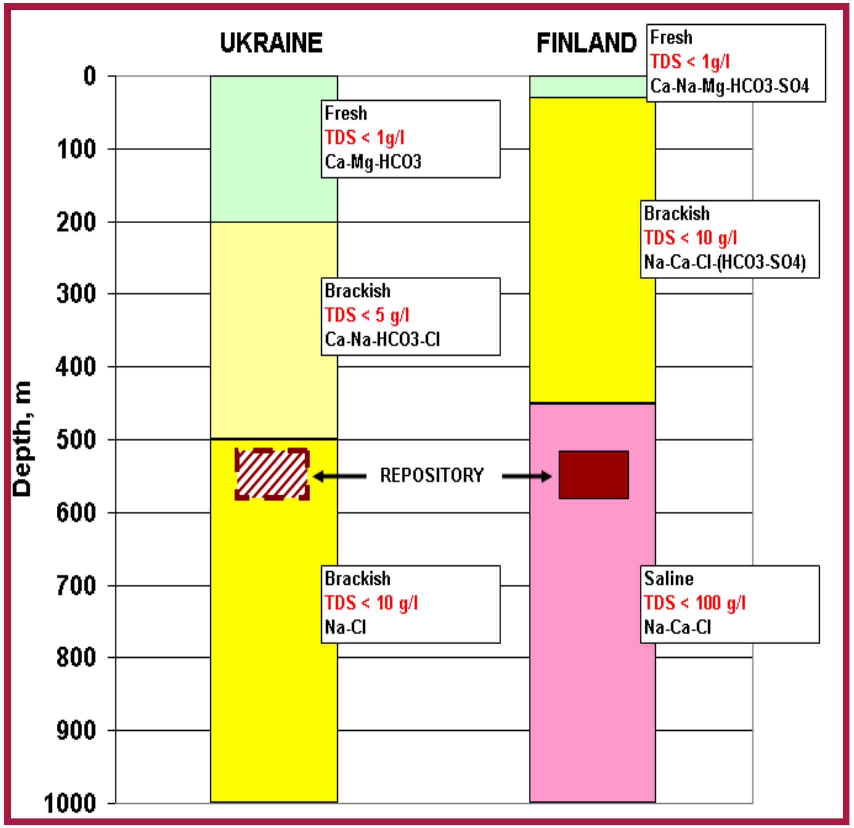
# Hydrogeological conditions are favorable for NW disposal in deep boreholes

| Hydrodynamic zones | Depth interval (below the roof of basement), m | Source and driving force of groundwater |
|---|---|---|
| Zone of intensive water exchange | 0 - 200 | Atmospheric precipitation. Force of gravity. |
| Zone of considerable water exchange | 200 - 1200 | |
| Zone of impeded water exchange | 1200 - - 2500 | Infiltration water, water from rock dehydration during their meta-morphization, juvenile water. Rock pressure, thermal anomaly, degassing of fluids and rocks. |
| Zone of highly impeded water exchange | > 2500 | |

## Sedimentary Cover



# Comparison with Scandinavian Sites




## SCANDINAVIAN SITES

- Forsmark, Simpevarp, Laxemar (Sweden),
- Olkiluoto (Finland)

