

# Measurements of natural radioactivity in the salt cavern of the Polkowice – Sieroszowice copper mine

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# Outline

- **Polkowice – Sieroszowice copper mine**
- **Location of the measurement site**
- **Measurements of the natural radioactivity  
in the ZG Polkowice-Sieroszowice**
- **Results**
- **Conclusions and future activities**

# Location of the Polkowice – Sieroszowice copper mine



- South – West of Poland,
- ~90 km North – West from Wrocław,
- Belongs to the KGHM Polska Miedź S. A. holding

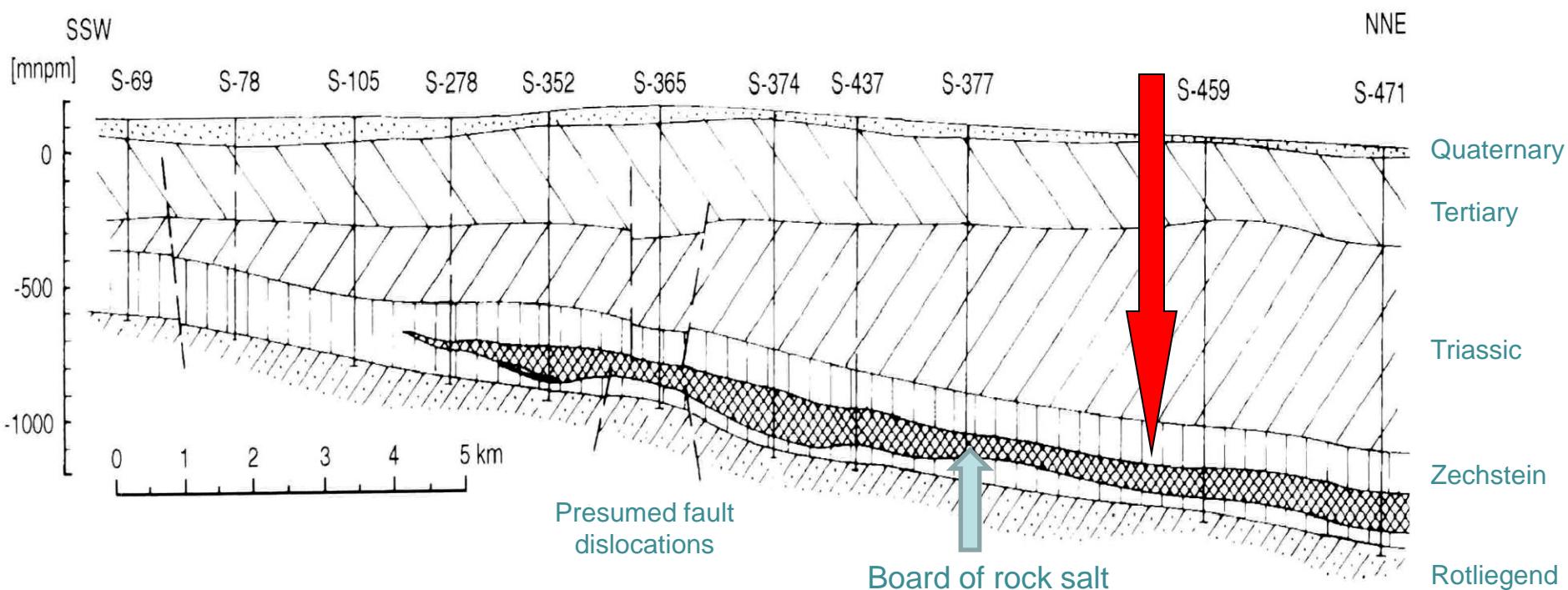
# Activity of KGHM Polska Miedź S.A. holding

- Copper – in the top ten of the world's exploitation ranking
- Silver – 3<sup>rd</sup> position
- Rock salt for winter maintenance of roads and pavements
- Products:
  - Copper – cathodes, wire rod, Cu-OFE wire, Cu-Ag wire, round billets, granulates
  - Precious metals – silver, gold
  - Rhenium – pellets of metallic rhenium, ammonium perrhenate
  - Other products – refined lead, sulphuric acid, copper sulphate, nickel sulphate, technical selenium



<http://www.kghm.pl/>

# Polkowice – Sieroszowice mine geological cross section



# Measurement site – salt cavern

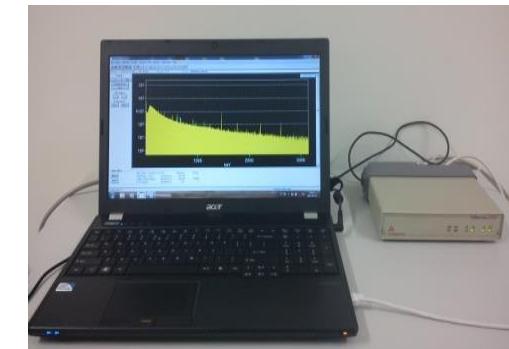
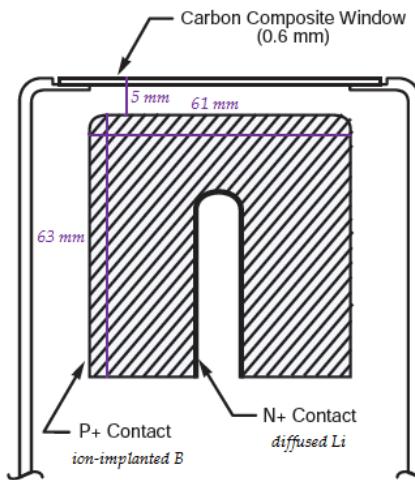


