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# Air pollution measurements in a semi-arid zone, using neutron activation analysis[1]

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ABSTRACT

Neutron activation analysis was used for measurement of air pollution in a semi-arid zone. After a careful selection of the air filter, air samples were filtered in the city of Beer-Sheva in the south of Israel.

The sampling took place over a period of 2 months with each sampling period lasting 2 days. The samples were irradiated in a thermal neutron flux of the order of $10^{13}$ n/cm$^2$ sec for 1 h and the gamma spectrum was measured several times. The concentration of elements was concluded from the measured gamma spectrum. Several conclusions were obtained by combining the weather conditions with the measurement results.

The air pollution can be divided into several sources: dust of a certain origin containing Fe, Co, Cr, Sc, Th and Na (probably from the Dead Sea area), other dust sources containing Sb, Eu, and Hf, and urban pollution due to industry and transportation—Br, Hg. The air pollution has its maxima and minima according to weather or industrial conditions. The pollution requires 4 days to clear out. Other relations to weather conditions were also found.

## 1. Introduction

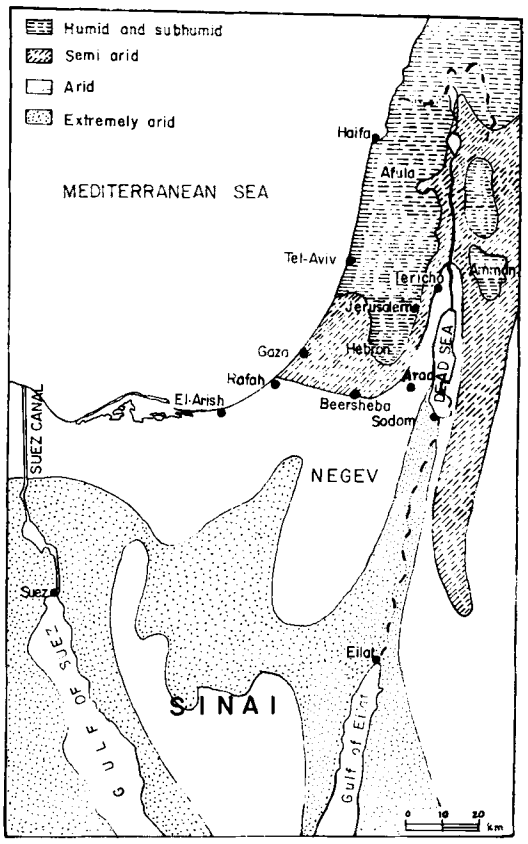
Neutron activation analysis has become a widely used technique for detection of trace elements. The use of the technique for air pollution research has been demonstrated in a number of publications, a few of them are: Parkinson & Grant (1963), Duce & Winchester (1965), Winchester (1965), Zoller & Gordon (1970), Dams et al. (1970), Gray et al. (1972), Tuttle et al. (1971), Shani et al. (1973), Shani & Haccoun (1976), Van der Sloot & Luten (1976), Jervis et al. (1976), De-Regge et al. (1976) and many others. In the present work, neutron activation analysis was used for detection of air pollution in a city on the border of the desert where, in addition to urban pollution, there are dust storms over the area from time to time. The area is considered a semi-arid zone and the air is very seldom cleared by rain. A map of the area is shown in Fig. 1.

Among the urban pollutants, Br is the easiest to detect with neutron activation analysis. Its concentration in the air is high due to the proximity of a bromine products plant. Other urban pollutants, although troublesome, are more difficult to detect with neutron activation analysis because they consist mainly of H, O, C and Cl. In this sense the method is not perfect.

A similar problem exists in dust detection. Certain trace elements are much easier to detect than the major elements in the dust which is composed of $CaCO_3$, $CaO$, $SiO_2$, $Al_2O_3$, etc. These elements are difficult to detect with neutron activation analysis unless special measures are taken. In the present work, the results show only the trace elements in the dust.

The measurements lasted about 2 months and the dependence of the pollution on weather condition was investigated. The pollutants can be divided into groups according to this dependence, and are probably due to dust of a definite origin (in addition to the urban pollution).

[1] The work was partially supported by the National Council for Research and Development.




## 2. Theoretical aspects

The theory of neutron activation analysis is well known and a thorough discussion of the theory is not needed. Only a few aspects, where particular measures were taken in the present work, will be mentioned. When $N_A$ atoms of a substance $A$ are irradiated with neutron flux, $\phi$, the activity after $T$ seconds is given by

$$A_c = N_A \sigma_a \phi (1 - e^{-\lambda T})$$

where $\sigma_a$ is the activation crosssection and $\lambda$ is the decay constant of the product. At any given moment $t$ after the end of irradiation, the activity is given by

$$A_c(t) = A_c(0) e^{-\lambda t}$$

The activity of the irradiated sample is measured for a certain length of time, hence the last equation must be integrated over that period.