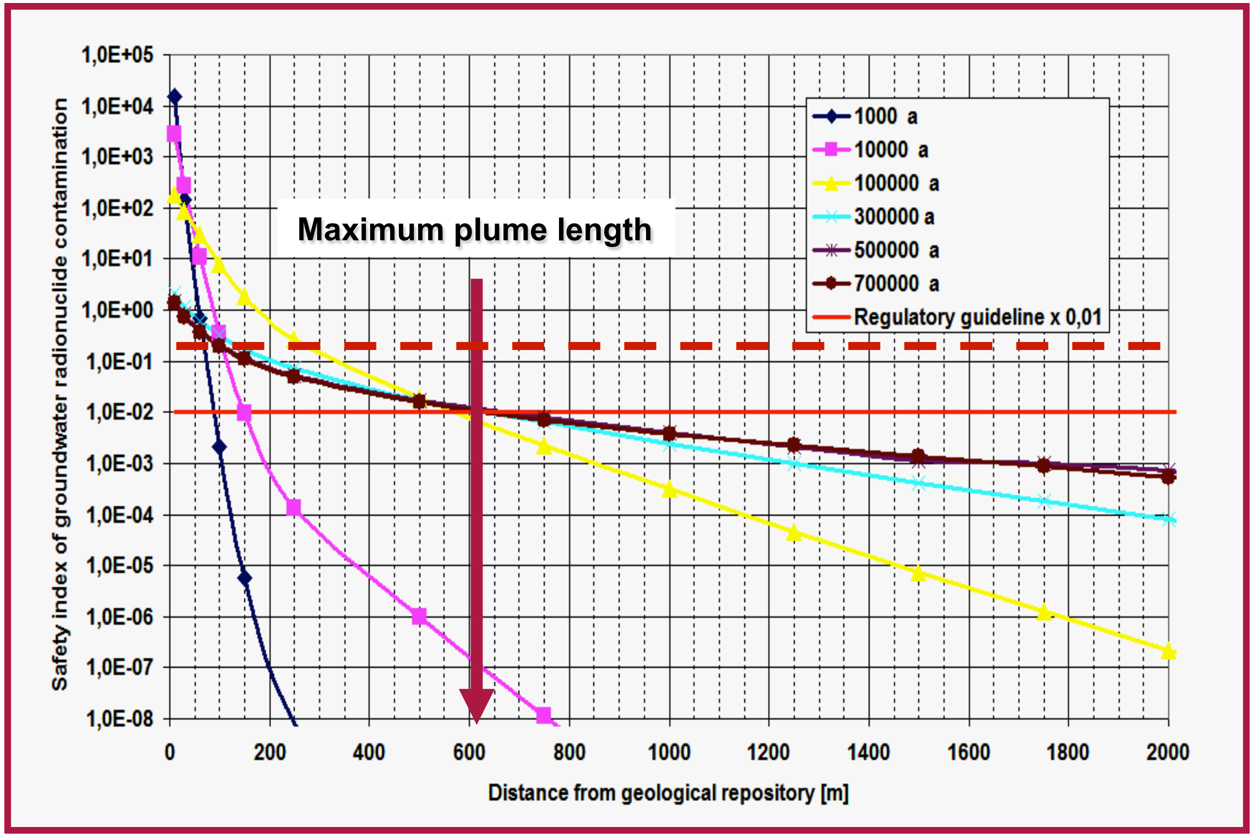
## Pros of Ukrainian sites

- Sedimentary cover 200-350 m deep with several aquifers
- Dilution and sorption of nuclides in the sediments
- Lower salinity on the depth of repository location
- Lower corrosion of engineered barriers
- Lower mechanical and geochemical effects of glaciations
- Lower neotectonic activity
- Lower influence of glaciations

## Cons

- Complexity of studies of deep crystalline rocks
- Colloidal form of radionuclide migration

# 2D Modeling of radionuclide migration from the deep borehole at Veresnia site




Modeling of radionuclides: $^{59}Ni$, $^{99}Tc$, $^{237}Np$, $^{238}U$, $^{239}Pu$, $^{240}Pu$, $^{241}Am$, $^{243}Am$, $^{245}Cm$