- Salt cavern depth ~930m (~2500m w.e.)
- Cavern dimensions: 15m×20m×100m
- Salt layer thickness of ~70m
- Surrounded by anhydrite
- Temperature ~36°C

# Measurements of the natural radioactivity

- **In-situ gamma spectrometry in the salt cavern (July 2014)**
- **HPGe detector (Canberra Industries Inc.)**

- Coaxial detector
- Reverse electrode type
- Model GR4020, S/N b12524
- 40% relative efficiency,
- resolution: 1.12keV @ 122keV and 2,08keV @ 1.33MeV
- P/C: 57/1
- Energy range 6 keV - 3200 keV
- Crystal length 63mm and diameter 61mm
- Carbon composite window (0.6mm)
- MCA InSpector 2000 (8194 channels)
- Genie2000 (Canberra) software for the spectrum registration and analysis

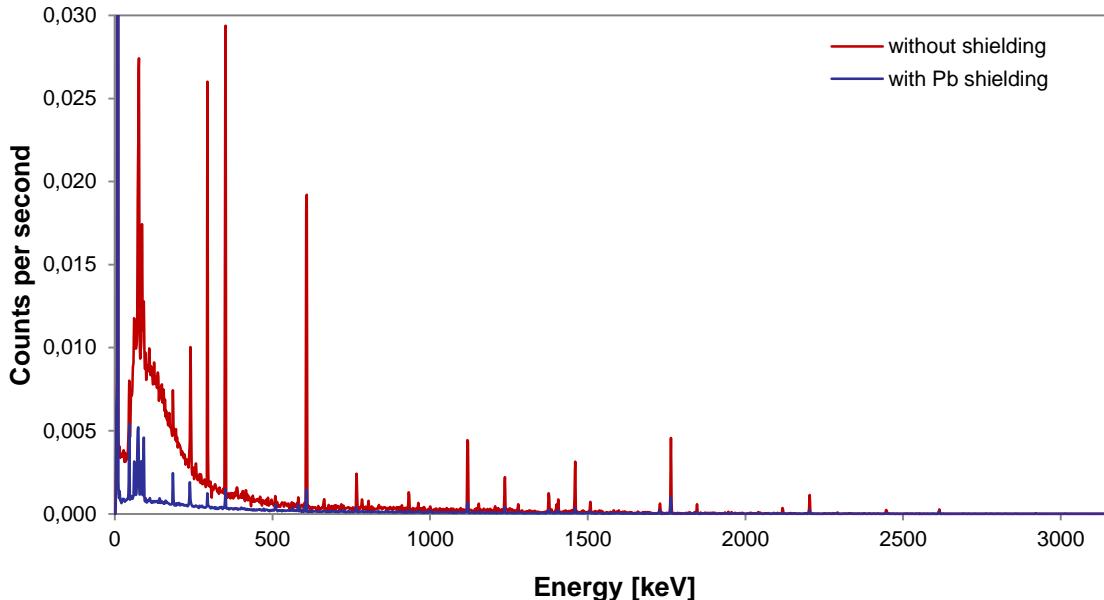


# Measurements of the natural radioactivity

- ***In-situ* gamma spectrometry in the salt cavern (July 2014)**
- Experimental conditions
  - One long registration ~21h
    - *With lead shielding (2.5cm)*
  - One short acquisition ~3h
    - *Without shielding*
  - Detector ~10cm above the salt ground



# Results – natural radioactivity



*Tab.1. Fluorescence X-rays.*

Energy [keV]	Isotope	cps	
		bare detector	with Pb shielding
10.55	X Pb - L <sub>α1</sub>	<b>0.4938</b> ± 0.0082	<b>0.5029</b> ± 0.0026
12.97, 13.62 (*)	X Th - L <sub>α1</sub> ; U - L <sub>α1</sub>	—	<b>0.0032</b> ± 0.0003
16.30	X Th, U - L <sub>β</sub>	—	<b>0.0111</b> ± 0.0004
74.97	X Pb - K <sub>α1</sub>	<b>0.0642</b> ± 0.0038	<b>0.0304</b> ± 0.0007
77.12 (*)	X Bi - K <sub>α1</sub>	<b>0.1025</b> ± 0.0044	<b>0.0073</b> ± 0.0005
84.94	X Pb - K <sub>β1</sub>	—	<b>0.0142</b> ± 0.0005
87.34	X Bi - K <sub>β1</sub>	<b>0.0287</b> ± 0.0066	<b>0.0057</b> ± 0.0004

(\*) Might also origin in Ge+n interactions.