There is one major problem in this method of determination of the quantity of a certain element, namely the energy dependence of the flux and the crosssection. The crosssection of the reaction used for the activation $(n, \gamma)$, in the low energy region is generally given by $\sigma = \sigma_0 v_0 / v$ where $\sigma_0$ and $v_0$ are the thermal crosssection and velocity respectively, and $v$ is the actual neutron velocity. Above the $1/v$ region there are resonances in the crosssection. For most elements, the $1/v$ region continues up to a few eV or more.

The flux in the thermal region has a Maxwellian distribution. Above the thermal region the flux is of the form $\phi(E) = \phi_0 E_0 / E$. The reaction rate which is given by $N \cdot \sigma \cdot \phi$ is actually the integral

$$N \int \sigma(E) \phi(E)\, dE = N \sqrt{\frac{m}{2}} \int \frac{\sigma_0}{\sqrt{E}} \frac{\phi_0 E_0}{E} dE$$

In the present work, a numerical integration was carried out between the limits of thermal and a few eV, where the reaction rate drops by a few orders of magnitude. This integration took care of the epithermal contribution to the activation.

In addition to time and energy considerations, the detector's efficiency (including geometry and energy dependence), isotope abundance and gamma branching ratio must be taken into consideration.

The number of atoms of each pollutant absorbed on the filter is found by its specific activity, its weight is then calculated from the measured activity. The final expression is the following:

$$W = \frac{N_c \lambda A}{N_a \cdot a \cdot \eta \cdot R \sigma_0 \phi_0 E_0^{3/2} \left(\frac{m}{2}\right)^{1/2} (1 - \exp(-\lambda t_1)) \times \exp(-\lambda t_2)(1 - \exp(-\lambda t_3)) \int_{E_0}^{E} \frac{dE}{E^{3/2}}} \qquad (1)$$

where:

$t_1$ = the irradiation time
$t_2$ = time elapsed from end of irradiation to beginning of counting
$t_3$ = time elapsed from end of irradiation to end of counting
$N_c$ = total number of counts of specific gamma ray emitted by the particular isotope, obtained during $t_3 - t_2$
$\lambda$ = decay constant of the measured isotope
$A$ = mass number of the measured isotope

$N_a$ = Avogadro's number
$a$ = percentage abundance of the measured isotope
$\eta$ = detector efficiency (energetic and geometrical)
$R$ = branching ratio
$\sigma_0$ = neutron absorption crosssection at $E_0$
$\phi_0$ = neutron flux at energy $E_0$
$E_0$ = reference neutron energy (thermal)
$E$ = neutron energy

## 3. Experimental technique

Air was sampled with type TF1A-2 Staplex air samplers on 11-cm diameter Whatwan 41 filters. Each sampling lasted 48 h with the sampler alternately on for half an hour and off for half an hour. The air flow through the sampler with the filter was 233 ± 6 litre/min.

When dust was collected on the filter, the air flow was reduced by 10% at most. The total air volume sampled in each case was 355 ± 8 $m^3$. Nineteen samples were taken between 4 April 1974 and 21 May 1974. The air sampler was located on the roof of a building at Ben-Gurion University, on the edge of the city near the industrial zone, and exposed to wind and dust coming from the desert.

The samples were then irradiated in the core of a pool-type reactor with flux of the order of $10^{13}$ n/$cm^2$ sec (thermal). In each irradiation of the filters, a small Au foil was also irradiated for flux measurement. The irradiation time was 1 h, and after a short cooling time the irradiated samples were taken for gamma spectroscopy. The measurements of the gamma spectrum were repeated several times until no new elements were discovered. Table 1 shows the time of measurement and the element discovered. The irradiation time—1 h—was selected so that there would be enough activity to see elements of very low concentration but, on the other hand, the irradiation samples would not be too active for handling.

The disadvantage of such an irradiation policy is that for the first few days the whole spectrum is covered by $Na^{24}$ and $Br^{82}$ spectra and short-life isotopes cannot be measured.

The gamma spectrum was measured with a 45 cc Ge(Li) detector and a 1024 channel analyser. The detector's energy dependence was measured with 1 μCi $Ra^{226}$ source whose spectra spans over the range up to 2.4 MeV. The geometrical efficiency was measured along with the flux measurement by the activated gold foil added to each group of filters. The Au foil activity was calculated with numerical integration as described above.

Table 1. *Time of measurement and element discovered*

| Meas. No. | Time after end of irradiation | Isotopes discovered | Half life |
|---|---|---|---|
| 1 | Two days | — | — |
| 2 | One week | $Na^{24}$ | 15 h |
| | | $Br^{82}$ | 35 h |
| 3 | Two weeks | | |
| 4 | Three weeks | Many isotopes seen but not accurate | |
| 5 | Five weeks | $Sc^{46}$ | 83.8 d |
| | | $Sb^{124}$ | 60 d |
| | | $Fe^{59}$ | 44.6 d |
| | | $Cr^{51}$ | 27.7 d |
| | | $Co^{60}$ | 5.22 y |
| | | $Hf^{181}$ | 42.4 d |
| | | $Hg^{203}$ | 46.6 d |
| | | $Se^{75}$ | 120 d |
| | | $Pa^{233}$ | 27 d |
| | | $Eu^{152}$ | 13 y |
| | | $Co^{58}$ | 71.3 d |
| | | $Cs^{134}$ | 2.06 y |
| | | $Ba^{133}$ | 10.4 y |
| | | $Mn^{54}$ | 312.5 d |
| | | $Tb^{160}$ | 72.3 d |
| 6 | Seven months | $Zn^{65}$ | 245 d |
| | | $Ag^{110}$ | 252 d |

The use of Au foil for flux calibration requires a much more accurate calibration of the counting system than adding a standard of each measured element. The integration over energy took care of the activation by epithermal neutrons. The accuracy of the absolute measurement was achieved by having an accurate geometric and energetic calibrated counting system.