$$SI = \sum \frac{A_i}{MCL_{A_i}}$$

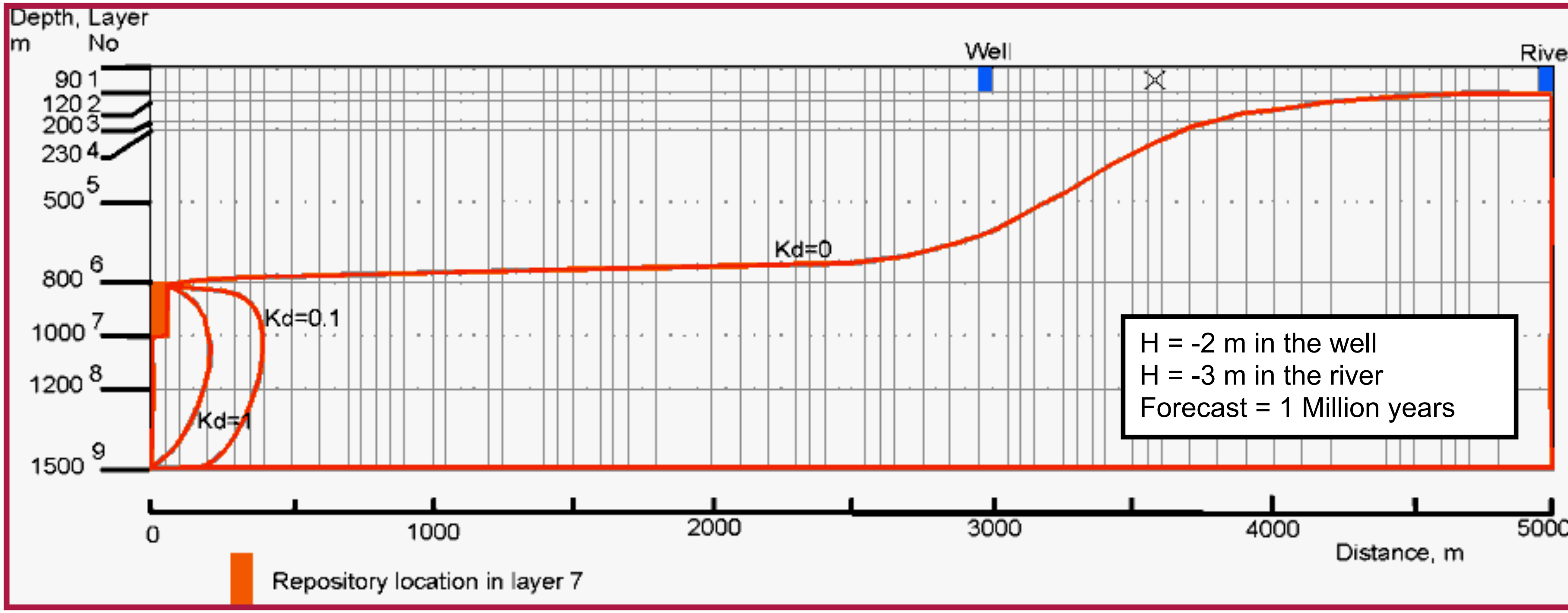
Forecast of the time evolution of radionuclide plume. No sorption scenario. Containers are located at 2-4 km depths

Max. plume length is 0.6 km.  After 100,000 years the plume remains constant.



[STCU 3187, 2006]

