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**INFLUENCE OF LARGE COAL WASTE  
DISPOSAL ON THE GROUND WATER QUALITY  
AND CONTROL METHODS**

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**ABSTRACT**

The importance of groundwater protection requires very careful planning of wastes disposal practices, also coal refuse disposal. The laboratory glass columns study and two field demonstration projects enabled to estimate which pollutants could be leached from the coal wastes and the rate of leaching. This makes possible a qualitative and quantitative forecast of hazard produced by coal refuse to the adjacent aquifer. The migration of pollutants within the aquifer has been studied and some spatial and time relations found. These findings enabled to recommend the methodology of wastes examination, sites classification, storage procedures improvement and monitoring.

**INTRODUCTION**

The renaissance of coal prosperity effected by energy - oil crisis in the beginning of 70-ties caused also the increase of coal refuse disposals problem. This situation concurred with much more attention paid in many countries to the environmental protection, in this to groundwater protection against pollution. The connection of these two issues stimulated the necessity of the research programme which goal was to identify the problem and to find what is the extent of hazard and to recommend the control activities, if needed.

The coal waste storage question occurred in the same time in the USA and in Poland, so this research project has been undertaken as a common venture of United States Environmental Protection Agency and Polish Central Research and Design Institute for Open Pit Mining POLTEGOR. The research, divided into some phases lasted from 1974 to 1979 and was concluded in two large reports published in Poland and in USA.

The whole research consisted of laboratory glass columns leaching study, field study—conducted first on small /1600 m<sup>3</sup>/ disposal and then on large /2 mill m<sup>3</sup>/ coal waste disposal. Supplementary research has been executed to investigate - on simulating pollutants migration models - those phenomena which could not be identified during field study.

#### THE LABORATORY GLASS COLUMNS LEACHING STUDY

In order to determine the qualitative character of the waste material, with respect to its leachability and pollution potential, samples of the disposed wastes were taken every 4 to 6 months. The samples came from recently disposed wastes and represented the material disposed at that time. About 10 kg of wastes was delivered to the laboratory for leaching tests.

The wastes were placed in glass columns, 100 cm high and with a diameter of 12 cm, equipped with valves which regulated the rate of water flow through the waste. The waste was placed in the column on a layer of sand taken from the disposal floor. The ratio of waste thickness to the sand's thickness was about 4:1. The material was washed using a peristaltic pump with distilled water in a closed cycle.

Three successive leachings were performed until 5 dm<sup>3</sup> of water had been used. Each of them lasted 24 hours. The leaching rate of the first test was 1 dm<sup>3</sup>/hr. and the others were 0.5 dm<sup>3</sup>/hr. A total of 11 samples /two or three a year/ were taken. Each was leached three times /as told above/ and the leachates were analysed to determine pollution potential of the refuse. Summary of the results of these analyses are presented in the Table No. 1. The content of leachable pollutants in the samples varied considerably, but the variations were within acceptable limits.

The refuse contained large amounts of coal sludge and therefore large amounts of colloid sediments were found in the leachate. The sediment at first caused gradual and then complete sealing of the underlying sand layer in the glass column. This phenomenon hindered the leaching tests but may be very important at an actual disposal site. Dusts and colloids leached out of the refuse could seal up the disposal site bottom and prevent pollutants from leaching into the groundwater.

After 72 hours dynamic contact with coal refuse the clean /distilled/ water changed into very polluted leachates which are much below the drinking water quality standards. In the nature, never or almost never the conditions of leaching would be so favorable to leach the pollutants from the disposal. However the figures give us an idea

what could be the range of pollution of leachates leaving the disposal, and entering and mixing with groundwater in the adjacent aquifer /Table 1./.

The same study enabled to calculate the quantitative potential of coal refuse in terms of mass of particular pollutant, which could be leached from-per weight unit of wastes. From one kg of wastes could be leached in average: TDS - 320 mg, Cl - 41,8 mg, SO<sub>4</sub> - 32,9 mg, Na - 48,74 mg, K - 5,26 mg, Ca - 15,18 mg, Mg - 1,46 mg, Mn - 0,146 mg, Fe - 4,93 mg, NH<sub>4</sub> - 0,347 mg, PO<sub>4</sub> - 0,104 mg, CN - 0,005 mg, Phenols - 0,0056 mg, Al - 2,34 mg, Zn - 0,177 mg, Cu - 0,0345 mg, Pb - 0,0391 mg, Cr - 0,0073 mg, As - 0,0016 mg, Sr - 0,081 mg, Hg - 1,03 mg, Cd - 0,005 mg, Mo - 0,003 mg and B - 0,171 mg.