The accuracy of the activity measurement was about ±5% which is the accuracy of the results reported later. The detection limit was set by the peak to background ratio and the statistical error. We requested that the peak height is at least twice as high as the background and that the statistical error of the integrated area does not exceed 10%.

A suitable filter was selected by activation of

many types of filters and careful study of their gamma spectrum. The activation was done with thermal neutrons and with 14 MeV neutrons. It was found that the best filter for air pollution research with neutron activation analysis is Whatman 41 (cf. Dams et al., 1972). The average content of elements in this type is

Br, 0.25 $\mu$g
Sc, $6.5 \times 10^{-4}$ $\mu$g
Sb, $4 \times 10^{-3}$ $\mu$g
Cr 0.135 $\mu$g
Na 50 $\mu$g
Hg $4 \times 10^{-2}$ $\mu$g

## 4. Results

### *4.1 Introduction*

The concentration of 11 elements in the air during the measured period is shown in Figs. 2–12. The concentration of five more is shown in Table 2. Two more elements, Ni and Tb, were found but their concentrations were not calculated. The quantities of elements in the air vary between tens of $\mu g/m^3$ (Fe) to fractions of $ng/m^3$ (Eu). Other elements (in addition to Fe) of high concentration are: Co, which is part of the dust, and Br, which is released by a bromine products plant in the neighbourhood. Na and Cr are in quantities of hundreds of $ng/m^3$. Na is part of the dust, probably coming from the Dead Sea. The origin of Cr is not known but its variation during the measured period is that of the dust, as explained below. Sb concentration is up to 50 $ng/m^3$ and the rest of the elements are of order of 10 $ng/m^3$ or less.

The time dependence of the concentration of six of the elements is similar to each other. These are Fe, Co, Cr, Sc, Na and Th, elements which might form a group of the same probable origin. The other elements which are plotted in Figs. 8–12 have different concentrations during the test periods. As mentioned, Br is known to be emitted by a bromine products plant and, according to long-time inspection, its concentration in the air depends mainly on the plant working schedule and Br release.

### *4.2 Weather dependence*

The weather conditions in the tested period are given in Tables 3–6.[1] Tables 3 and 4 give the wind direction and velocity in April and May 1974 and Tables 5 and 6 give other weather conditions.

There is a strong dependence of the air pollution concentration on weather conditions, as shown below.

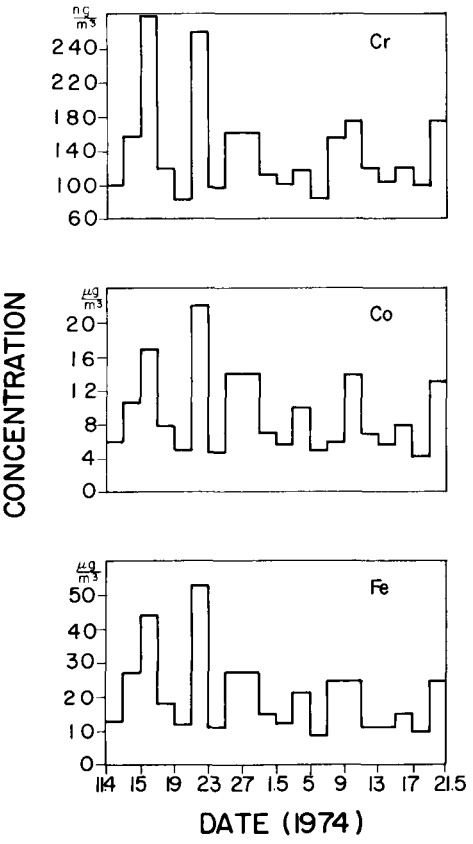



*Fig. 2.* Concentration of Fe.
*Fig. 3.* Concentration of Co.
*Fig. 4.* Concentration of Cr.

*World Meteorological Organisation, Weather Reports, WMO No. 9 TP4*

WW—Present Weather, Code 4677

01—Clouds generally dissolving or becoming less developed
02—State of sky on the whole unchanged
03—Clouds generally forming or developing
05—Haze
06—Windspread dust in suspension in the air, not raised by wind at or near the station at the time of observation
08—Well-developed dust whirl(s) or sand whirl(s) seen at or near the station during the preceding hour or the time of observation, but no dust storm or sand storm

[1] 'Weather condition information obtained from the Israeli Meteorological Service.