# 2D modeling of sorption effects

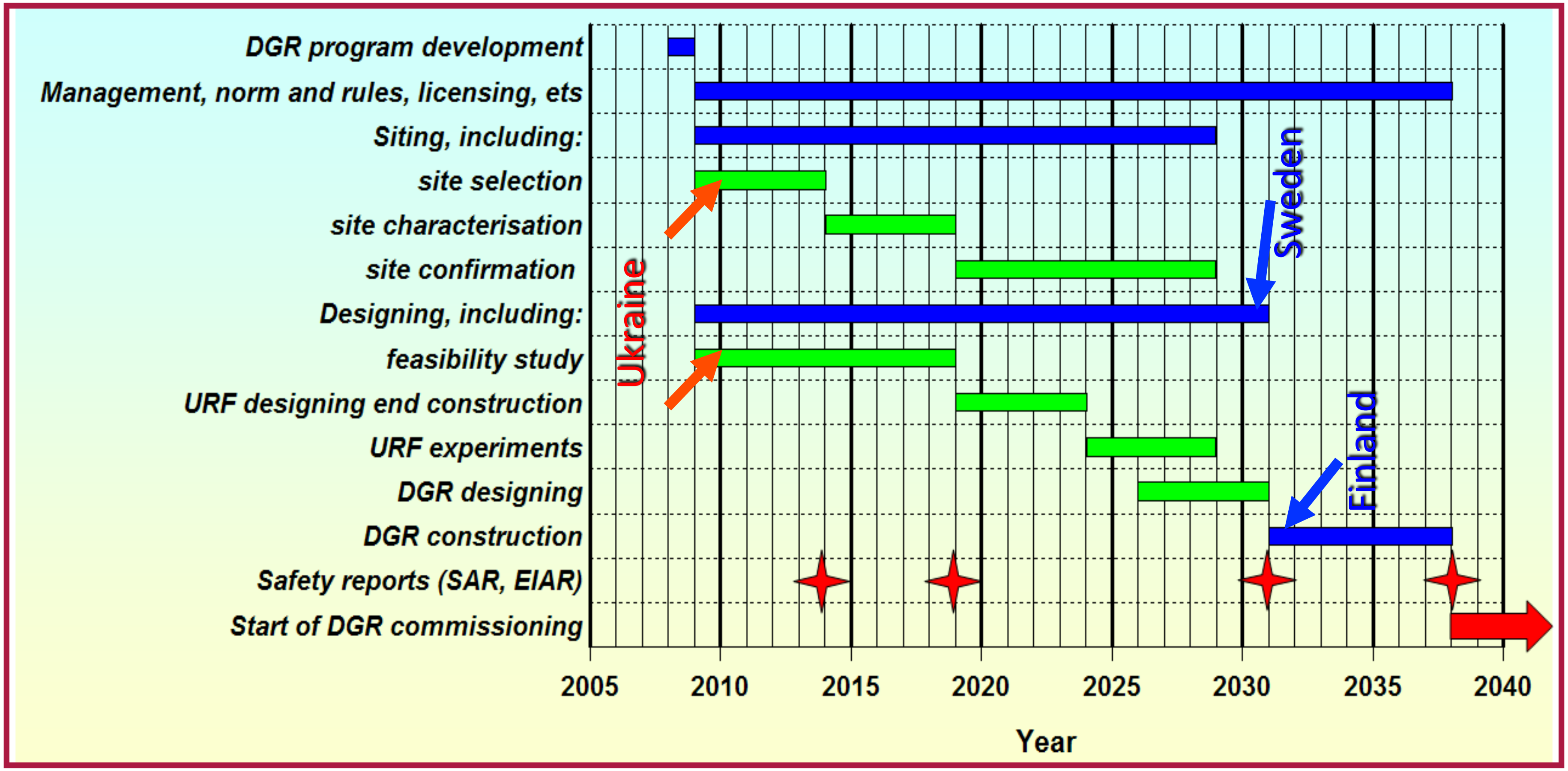



The contamination plume spreading (relative concentration is $10^{-6}$ in comparison to source concentration) for different $K_d$ = 0 (Cl, I), 0.1 (C, Se, Sr) and 1 (Cs, Ra) L/kg

- for Tc, U, Np, Pu, Am, Cm value of $K_d$ > 1000 L/kg (> 1 $m^3$/kg)
- relative concentration $10^{-6}$ for $^{129}I$ is equal to 0.04 Bq/$m^3$ (permissible concentration of $^{129}I$ in the drinking water is 700 Bq/$m^3$)

[IAEA CRP T2.10.24, 2010]

# Timeline of the DGR program



# Adopted recommendations of the 2010 Sandia-MIT Workshop on technical challenges and R&D

- **Design Pilot Tests**: (a) shallow depth – testing emplacement engineering; (b) full depth – prove DBD can be done and containers recovered.
- **Borehole sealing/drilling**: assess consequences if the borehole cannot be sealed.
- **Geochemistry**: evaluation of deep hydrogeochemical stability and heterogeneity,
- **Drilling**: evaluate whether the borehole drilling perturbs by surrounding rock,
- **Reliability and Surveillance**: demonstrate key aspects of deep borehole and emplacement system design, including sensors network,
- **Hydrogeology**: establish how lithological heterogeneity controls large-scale fluid convection in the borehole disturbed zone.
- **Waste Form and Package Design**: materials for packaging; the use of consolidation for SF.
- **Downhole Testing**: tools that may need development, e.g. acoustic and electromagnetic techniques that allow continuous surveillance of vertical fluid motion.
- **Geology**: how to detect, predict or pre-screen for geopressured zones at depth and how to determine if and when this is important.
- **Drilling/casing**: evaluate the casing design of deep boreholes