# Results – natural radioactivity

*Tab.2. Gamma radiation from Uranium, Actinium and Thorium series.*

Energy [keV]	Isotope	cps	
		bare detector	with Pb shielding
46.54	<sup>210</sup> Pb	<b>0.0187</b> ± 0.0041	<b>0.0270</b> ± 0.0008
63.29	<sup>234</sup> Th	<b>0.0187</b> ± 0.0038	<b>0.0160</b> ± 0.0009
73.92	<sup>234</sup> Pa	—	<b>0.0153</b> ± 0.0006
92.59	<sup>234</sup> Th	<b>0.0184</b> ± 0.0057	<b>0.0192</b> ± 0.0010
112.81	<sup>234</sup> Th	—	<b>0.0006</b> ± 0.0004
143.76	<sup>235</sup> U	—	<b>0.0021</b> ± 0.0005
163.36	<sup>235</sup> U	—	<b>0.0015</b> ± 0.0005
186.10; 185.71	<sup>226</sup> Ra; <sup>235</sup> U	<b>0.0108</b> ± 0.0033	<b>0.0108</b> ± 0.0006
205.31	<sup>235</sup> U	—	<b>0.0016</b> ± 0.0005
238.63	<sup>212</sup> Pb	<b>0.0106</b> ± 0.0017	<b>0.0092</b> ± 0.0004
241.98	<sup>214</sup> Pb	<b>0.0511</b> ± 0.0028	<b>0.0024</b> ± 0.0003
269.459; 271.23	<sup>223</sup> Ra, <sup>219</sup> Rn	—	<b>0.0044</b> ± 0.0002
295.21	<sup>214</sup> Pb	<b>0.1342</b> ± 0.0045	<b>0.0043</b> ± 0.0006
338.32	<sup>228</sup> Ac	—	<b>0.0004</b> ± 0.0003
351.92	<sup>214</sup> Pb	<b>0.2156</b> ± 0.0054	<b>0.0075</b> ± 0.0006
401.81	<sup>219</sup> Rn	—	<b>0.0039</b> ± 0.0002
510.77 (*)	<sup>208</sup> Tl	<b>0.0035</b> ± 0.0012	<b>0.0028</b> ± 0.0004
583.19	<sup>208</sup> Tl	<b>0.0028</b> ± 0.0012	<b>0.0021</b> ± 0.0003
609.31	<sup>214</sup> Bi	<b>0.1827</b> ± 0.0046	<b>0.0125</b> ± 0.0004
665.45	<sup>214</sup> Bi	<b>0.0053</b> ± 0.0012	<b>0.0002</b> ± 0.0002
727.33	<sup>212</sup> Bi	—	<b>0.0005</b> ± 0.0002
768.36	<sup>214</sup> Bi	<b>0.0176</b> ± 0.0018	<b>0.0023</b> ± 0.0003
911.21	<sup>228</sup> Ac	—	<b>0.0004</b> ± 0.0002

(\*) Might also partly rise from 511 keV

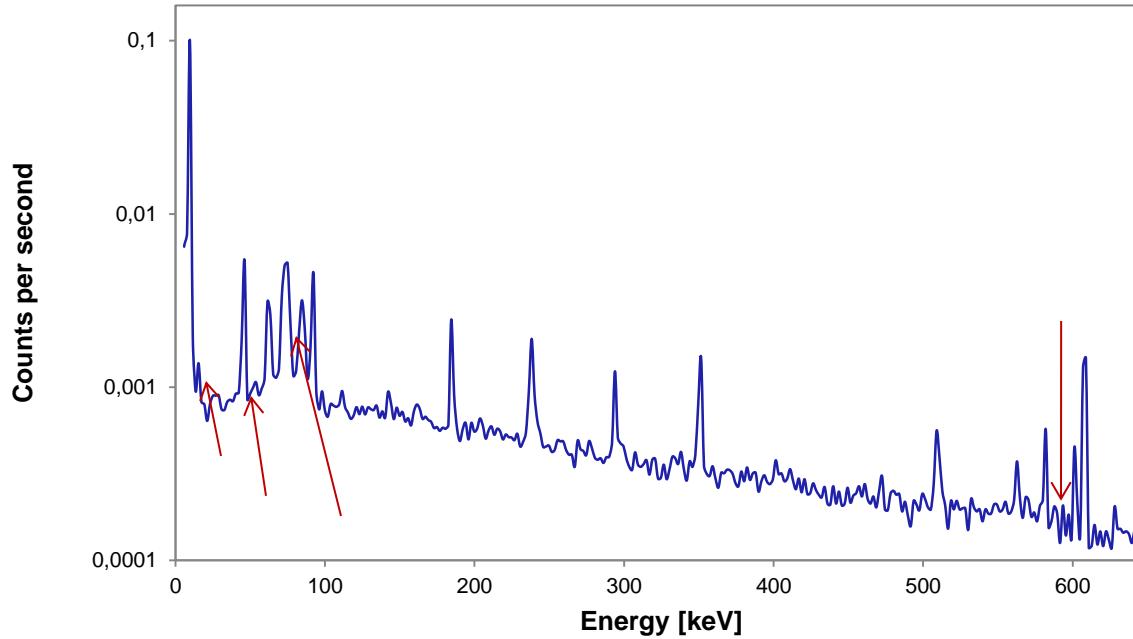
Energy [keV]	Isotope	cps	
		bare detector	with Pb shielding
934.06	<sup>214</sup> Bi	<b>0.0092</b> ± 0.0016	<b>0.0010</b> ± 0.0003
964.77	<sup>228</sup> Ac	<b>0.0018</b> ± 0.0009	<b>0.0003</b> ± 0.0002
968.97	<sup>228</sup> Ac	—	<b>0.0006</b> ± 0.0002
1001.03	<sup>234</sup> Pa	—	<b>0.0008</b> ± 0.0002
1120.29	<sup>214</sup> Bi	<b>0.0406</b> ± 0.0023	<b>0.0055</b> ± 0.0004
1155.19	<sup>214</sup> Bi	<b>0.0015</b> ± 0.0010	<b>0.0006</b> ± 0.0002
1238.11	<sup>214</sup> Bi	<b>0.0144</b> ± 0.0015	<b>0.0024</b> ± 0.0002
1280.96	<sup>214</sup> Bi	<b>0.0036</b> ± 0.0008	<b>0.0006</b> ± 0.0002
1377.67	<sup>214</sup> Bi	<b>0.0092</b> ± 0.0014	<b>0.0024</b> ± 0.0002
1401.50	<sup>214</sup> Bi	<b>0.0021</b> ± 0.0006	<b>0.0005</b> ± 0.0001
1407.98	<sup>214</sup> Bi	<b>0.0043</b> ± 0.0007	<b>0.0011</b> ± 0.0001
1460.83	<sup>40</sup> K	<b>0.0212</b> ± 0.0018	<b>0.0023</b> ± 0.0002
1509.23	<sup>214</sup> Bi	<b>0.0031</b> ± 0.0009	<b>0.0007</b> ± 0.0002
1683.99	<sup>214</sup> Bi	—	<b>0.0005</b> ± 0.0001
1729.60	<sup>214</sup> Bi	<b>0.0053</b> ± 0.0008	<b>0.0015</b> ± 0.0002
1764.50	<sup>214</sup> Bi	<b>0.0318</b> ± 0.0019	<b>0.0068</b> ± 0.0003
1847.42	<sup>214</sup> Bi	<b>0.0035</b> ± 0.0006	<b>0.0007</b> ± 0.0001
1873.16	<sup>214</sup> Bi	—	<b>0.0002</b> ± 0.0001
2118.55	<sup>214</sup> Bi	<b>0.0028</b> ± 0.0006	<b>0.0005</b> ± 0.0001
2204.21	<sup>214</sup> Bi	<b>0.0080</b> ± 0.0010	<b>0.0017</b> ± 0.0002
2293.36	<sup>214</sup> Bi	—	<b>0.0002</b> ± 0.0001
2447.86	<sup>214</sup> Bi	<b>0.0029</b> ± 0.0005	<b>0.0004</b> ± 0.0001
2614.53	<sup>208</sup> Tl	<b>0.0024</b> ± 0.0005	<b>0.0012</b> ± 0.0001