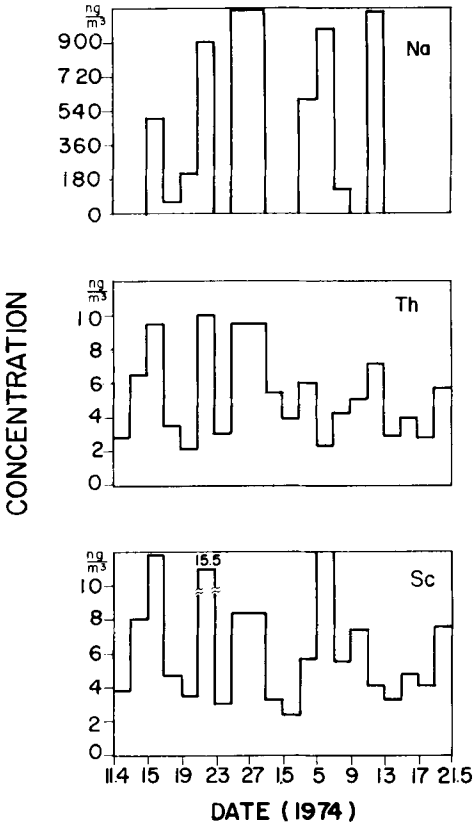



*Fig. 5.* Concentration of Sc.
*Fig. 6.* Concentration of Th.
*Fig. 7.* Concentration of Na.

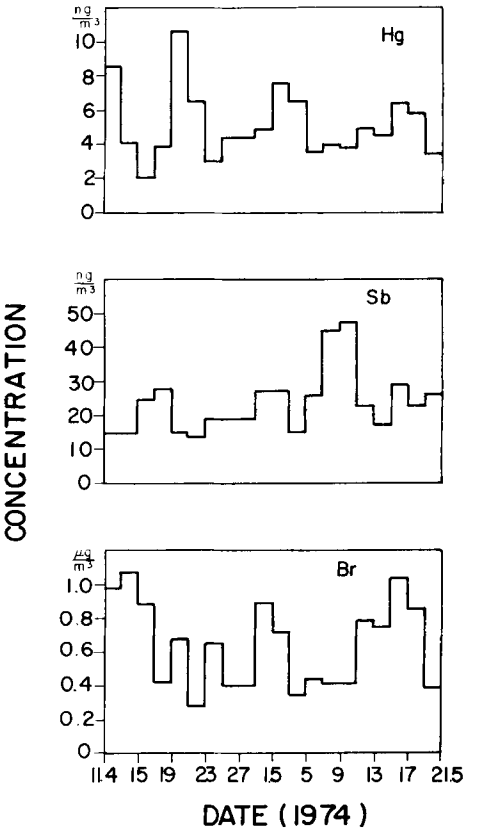



*Fig. 8.* Concentration of Br.
*Fig. 9.* Concentration of Sb.
*Fig. 10.* Concentration of Hg.

10—Mist
25—Showers of rain
32—Slight or moderate dust storm or sand storm
40—Fog at a distance at the time of observation
42—Fog (sky visible), become thinner during preceding hour
44—Fog (sky visible), no appreciable change during the preceding hour
46—Fog (sky visible) has begun to thicken during the preceding hour
47—Fog, sky invisible
63—Rain continues, moderate at time of observation
80—Rain shower(s), slight
81—Rain shower(s), moderate or heavy
95—Thunderstorm, slight or moderate with rain

The wind after midnight generally blows from the east and changes to be from the west between 8 and 11 a.m. In the evening and later at night the wind blows from northwest. This is the general trend, but there are some exceptions when the wind blows from the west, even after midnight.

Other weather conditions seem to be of greater importance than the wind. On some days, dust storms or haze cover the area. On these days the concentration of some elements increases a great deal, such as on 15, 21 and 26 April and 6, 11 and 19 May 1974, when the dust content in the air was high. An interesting observation is that days of high dust concentration are not necessarily days with high wind velocity or particular direction. The dust is probably created far away from the measured location.

It is also interesting to note that when the wind blows from the west during the entire night the concentration of a group of elements in the dust is low. This might be a clue that these elements come with dust from the east. In other work done in this area (Shani & Haccoun, 1976), it was found that whenever the wind blew from the east, the concentration of Fe increased.

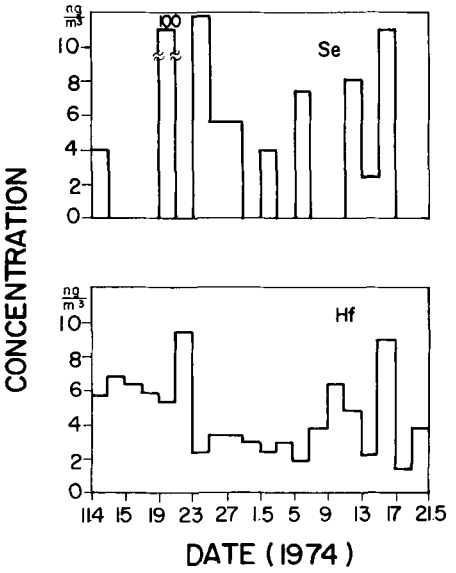



*Fig. 11.* Concentration of Hf.
*Fig. 12.* Concentration of Se.