# Summary of deep boreholes in Russia and Ukraine

| No. | Borehole | Depth, m | | Core recovery | Date | | Design | | Location | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Target | Reached 910601 | m/% | Spudding | Completion | Diameter (mm) and casing depth (m) | Nominal diameter (mm) of the open borehole | Geological | Geographic |
| 1 | Kola | 15000 | 12261 | 3591.9/29.3 | 70.05.25 | | 720/39<br>324/2000<br>245/8770 | 215 | The NE part of the Baltic Shield, in the Pechenga synclinorium | 10 km S of the town Zapolyarny |
| 2 | Krivoy Rog | 12000 | 4596 | 2850.0/62.0 | 84.09.20 | | 720/62<br>508/850<br>426/2800 | 215 | Krivoy Rog-Kremenchug structure in the Ukranian Shield | 15 km NW of the town Krivoy Rog |
| 3 | Tyrnauz | 4000 | 4001 | 2683.0/67.0 | 87.11.18 | 89.11.01 | 530/12<br>324/290 | 215 | The eastern part of the Pshekish-Tyrnauz zone in the Caucasian folded belt | 1.5 km SW of the town Tyrnauz. |

# Selected References


- MINISTRY of EMERGENCY
- Development of Methodology on Comrehensive Geological Investigations for Siting Geological Repository, 2001-03
- Assessment of Possibility for Long-lived Waste Disposal within the Chernobyl Exclusion Zone, 2003-04
- Development of the Ukrainian State Program of Radioactive Waste Management (including Development of Geological Repository), 2006-07
- Draft of the comprehensive program for site investigation for geological disposal, 2008-09

- TASIC
- U 4.02/93: Site selection for radwaste disposal in Ukraine, 1996 (Cassiopeia)
- U 4.03/04: Development of the Strategy and Concept for State Programme for Radioactive Waste Management in Ukraine, 2006-08

- STCU
- 1396: Substantiation for ChNPP Waste Disposal in Deep Boreholes, 2000-03
- 3187: Wastes Disposal within Eastern Part of Korostensky Massif (Field and Model Studies), 2004-06

- IAEA
- CRP T2.10.24: The use of numerical models in support of siting and PA studies of geologic repositories, 2006-08

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IAEA (2009): Classification of radioactive waste: safety guide. – Vienna, 2009.

IAEA (2013): The Use of Numerical Models in Support of Site Characterization and Performance Assessment Studies of Geological Repositories. - TECDOC series, no. 1717, Vienna, 2013.

NRBU-97/D-2000: Radiation protection against the potential radiation exposure sources (Addendum to Radiation safety norms of Ukraine-97). - Kiev, Main Sanitary Inspector of Ukraine , 2000.

OSPU-2005: The main sanitary rules of radiation safety assurance in Ukraine. – Kiev, Ministry of Health of Ukraine, 2005.

Shestopalov V. et al (2006): Geological disposal of radioactive waste in Ukraine. – Kiev, REC, 2006

# National Legislation of Radioactive Waste Management

1. Ukraine ratified several Joint Conventions, including the Joint Convention on Safety for SF and RW Management, 2000.

2. Ukraine passed all needed basic laws, including:

"On Utilization of Nuclear Power and Radiation Safety," 1995

"On Radioactive Waste Management," 1995

3. State Principal Program of Radioactive Waste Management acts from 2008 (including the tasks for the next 10 years)

4. National Strategy of Radioactive Waste Management is adopted by the Cabinet of Ministers in 2009

# International Studies of DBD – Denmark, Finland, France, Germany, Sweden, Switzerland, UK, Ukraine, USA, IAEA

Åhäll, K-I, *Final Deposition of High-level Nuclear Waste in Very Deep Boreholes: an evaluation based on recent research of bedrock conditions at great depth*s. MKG Report No 2. Miljöorganisationernas kärnavfallsgranskning, Stockholm, Sweden, 2010.

*"…**very deep borehole disposal appears to permit emplacement of the waste at depths where the entire repository zone would be surrounded by stable, density-stratified groundwater having no contact with the surface**…"*

*"**This hydrogeological difference is a major safety factor**, which is particularly apparent in all scenarios that envisage leakage of radioactive substances. Another advantage of a repository at a depth of 3 to 5 km is that it is less vulnerable to impacts from expected events (e.g., changes in groundwater conditions during future ice ages) as well as undesired events (e.g. such as terrorist actions, technical malfunction and major local earthquakes)."*