Uranium series: 0.6623 / 0.1023 cps

Thorium series: 0.0211 / 0.0170 cps

Actinium series: 0.1423 / 0.0408 cps

# Results – neutron interactions with germanium

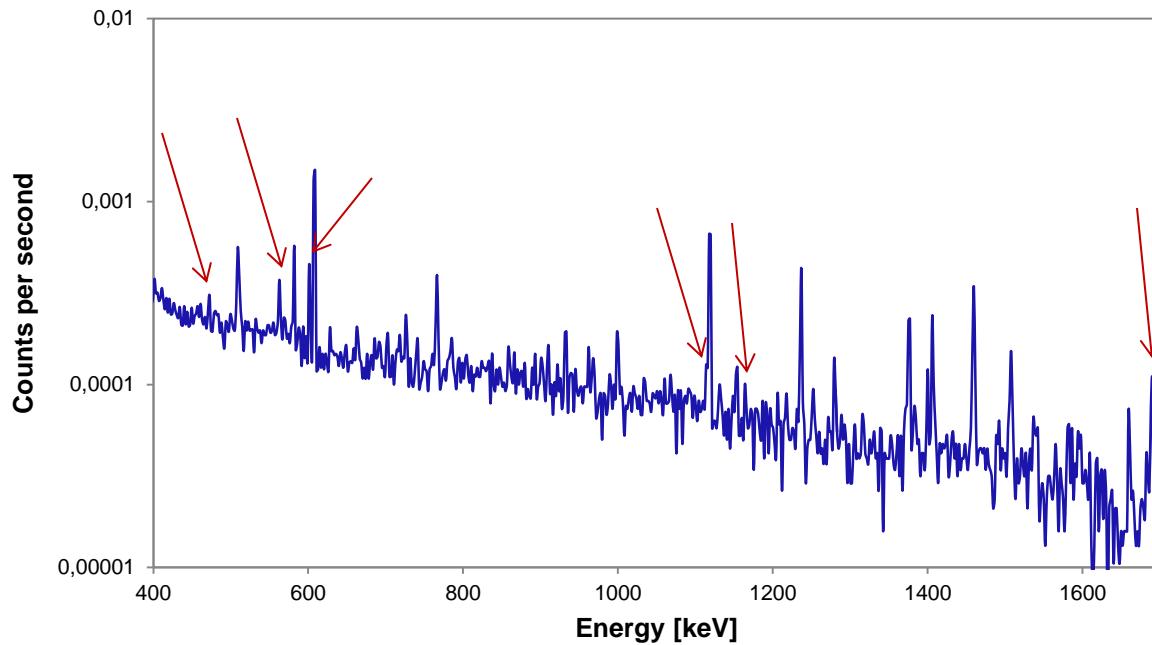


*Tab.3. Neutron interactions with germanium crystal.*

Energy [keV]	Reaction mechanism	cps	
		bare detector	with Pb shielding
13.27 (*)	$^{72}\text{Ge}(n,\gamma)^{73m}\text{Ge}$	<b>0.0035</b> ± 0.0001	<b>0.0032</b> ± 0.0003
53.44	$^{72}\text{Ge}(n,\gamma)^{73m}\text{Ge}$	<b>0.0053</b> ± 0.0049	<b>0.0010</b> ± 0.0004
77.86 (*)	$^{74}\text{Ge}(n,\gamma)^{75m}\text{Ge}$	<b>0.1025</b> ± 0.0044	<b>0.0073</b> ± 0.0005
595.85	$^{73}\text{Ge}(n,\gamma)^{74}\text{Ge}(n,n')$	—	<b>0.0018</b> ± 0.0002

(\*) Might also be a fluorescence X-rays from Th, U, Pb and Bi.