The reason for the low concentration of air pollution at the beginning of the measurement period is that 10 April 1974 was a rainy day and the air was therefore cleansed (except for Br).

### *4.3. Air pollutants as a group*

As mentioned, six of the elements, Fe, Co, Cr, Th, Sc, and Na, seem to form a group of one origin and similar time dependence. The concentration of the elements within the group varies from tens of $\mu g/m^3$ for Fe to a few $ng/m^3$ for the Th. The dust in the area is known to be composed mainly of

Table 2. *Pollutant concentration* ($ng/m^3$)

| Date | Eu | Cs | Ba | Ag | Zn |
|---|---|---|---|---|---|
| 11.4–13.4 | 0.43 | 2.79 | 82.3 | 2.13 | 250.2 |
| 13.4–15.4 | 0.46 | 2.2 | 113.8 | 1.01 | 161.4 |
| 19.4–21.4 | 0.23 | 1.25 | 132.1 | 1.46 | 92 |
| 23.4–25.4 | 0.17 | 1.87 | 121.9 | 1.03 | 88.8 |

Table 3. *Wind direction and velocity in April 1974 (degrees from north, knots)*

| | Time | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 (a.m.) | | 5 | | 8 | | 11 | | 14 (p.m.) | | 17 | | 20 | | 23 | |
| Date | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. |
| 10 | 300 | 5 | 240 | 1 | 280 | 10 | 280 | 10 | 260 | 14 | 270 | 12 | 260 | 2 | 240 | 4 |
| 11 | 210 | 4 | 220 | 7 | 220 | 5 | 260 | 4 | 290 | 7 | 300 | 6 | 330 | 5 | 60 | 5 |
| 12 | 90 | 4 | 90 | 7 | 90 | 8 | 120 | 13 | 120 | 9 | 120 | 10 | 100 | 6 | 100 | 6 |
| 13 | 250 | 10 | 250 | 4 | 220 | 2 | 230 | 6 | 290 | 9 | 290 | 4 | 120 | 3 | 200 | 5 |
| 14 | 40 | 2 | 50 | 10 | 90 | 7 | 90 | 3 | 30 | 7 | 280 | 7 | | | 90 | 5 |
| 15 | 90 | 5 | 90 | 6 | 80 | 10 | 110 | 12 | 60 | 2 | 340 | 10 | | | | |
| 16 | 260 | 3 | 260 | 3 | | | 310 | 4 | 290 | 6 | 340 | 8 | 280 | 2 | 340 | 2 |
| 17 | 350 | 2 | | | | | 320 | 2 | 240 | 11 | 310 | 12 | | | 90 | 4 |
| 18 | 80 | 7 | 80 | 5 | 110 | 5 | 260 | 8 | 270 | 14 | 290 | 9 | | | 250 | 2 |
| 19 | 250 | 4 | 300 | 2 | | | 280 | 6 | 300 | 10 | 300 | 9 | 310 | 5 | | |
| 20 | | | 90 | 2 | 90 | 4 | 20 | 2 | 320 | 6 | 330 | 10 | 320 | 2 | 90 | 4 |
| 21 | 90 | 5 | 90 | 2 | 100 | 9 | 140 | 6 | 260 | 3 | 300 | 10 | 280 | 7 | 210 | 3 |
| 22 | | | | | 200 | 1 | 200 | 4 | 230 | 7 | 290 | 10 | 310 | 5 | 300 | 12 |
| 23 | 320 | 2 | 320 | 2 | 270 | 8 | 270 | 5 | 260 | 16 | 300 | 10 | 310 | 7 | | |
| 24 | | | | | 60 | 2 | 250 | 3 | 300 | 5 | 340 | 8 | 340 | 6 | | |
| 25 | 120 | 1 | 90 | 4 | 70 | 3 | 100 | 6 | 100 | 10 | 110 | 10 | 80 | 7 | 90 | 12 |
| 26 | 80 | 12 | 20 | 8 | 250 | 12 | 280 | 10 | 290 | 12 | 310 | 3 | 280 | 2 | 260 | 1 |
| 27 | 250 | 3 | 270 | 5 | 260 | 5 | 290 | 5 | 280 | 8 | 300 | 10 | 300 | 6 | | |
| 28 | | | | | 100 | 10 | 290 | 3 | 300 | 6 | 330 | 10 | 300 | 3 | 310 | 2 |
| 29 | 280 | 2 | | | 110 | 2 | 140 | 2 | 320 | 8 | 340 | 10 | | | 300 | 4 |
| 30 | 50 | 2 | 90 | 4 | 40 | 1 | 80 | 4 | 350 | 20 | 350 | 2 | 60 | 3 | 90 | 4 |