#### Concentration of Pollutants in Glass Columns Leachates /Table 1/

The figures of this table could be used for the forecasts of amounts of leachable pollutants contained in the stored coal wastes. However, these coefficients cannot be used as universal for detail predictions. Each coal refuse is different but the values found under that research may be used for preliminary studies.

### THE FIELD STUDY

The field study was conducted in two phases.

#### Small Scale Study

In the first phase the disposal of coal waste /70 %/ mixed with bottom ash from coal fired power plant /30 %/ of the total volume of 1600 m<sup>3</sup> was constructed at the bottom of old sand pit. Groundwater table, in saturated 2 m thick sands, was just below the disposal bottom. The disposed wastes were leached by the precipitational /rain/ water. The rate of precipitation was measured by the near gaging station. The climate of the area was a moderate one, the annual rate of precipitation about 600-700 mm. Around and within the disposal 12 monitoring wells were drilled. These wells have been sampled every three weeks during 15 months period, and every six weeks during next 15 months period. The samples were discharged to the chemical laboratory where they have been analyzed for 19 designations each series of samples and for 42 designations /including heavy metals/ every third series of samples. The reference sample of clean groundwater taken upstream of groundwater flow /comparing with the disposal location/ was simultaneously taken for comparison.

First significant pollution of groundwater was found about 6 months after storage and lasted about 2 1/2 year, then decreased. The concentration of particular components in

polluted groundwater to compare with the clean groundwater was three to fourty times. The most significant was in terms of TDS, Cl, SO<sub>4</sub>, Mo, B, Cu, Sr.

Within approximately 3 years about 11.000 kg of TDS was leached from 1.600 m<sup>3</sup> of coal refuse and ashes to the aquifer, which means 0.7 percent of the disposal mass and about 70 percent of potentially leachable substances.

It was also found that the pollutants migrate within the aquifer almost only toward the most steep groundwater flow dipping and only very small and insignificant dispersional migration occurred.

#### Full scale study

The second phase of research have been conducted on the full size disposal on which the beginning of coal refuse storage was being planned for the year 1975. The site was an old abandoned sand pit comprised of three separate pits connected to one another near their southern end. Two of these pits /Central and Western/ were used for waste disposal.

The Central pit, where wastes were disposed first was about 500 m long and 170 m wide, and had an average depth of 16.5 m. The pit bottom and slopes were sand sometimes containing clay and silt. The thickness of sand layer in the northern part of the disposal area has about 7.5 m and in the southern part it increased to about 9 m, but in some places decreased to zero. The groundwater table was from 0 to 2 m below the pit bottom.

The Western pit planned as a reserve disposal area, was about 580 m long, about 150 m wide and had an average depth of about 7 m. Its bottom and slopes were sand sometimes containing clay and silt. The thickness of the sand layer in the pit varied from about 1 m at its eastern end to about 6 m in its western end. The groundwater table was from 0.5 to 3 m below the pit bottom.

The both pits are within a quaternary aquifer. The thickness of the aquifer is 3 to 20 m. The permeability coefficient is 1 to 33 m per 24 hours, mostly 3 to 12 m per 24 hours. The corresponding specific yield are 0.11 to 0.15. The absolute values of the position of groundwater table are within a range of 270 m in southern area to 250 m above sea level in northern area. Velocities of the flow of groundwater in the aquifer /computed on the basis of heads distribution and permeability/ varies within 0.15 to 3 meters per day.

The average precipitation for the area during the years 1974-79 was 788 mm per year and varied from 633.0 mm to 68

958.6 mm. The highest monthly precipitation was 156.5 mm and the lowest 3.6 mm. The maximum daily precipitation was 62.5 mm. The coefficient of infiltration was estimated being 0.4 to 0.7.