# Results – neutron interactions with other materials



*Tab.4. Neutron interactions with other materials.*

Energy [keV]	Origin	cps	
		bare detector	with Pb shielding
472.90	$^{23}\text{Na}(\text{n},\gamma)^{24}\text{Na}$ prompt	—	<b>0.0006</b> $\pm$ 0.0002
564.24	$^{121}\text{Sb}(\text{n},\gamma)^{122}\text{Sb}$ decay	—	<b>0.0014</b> $\pm$ 0.0004
602.73	$^{123}\text{Sb}(\text{n},\gamma)^{124}\text{Sb}$ decay	—	<b>0.0017</b> $\pm$ 0.0002
1115.55	$^{64}\text{Zn}(\text{n},\gamma)^{65}\text{Zn}$ decay	—	<b>0.0003</b> $\pm$ 0.0001
1164.87	$^{35}\text{Cl}(\text{n},\gamma)^{36}\text{Cl}$ prompt	—	<b>0.0010</b> $\pm$ 0.0001
1690.98	$^{123}\text{Sb}(\text{n},\gamma)^{124}\text{Sb}$ decay	—	<b>0.0007</b> $\pm$ 0.0001

# Conclusions and future activities

- Natural radioactivity is one the order of magnitude lower than in other underground laboratories (measured within ILIAS project).
- Four lines at the registered spectra were identified as those connected with neutron interaction with germanium crystal of a spectrometer (13.27, 53.44, 77.86 and 596 keV).
- Prompt gamma radiation from reactions  $^{23}\text{Na}(\text{n},\gamma)$  and  $^{35}\text{Cl}(\text{n},\gamma)$  were detected.
- There is a need to perform a longer data acquisition (due to poor counting statistics), especially for the bare detector to investigate the efficiency of a Pb shielding.
- There is a possibility to compare the presented measurements with those performed at the ground for different neutron sources.

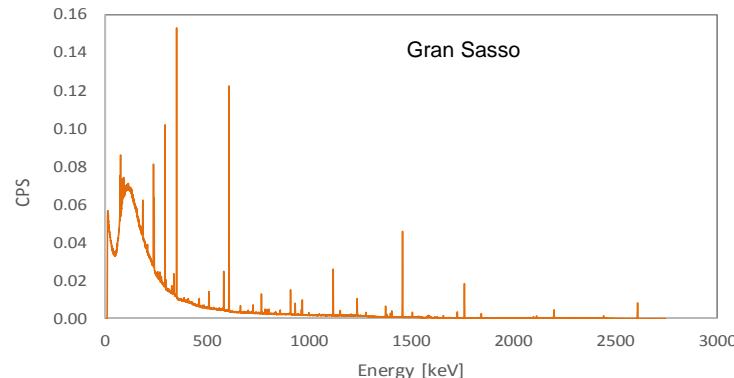
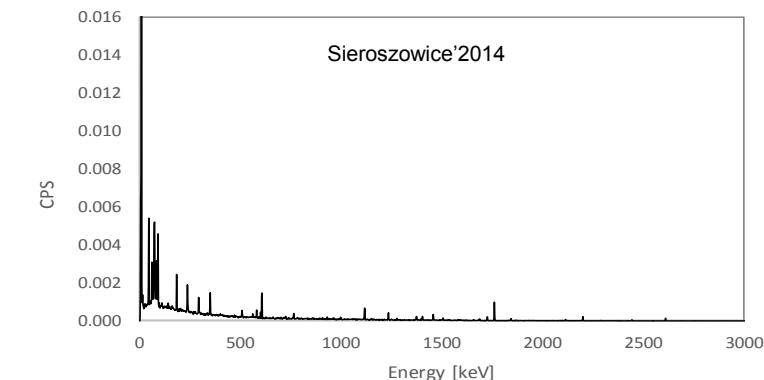
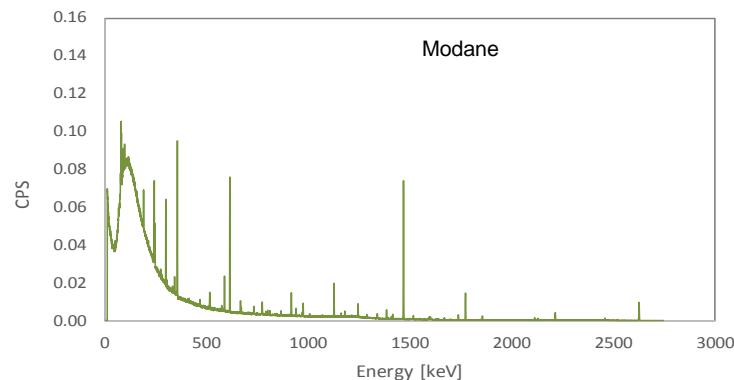
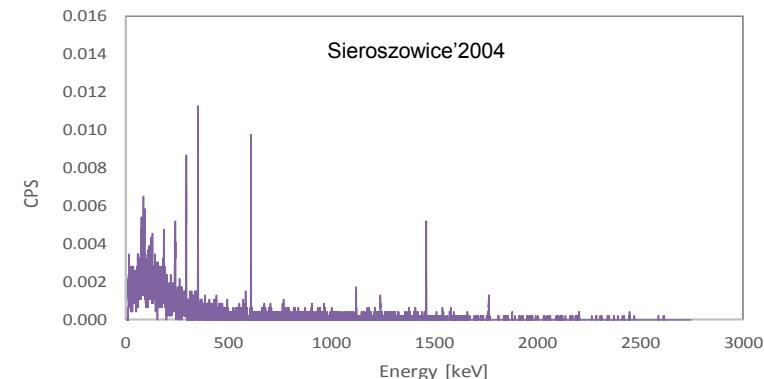
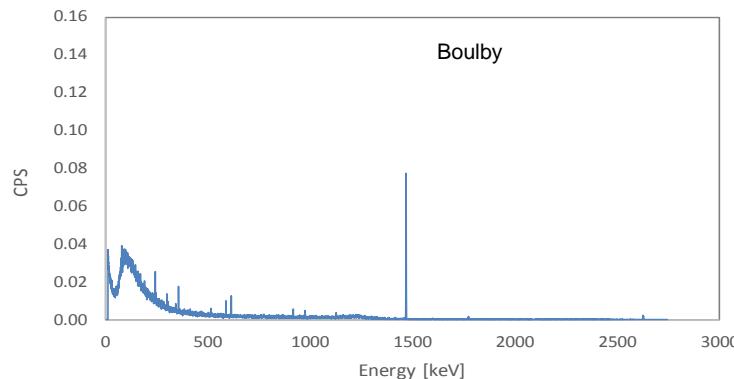
*Thank you for your attention...*