Table 4. *Wind direction and velocity in May 1974 (degrees from north, knots)*

| | Time | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 (a.m.) | | 5 | | 8 | | 11 | | 14 (p.m.) | | 17 | | 20 | | 23 | |
| Date | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. |
| 1 | 80 | 5 | 80 | 5 | 70 | 6 | 120 | 10 | 160 | 10 | 90 | 4 | 70 | 6 | 90 | 5 |
| 2 | 120 | 5 | 250 | 12 | 250 | 7 | 280 | 9 | 300 | 11 | 290 | 10 | 290 | 5 | 300 | 4 |
| 3 | | | | | | | 270 | 8 | 280 | 10 | 290 | 10 | 290 | 4 | | |
| 4 | | | 80 | 1 | 210 | 2 | 250 | 4 | 300 | 8 | 300 | 10 | 340 | 4 | 90 | 2 |
| 5 | | | | | 30 | 2 | 90 | 8 | 220 | 2 | 350 | 10 | 330 | 10 | 90 | 2 |
| 6 | | | 80 | 2 | | | 290 | 2 | 320 | 10 | 320 | 12 | 260 | 2 | 270 | 2 |
| 7 | | | 90 | 2 | 140 | 1 | 290 | 8 | 300 | 12 | 320 | 10 | 310 | 2 | 270 | 4 |
| 8 | | | | | 280 | 2 | 330 | 10 | 330 | 14 | 340 | 14 | 290 | 2 | 270 | 2 |
| 9 | | | 90 | 1 | | | 320 | 5 | 310 | 5 | 310 | 10 | 310 | 7 | | |
| 10 | 90 | 4 | | | 90 | 1 | 300 | 4 | 250 | 3 | 320 | 8 | | | | |
| 11 | 240 | 14 | 260 | 10 | 290 | 16 | 270 | 9 | 300 | 10 | 300 | 14 | 300 | 6 | 300 | 2 |
| 12 | | | 100 | 3 | | | 350 | 2 | 300 | 8 | 330 | 10 | 330 | 7 | 340 | 4 |
| 13 | | | | | | | 350 | 3 | 350 | 9 | 310 | 12 | 300 | 5 | 320 | 1 |
| 14 | 340 | 2 | | | 330 | 5 | 290 | 4 | 330 | 8 | 330 | 10 | 320 | 6 | 340 | 2 |
| 15 | | | | | | | 310 | 3 | 320 | 9 | 320 | 10 | 340 | 4 | | |
| 16 | | | 80 | 2 | 100 | 3 | 200 | 3 | 260 | 8 | 320 | 12 | 340 | 4 | | |
| 17 | 100 | 2 | 90 | 2 | | | 260 | 2 | 10 | 6 | 340 | 9 | 350 | 3 | | |
| 18 | 90 | 2 | 90 | 4 | 90 | 4 | 20 | 2 | 310 | 11 | 320 | 9 | 340 | 4 | | |
| 19 | 90 | 2 | 80 | 3 | | | 300 | 3 | 320 | 5 | 340 | 10 | 340 | 4 | | |
| 20 | | | 80 | 3 | 100 | 1 | 110 | 3 | 190 | 3 | 300 | 7 | 80 | 2 | 90 | 1 |
| 21 | 80 | 6 | 260 | 14 | 260 | 8 | 290 | 11 | 290 | 12 | 310 | 10 | 340 | 2 | | |
| 22 | 70 | 2 | 90 | 1 | 230 | 2 | 240 | 8 | 300 | 9 | 300 | 10 | 300 | 4 | | |
| 23 | | | | | 330 | 1 | 270 | 5 | 290 | 8 | 280 | 8 | 310 | 6 | | |
| 24 | | | | | | | 310 | 4 | 330 | 10 | 320 | 13 | 320 | 11 | 280 | 2 |

$CaCO_3$, $MgCO_3$, $SiO_2$ and $Al_2O_3$. The soil in the Dead Sea area contains large quantities of NaCl and KCl; Fe might be impurity in all these compounds. As mentioned (Shani & Haccoun, 1976), when the wind is mainly from the east (from the direction of the Dead Sea) the amount of Fe in the air is increased. This indicates that the Fe is particularly an impurity in the dust originating in that area. The days when Fe concentration is high are days of dust storm or haze: 15, 21 and 26 April; 6 and 19 May. The wind on these days was from the east during the morning hours.

Co is next to Fe in concentration level. Its time dependence is similar to that of Fe except for 7 and 8 May when the Fe concentration was relatively high. The average concentration of Cr is relatively high and its incidence is similar to the other element of the group during the measured period.

The concentration of Th and Sc is low. The general time dependence of these elements is similar to the others but Sc variations are much larger than those of Th. While Th varies between 2 and 7 ng/m$^3$ (with few exceptions) Sc varies between 2 and 16 ng/m$^3$. On two particular occasions, 25 to 28 April and 11 and 12 May, Th concentration was relatively high. During this time there were dust clouds in the air and the wind blew from the west all night. It is concluded then, that although Th's general behaviour is similar to the rest of the group, it is quite possible that there is another Th source in the west. Generally, when the wind blows from the west throughout the night, the group concentration is low.