Continuous disposal of coal wastes from the adjacent bituminous coal mine began in January 1975. Approximately 30,000 to 45,000 m<sup>3</sup> of wastes were disposed monthly. From the total 2 mill. m<sup>3</sup> of wastes 1.5 mill. m<sup>3</sup> was disposed in the central pit and 0.5 mill. m<sup>3</sup> in western one. Between 1975 and 1977 the surface area of waste disposal gradually increased from 30,000 to 100,000 m<sup>2</sup> and was fully exposed for rain fall infiltration; since 1978 the current compaction and clay cover reclamation was introduced, which reduced the directly exposed area from 100,000 to 75,000 m<sup>2</sup>.

In March 1974 14 monitoring wells were installed to monitor the aquifer surrounding the disposal. The wells were bored in 5 radial sections radiating from the Central Pit toward North, North-East, East, South and West, at distances 50 to 150 m from the pit edge /the closest wells/ 250 to 300 m the next ones, and 500 to 700 m the farrest wells.

Water samples for physico-chemical analysis were taken from the wells from 1974 until the end of 1979. Prior to the water sampling the groundwater table in each well was measured within  $\pm 2$  cm accuracy. Then a volume of water equal to that in the wells was removed. After the well had again filled with fresh groundwater, it was sampled. This procedure was applied to prevent from sampling water which had been in the well for a long period of time, in contact with air and pipe. The small volume of water removed from each well was found as the most proper to prevent the disruption of the natural hydrodynamic system which may happen if large volume were removed.

The measuring and sampling operations were performed on a regular 3 week interval. First 20 months every fourth sample was taken for full analysis /42 designations/ while all others were taken for sample analysis /14 designations/. In next period every third sample was taken for full analysis. A total of 85 sets of water samples were taken for analysis during the whole research of which 26 had full analysis.

It can be concluded that both wells locations and the system of measurement and sampling proved useful and enabled the assessment of the tested phenomena.

The samples of water were discharged to the laboratory for physico-chemical analysis which were performed according to ASTM standards.

The results of the above investigations showed that the northern part of the aquifer, i.e. this being toward groundwater downstream from the disposal has been considerably polluted. However, the pollution was not equal in all wells located in that part of aquifer; the differences between particular wells are quite big. Some of these differences could be explained by the different permeability of the aquifer and some of them are difficult to be explained.

The average and the maximum pollution of the aquifer compared with the groundwater quality of the same aquifer before storage is shown in the Table No. 2.

The most important indicator of the total pollution is Total Dissolved Solids /TDS/ content. It could be found that the disposal effected increase of TDS content in the polluted part of the aquifer in average two times and in maximum more than three times. Other important polluting components were Cl /2.7 and 4 times respectively/ SO<sub>4</sub> /2.2 and 3.9/, PO<sub>4</sub> /1.7 and 3.8/ Pb, As, Sr, Sc and <sup>4</sup>B.

The first indication of groundwater pollution occurred in the form of singular waves of pollutants in particular wells 12 to 18 months after disposal operations had begun. However, these developments were difficult to monitor. Continuous pollution began two years after the commencement of storage operations.

The duration of heavy pollution was 2<sup>1</sup>/<sub>2</sub> years, then it decreased. This phenomenon could be explained as a result of two factors:

- the surface area of the disposal site exposed to rain infiltration was reduced by reclamation of about 30 to 40 percent of the surface; the reclamation was made by grading, compaction and clay cover;

- the bottom of the disposal site was self sealed when the silty wastes were washed from the disposal body and settled on the bottom of the pit.

This proves that if disposal is located above groundwater table and is leached only by rain water its polluting influence on the underlying aquifer could be significantly reduced by careful reclamation.

For the planning storage operations very important question is the possibility of prediction the extent of aquifer pollution on the base of laboratory leaching studies in glass columns.