# Results – neutron interactions with germanium

Energy [keV]	Reaction mechanism	cps				
		AmBe	AmBe + H <sub>2</sub> O	PuBe	<sup>252</sup> Cf	ZG Polkowice-Sieroszowice
13.27	<sup>72</sup> Ge(n, $\gamma$ ) <sup>73m</sup> Ge	—	—	<b>1,014</b> ± 0,106	<b>1,497</b> ± 0,023	<b>0,0032</b> ± 0,0003
53.44	<sup>72</sup> Ge(n, $\gamma$ ) <sup>73m</sup> Ge	—	—	<b>0,490</b> ± 0,106	—	<b>0,0010</b> ± 0,0004
66.70	<sup>72</sup> Ge(n, $\gamma$ ) <sup>73m</sup> Ge(n,n')	—	—	—	<b>0,830</b> ± 0,090	—
77.86	<sup>74</sup> Ge(n, $\gamma$ ) <sup>75m</sup> Ge	—	—	<b>1,116</b> ± 0,053	<b>10,774</b> ± 0,040	<b>0,0073</b> ± 0,0005
139.68	<sup>74</sup> Ge(n, $\gamma$ ) <sup>75m</sup> Ge	—	—	<b>0,506</b> ± 0,093	<b>0,677</b> ± 0,065	—
174.90	<sup>70</sup> Ge(n, $\gamma$ ) <sup>71m</sup> Ge	—	—	—	<b>0,885</b> ± 0,057	—
198.90	<sup>70</sup> Ge(n, $\gamma$ ) <sup>71m</sup> Ge	—	—	—	<b>1,060</b> ± 0,005	—
311.30	<sup>73</sup> Ge(n, $\gamma$ ) <sup>74</sup> Ge	—	—	<b>0,297</b> ± 0,067	—	—
331.43	<sup>70</sup> Ge(n, $\gamma$ ) <sup>71</sup> Ge	—	—	<b>0,335</b> ± 0,034	<b>0,142</b> ± 0,037	—
499.87	<sup>70</sup> Ge(n, $\gamma$ ) <sup>71</sup> Ge	—	—	—	<b>0,054</b> ± 0,008	—
595.85	<sup>73</sup> Ge(n, $\gamma$ ) <sup>74</sup> Ge(n,n')	<b>0,050</b> ± 0,003	—	—	<b>0,129</b> ± 0,017	<b>0,0018</b> ± 0,0002
608.35	<sup>73</sup> Ge(n, $\gamma$ ) <sup>74</sup> Ge(n,n')	—	—	—	<b>0,079</b> ± 0,014	—
652.87	<sup>73</sup> Ge(n, $\gamma$ ) <sup>74</sup> Ge	<b>0,240</b> ± 0,007	—	—	—	—
689.60	<sup>72</sup> Ge(n,n') <sup>72</sup> Ge*	<b>0,198</b> ± 0,004	—	<b>0,062</b> ± 0,029	<b>0,232</b> ± 0,006	—
709.06	<sup>73</sup> Ge(n, $\gamma$ ) <sup>74</sup> Ge	<b>0,036</b> ± 0,005	—	—	<b>0,236</b> ± 0,006	—
721.56	<sup>73</sup> Ge(n, $\gamma$ ) <sup>74</sup> Ge	<b>1,203</b> ± 0,007	<b>0,030</b> ± 0,002	<b>0,091</b> ± 0,018	<b>1,265</b> ± 0,006	—
737.93	<sup>73</sup> Ge(n, $\gamma$ ) <sup>74</sup> Ge	<b>0,037</b> ± 0,005	—	—	<b>0,027</b> ± 0,005	—
867.90	<sup>73</sup> Ge(n, $\gamma$ ) <sup>74</sup> Ge	—	—	—	<b>0,077</b> ± 0,001	—
961.06	<sup>73</sup> Ge(n, $\gamma$ ) <sup>74</sup> Ge	—	—	—	<b>0,044</b> ± 0,005	—
1039.20	<sup>70</sup> Ge(n,n') <sup>70</sup> Ge*	—	—	—	<b>0,102</b> ± 0,005	—
1101.28	<sup>73</sup> Ge(n, $\gamma$ ) <sup>74</sup> Ge	—	—	—	<b>0,255</b> ± 0,005	—
1107.01	<sup>70</sup> Ge(n,2n) <sup>69</sup> Ge	—	—	—	<b>0,046</b> ± 0,005	—
1204.20	<sup>73</sup> Ge(n, $\gamma$ ) <sup>74</sup> Ge(n,n')	—	—	—	<b>0,241</b> ± 0,004	—
1215.37	<sup>70</sup> Ge(n,n') <sup>70</sup> Ge*	—	—	—	<b>0,011</b> ± 0,003	—