Sc deviated from the group only on 5 and 6 May; on those days haze was reported but no special wind conditions. Generally, on days of dust or haze, the whole group has a higher concentration.

Na seems to be another element of the group, although on some days its concentration was as low

Table 5. *Weather conditions in April 1974 (see WMO Code)*

| Date | Time | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2 (a.m.) | 5 | 8 | 11 | 14 (p.m.) | 17 | 20 | 23 |
| 10 | | 25 | 80 | 95 | 81 | 01 | 10 | 63 |
| 11 | 01 | 03 | 10 | 03 | 03 | 01 | 01 | 02 |
| 12 | 03 | 03 | 01 | 02 | 03 | 01 | 02 | 03 |
| 13 | 02 | 02 | 05 | 05 | 05 | 05 | 05 | 05 |
| 14 | 05 | 05 | 05 | 05 | 02 | 03 | 01 | 02 |
| 15 | 02 | 02 | 05 | 05 | 32 | 05 | 05 | 05 |
| 16 | 05 | 05 | 05 | 05 | 02 | 03 | 01 | 01 |
| 17 | 02 | 02 | 05 | 05 | 05 | 03 | 01 | 02 |
| 18 | 02 | 02 | 05 | 05 | 05 | 05 | 01 | 02 |
| 19 | 03 | 02 | 02 | 03 | 01 | 01 | 03 | 03 |
| 20 | | 01 | 01 | 02 | 02 | 03 | 05 | 01 |
| 21 | 02 | 03 | 01 | 03 | 06 | 06 | 05 | 01 |
| 22 | | 03 | 02 | 05 | 05 | 02 | 10 | 01 |
| 23 | 03 | 01 | 03 | 01 | 03 | 01 | 01 | 01 |
| 24 | 02 | 03 | 02 | 01 | 02 | 02 | 02 | 02 |
| 25 | 02 | 02 | 03 | 03 | 03 | 02 | 02 | 05 |
| 26 | | 03 | 06 | 05 | 05 | 05 | 10 | 03 |
| 27 | 02 | 03 | 01 | 05 | 01 | 01 | 10 | |
| 28 | | | 03 | 01 | 03 | 02 | 03 | 03 |
| 29 | 10 | 10 | 05 | 01 | 02 | 02 | 02 | 02 |
| 30 | 02 | 03 | 03 | 03 | 02 | 02 | 02 | 01 |

as the background contributed by the filter itself. The days when Na concentration has its peaks are the same days as the peaks of other elements of the group except for 5 and 6 May (similar to Sc). It has already been mentioned that the Dead Sea area contains a very high concentration of NaCl and that the group's concentration rises when the wind blows from that direction. It takes about 4 days for the group's concentration to be reduced to its minimum level.

A general remark can conclude the group's concentration: it was high on days of dust storms or haze (15.4, 21.4, 26.4, 10–11.5 and 19–20.5) and was low on days when the wind blew from the west all day and night (10, 19, 23 and 27 April; 2, 11 and 14 May). The measurement from 25–28 April (which was one measurement) contains 1 day of maximum condition (26 April) and 1 day of minimum condition, hence it represents an average concentration. (The sampling machine ran for 4 consecutive days because a 2-day holiday intervened.)

### *4.4. Nongrouped pollutants*

The other five elements whose concentrations are reported in detail, change differently with time from the elements of the group above. Br has the highest concentration, being of the order of 1 $\mu g/m^3$. As mentioned, Br is discharged into the air by a bromine products plant in the neighbourhood, and is not brought to the area by weather conditions, unlike the dust. The Br amount released to the atmosphere is generally constant in small quantities, but from time to time there is an accidental or deliberate release of larger amounts. It is seen in Fig. 8 that Br had three peaks during the measured period on different days from the dust group. The rise of these peaks is generally sudden, but it takes more than 4 days for the concentration decrease (either by sinking or by transportation). The decrease is slower on the first 2 days and then proceeds faster. The peaks are of the order of 1 $\mu g/m^3$ and the dips are about 0.4 $\mu g/m^3$. In some cases, the dips in Br concentration are when the dust concentration is at a peak.

Next in concentration is Sb; it increased to almost 50 $ng/m^3$, although its concentration was