Our experiences and calculations showed that for moderate climate, similar type of coal refuse and average hydrogeological conditions the following coefficients could be used in order to obtain average /first figure/ and maximum

/second figure/ concentration of pollutants in the aquifer comparing with glass columns leachates: TDS - 0.20 to 0.40; Cl - 0.20 to 0.35; SO<sub>4</sub> - 0.72 to 1.28; Na - 0.14 to 0.34; K - 0.21 to 0.43; Ca - 0.45 to 0.71; Fe - 0.15 to 0.35; PO<sub>4</sub> - 0.047 to 0.10; CM - 0.23 to 0.68; Phenols - 0.13 to 0.23; Al - 0.02 to 0.038; Zn - 0.19 to 0.56; Cu - 0.16 to 0.5; Pb - 0.13 to 0.24; Cr - 0.15 to 0.21; As - 0.47 to 0.98; Sr - 0.36 to 0.53; Hg - 0.12 to 0.25; Cd - 0.15 to 0.24; Mo - 0.49 to 1.41 and B - 0.08 to 0.11.

The above coefficients of course cannot be used as a universe directly to predict each disposal influence. However, they give an idea about the range of expected pollution.

### THE MODELLING SIMULATION

To describe the phenomena which could not be identified within the field investigation the three series of model simulating tests have been executed.

The ground models, Hele - Shaw type model and EHDA models were applied. Many alternatives were tested and the results of testing could be concluded in following statements:

- 1 - for 2 percent weight by volume difference from the wastes leachates to the pure groundwater /all the leachates from coal refuse showed that difference below 0,5 percent/ gravitational mixing did not cause vertical migration of pollutants under-neath disposal;
- 2 - the pollutants dropping to the aquifer from the disposal sited above groundwater table migrate within the aquifer near the groundwater table;
- 3 - when the disposal is immersed within the aquifer the pollutants migrate closer to the groundwater table when the permeability of disposal is smaller than that one of aquifer;
- 4 - local increases and decreases of aquifer thickness along the polluted stream cause respective increase and decrease of polluted stream thickness.

### CONCLUSIONS

1. The storage of coal wastes in the openpits of permeable bottom and/or slopes causes significant pollution of adjacent aquifer.
2. The degree of pollution, the polluted area can be predicted on the base of preceding laboratory leaching tests and on the base of hydrogeological site examination with quite satisfying accuracy.

3. The hazard of pollution in the case of disposals located above groundwater table could be significantly decreased by shaping, compaction and clay cover of the disposal surface; this could significantly reduce the infiltration rate.

4. The pollution monitoring system could be adjusted to the local hydrogeological conditions, the degree of required groundwater protection and to the construction of the disposal itself.

5. All details and recommendations could be found in the reports mentioned in the references.

#### References

- 1 Libicki, J.S. - Effects of the Disposal of Coal Waste and Ashes in Open Pits - EPA - 600/7 - 78 - 067 /USA/ and Poltegor /Poland/, /1978/
- 2 Libicki, J.S. - Impact of Coal Refuse Disposal and Groundwater - US EPA, Cincinnati, Ohio 45268 and Poltegor, Wroclaw, Poland. /1981/

Table 1.

Designation	Maximum mg/dm <sup>3</sup>	Minimum mg/dm <sup>3</sup>	Average mg/dm <sup>3</sup>
pH	9.9	7.3	8.4
Conductivity /us/cm/	2140	500	1500
TDS	3372	548	1600
Cl	479	51	209.2
SO <sub>4</sub>	230	50	164.6
Na	357	44.5	243.7
K	48	4.1	26.3
Ca	355.9	5.2	75.9
Mg	21.85	0.42	7.3
Mn	2.995	0.035	0.729
Fe	75.8	0.11	24.65
N/NH <sub>4</sub> /	4.46	0.32	1.733
PO <sub>4</sub>	3.140	0.036	0.522
CN	0.066	0.003	0.0252
Phenols	0.088	0.008	0.0282
Al	38.5	0.175	11.71
Zn	3.085	0.360	0.883
Cu	0.925	0.019	0.1974
Pb	0.271	0.034	0.1956
Cr	0.089	0.011	0.0364
As	0.133	0.008	0.0581
Sr	2.050	0.037	0.406
Hg	10.9	0.6	5.17
Cd	0.056	0.005	0.024
Mo	0.029	0.003	0.017
B	3.600	0.095	0.855

Table 2.