# Comparison with underground laboratories

## Results from ILIAS project

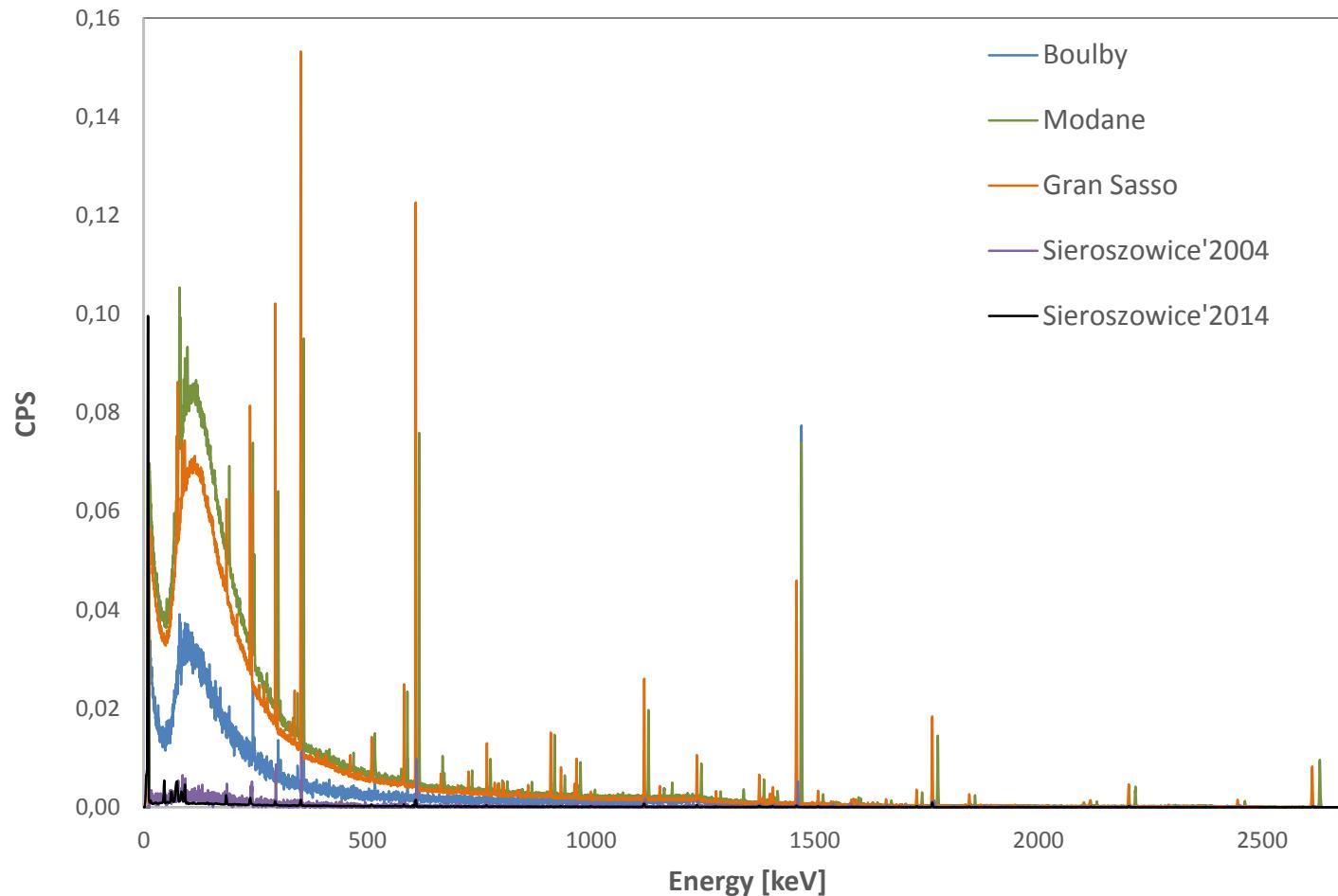


**Integral background counting rates 50 – 2700 keV  
[CPS/keV·kg]**

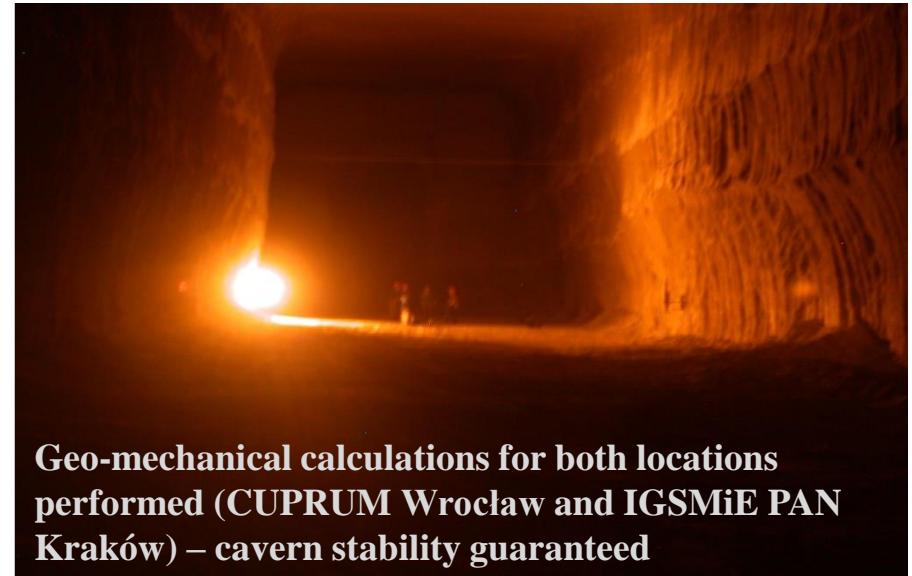
Modane	66.06 (0.03)
Gran Sasso	57.68 (0.02)
Boulby	23.83 (0.05)
Sieroszowice'2004	2.30 (0.02)
Sieroszowice'2014	6.32 / 1.11 (0.02)

# Comparison with underground laboratories

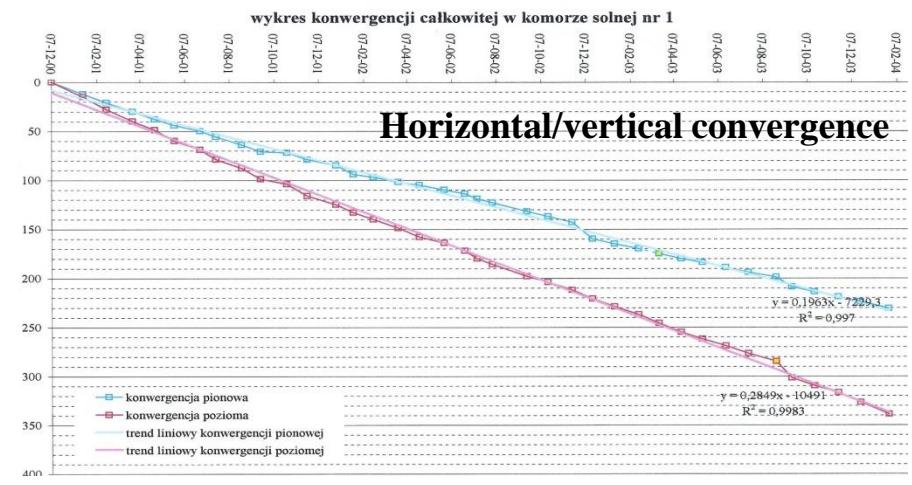
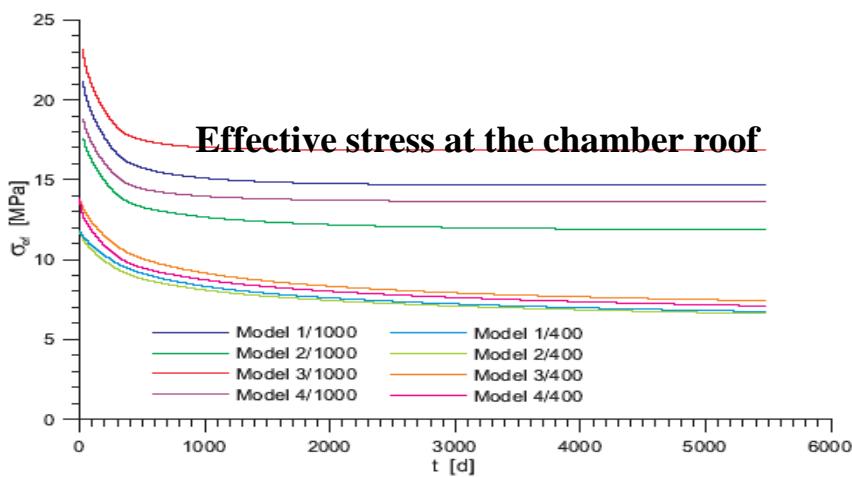
## Results from ILIAS project



# Salt cavern stability



Geo-mechanical calculations for both locations performed (CUPRUM Wrocław and IGSMiE PAN Kraków) – cavern stability guaranteed



**Salt caverns are stable: result of continuous measurements of cavern wall movements and simulations**