Designation	Average concentration before disposal influence	Average concentration during disposal influence	Maximum concentration during disposal influence
pH	6.66	6.25	6.88
Conductivity /us/cm/	247.1	460.72	801.0
TDS	169.2	329.13	550.07
Cl	15.08	40.84	72.73
SO <sub>4</sub>	54.1	117.98	209.89
Na	7.84	33.50	81.99
K	2.77	5.51	11.31
Ca	16.26.	34.11	53.60
Mg	4.95	10.23	17.39
Mn	0.24	0.266	0.79
Fe total	4.60	3.7433	8.75
NNH <sub>4</sub>	0.43	1.22	2.47
PO <sub>4</sub>	0.014	0.0244	0.053
CN	0.0049	0.0059	0.0172
Phenols	0.0034	0.0036	0.0066
Al	0.16	0.181	0.444
Zn	0.360	0.1672	0.497
Cu	0.023	0.0102	0.0313
Pb	0.0165	0.0246	0.047
Cr	0.0064	0.0056	0.0075
As	0.0168	0.0274	0.057
Sr	0.130	0.1472	0.216
Mg	0.630	0.6294	1.300
Cd	0.0024	0.0037	0.0058
Mg	0.0148	0.0083	0.024
B	0.032	0.0685	0.095

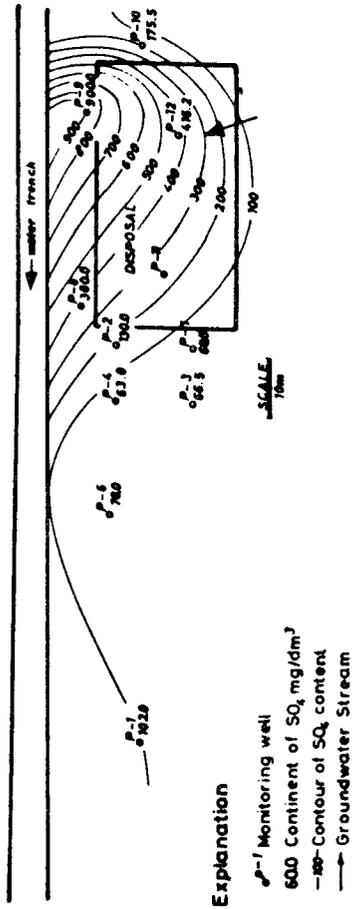
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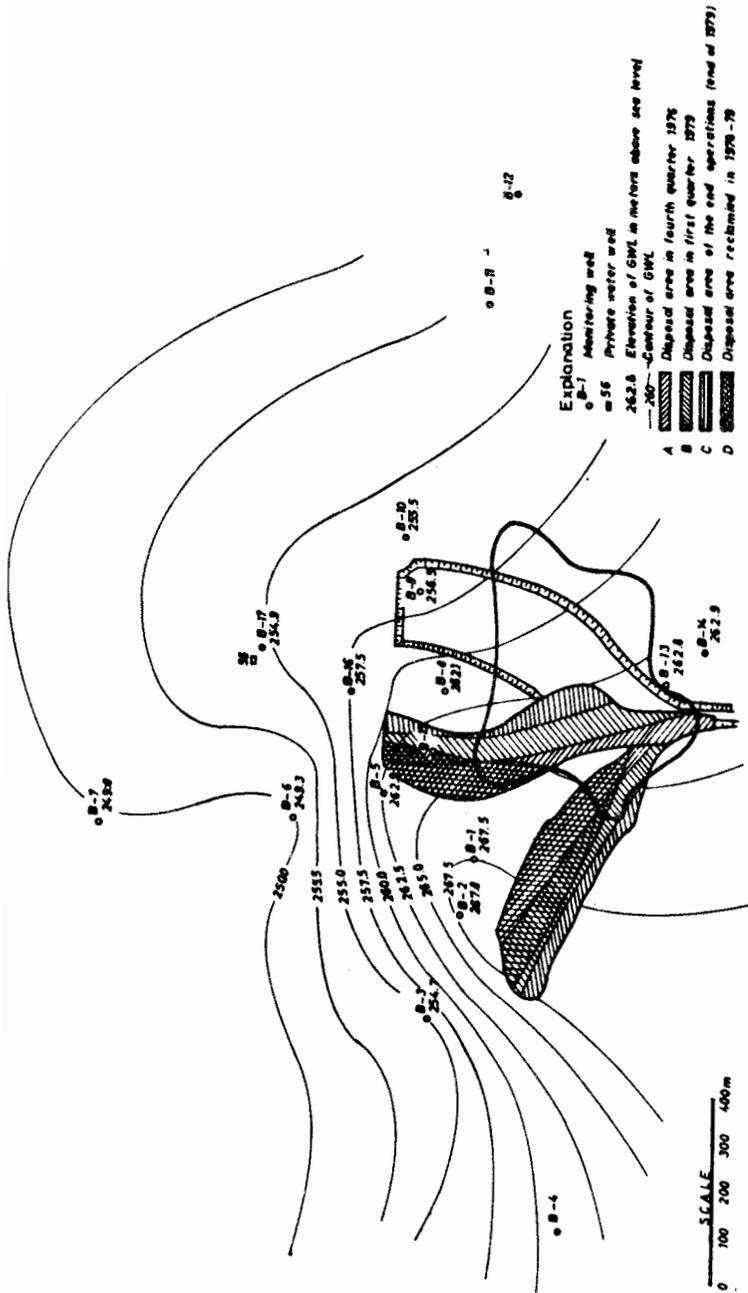
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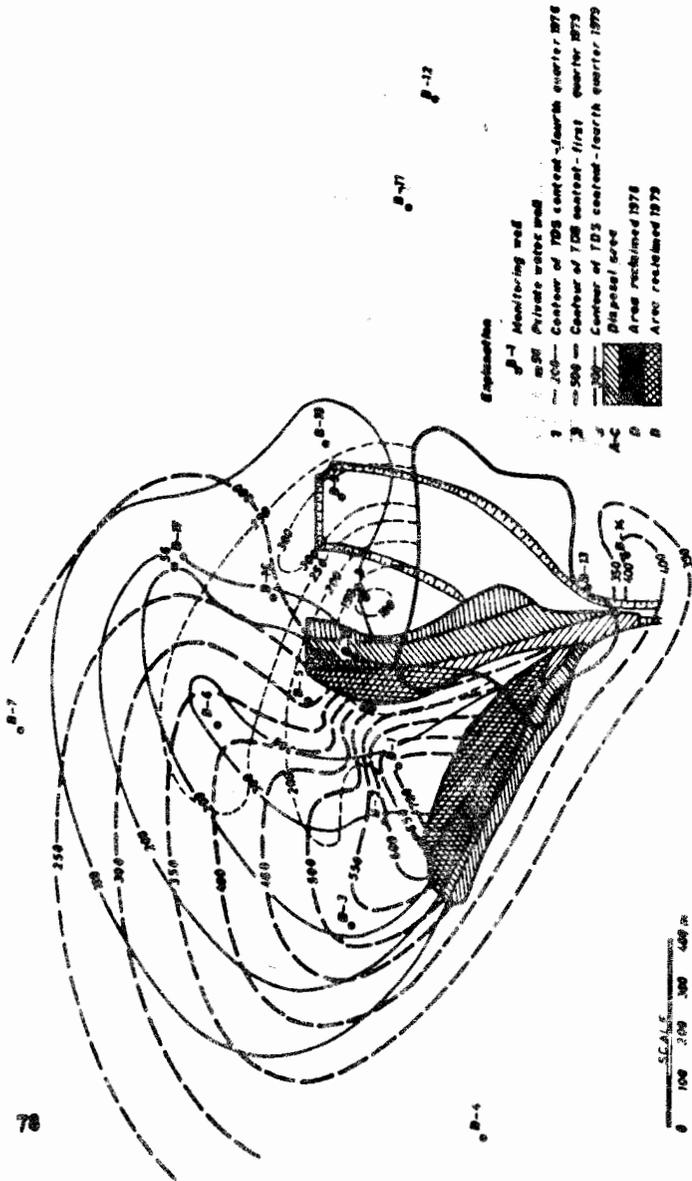
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SMALL SCALE STUDY - THE CONTOUR MAP OF  $\text{SO}_4^{2-}$  ION  
 CONTENT AUG. 13. 1976 / 20 months after storage /  
 FIG.1



FULL SCALE STUDY— THE CONTOUR MAP OF GROUND-WATER TABLE IN 1979  
FIG.2



FULL SCALE STUDY - THE CONTOUR MAP OF CONTENT IN 1979  
FIG. 3

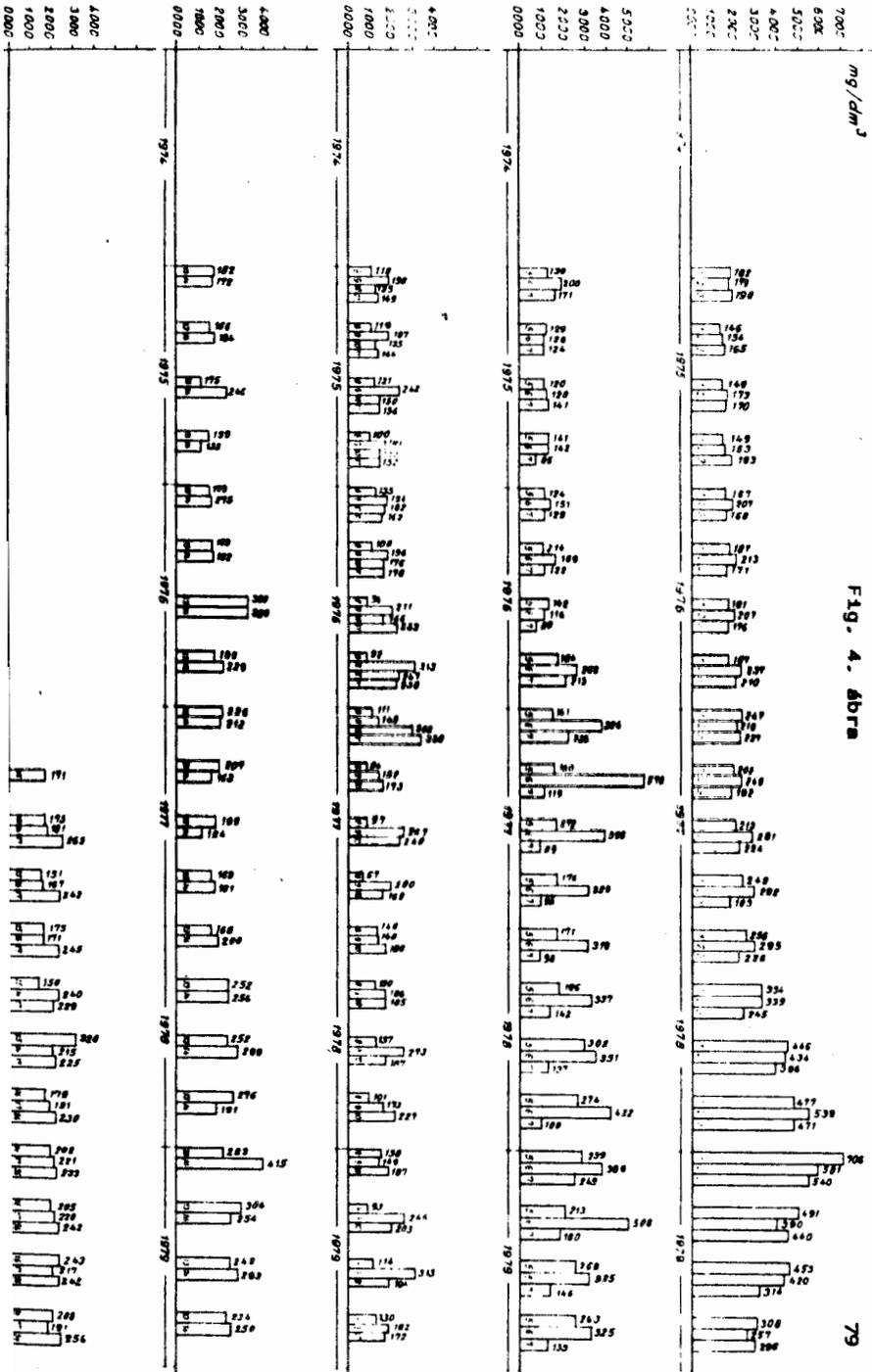


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