Table 6. *Weather condition in May 1974 (see WMO Code)*

| Date | Time | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2 (a.m.) | 5 | 8 | 11 | 14 (p.m.) | 17 | 20 | 23 |
| 1 | 01 | 03 | 05 | 05 | 05 | 02 | 02 | 02 |
| 2 | 01 | 03 | 03 | 01 | 01 | 02 | 01 | 03 |
| 3 | 01 | 03 | 05 | 02 | 01 | 01 | 01 | 02 |
| 4 | 02 | 02 | 03 | 01 | 02 | 02 | 02 | |
| 5 | | 02 | 01 | 02 | 02 | 02 | 02 | 02 |
| 6 | 02 | 42 | 05 | 02 | 05 | 02 | 00 | 44 |
| 7 | 03 | 42 | 05 | 02 | 02 | 02 | 02 | 02 |
| 8 | 03 | 47 | 10 | 01 | 03 | 01 | 01 | 40 |
| 9 | 01 | 40 | 10 | 03 | 03 | 02 | 01 | 10 |
| 10 | 03 | 02 | 03 | 02 | 01 | 03 | 03 | 02 |
| 11 | 32 | 03 | 03 | 01 | 01 | 01 | 02 | 02 |
| 12 | 02 | 03 | 03 | 01 | 01 | 01 | 02 | 02 |
| 13 | | 02 | 03 | 02 | 01 | 02 | 02 | 02 |
| 14 | 02 | 03 | 01 | 02 | 01 | 02 | 03 | 01 |
| 15 | 02 | 02 | 03 | 01 | 02 | 01 | 02 | 10 |
| 16 | | 02 | 02 | 02 | 08 | 02 | 02 | 02 |
| 17 | 02 | 02 | 02 | 02 | 02 | 02 | 02 | 02 |
| 18 | 02 | 02 | 02 | 02 | 02 | 02 | 02 | 02 |
| 19 | | | 05 | 02 | 02 | 05 | 01 | |
| 20 | | 02 | 05 | 02 | 02 | 02 | 02 | 02 |
| 21 | | 05 | 05 | 05 | 05 | 01 | 02 | 02 |
| 22 | | 03 | 02 | 02 | 01 | 01 | 02 | 10 |
| 23 | | 10 | 01 | 02 | 03 | 01 | 02 | 10 |
| 24 | | 03 | 05 | 02 | 02 | 02 | 02 | 10 |

generally around 25 ng/m$^3$. Sb concentration was low at the beginning of the measured period, probably due to the rain on 10 April 1974. The concentration went up during the first week but not in the same way as the dust group. It differed from the group also in the fact that it had peaks and dips on different days. In some cases (21, 22 April) it had a dip when the group had a peak. The only day when Sb fit the group is on 10 May when a dust storm took place at night between 10 and 11 May; the wind blew from the west all that night.

Except for the period from 7–10 May, Sb concentration stayed within the limits of 14 ng/m$^3$ to 28 mg/m$^3$ with no remarkable change. Sb concentration has three peaks (17, 18 April, 1–2 May and 9–10 May), it took 8 days for the concentration to reach the peaks and 2 to 4 days to fall off.

Hg concentration is about the average air pollution concentration of the order of 2 to 10 ng/m$^3$. It obviously does not belong to the dust group, since its peaks are on different days (19–20 April, 1–2 May and 15–16 May), when some dust was reported in the air. These are also the days when the wind blew all night from the west (days when the group concentration was low). There is no explanation why a western wind between 2 and 8 a.m. brings about all these changes in pollution concentration, since the wind blows from the west for the rest of the day every day. The high concentration of Hg on 11–12 April after a rainy day is also surprising, although on 11 April the wind blew from the west–southwest all night.

Hg concentration increased and decreased in periods of 2 weeks; generally the rise to the peak lasted about 10 days and the fall 4 days. If Hg is an urban pollutant, some special event must have caused its high concentration on 11–12 April since the period until 19–20 April is much shorter than the other periods.

The concentration of Hf has some similarity to that of the dust group. The concentration changes smoothly at low levels (around 4 ng/m$^3$) except for two peaks on 21–22 April and 15–16 May which also do not exceed 10 ng/m$^3$. The peaks in Hf concentration do not correspond to the peaks in the dust group concentration; it also does not quite fit the peaks of Hg and Sb. The source of Hf might be an impurity in dust of some other origin. Because of its low concentration it does not seem to be an important pollutant.

Se is another element that does not behave like the group or any other element reported here. It has some similarities to Hg and Hf concentrations but it is far from being identical and cannot be attributed to the same origin. A thorough investigation of the industrial waste released into the air is needed for definite identification of the origin of each of these pollutants.

### *4.5. Long-life isotopes*

As for the elements Eu, Cs, Ba, Ag and Zn, shown in Table 2, it is difficult to make conclusions about their origin and weather dependence from the four concentrations given. Comparing these values with the other elements discussed, it seems that none of these elements belong to the dust group. Three of them (Cs, Ag and Zn) have the highest value on 11–13 April, when the group has a minimum. Ba has a maximum (on 19–21 April), when the group has a minimum and Eu has a much higher concentration on 11–13 April than on 23–25 April, the group concentration is equal on these days. Cs, Ag, and Zn which have high concentrations on 11–13 April, in spite of the weather conditions, are probably urban pollution. Ba and Eu can be impurities in the dust, but more information is needed for solid conclusions.

## 5. Conclusions

It has been demonstrated in the past that neutron activation analysis is a good method for the detection of trace elements. In the present work it is shown that with some additional measurements of meteorological conditions much more information can be derived. The division of the pollutants into groups of one origin and of individual pollutants is of great importance. Additional investigation is needed to find out which of the individual pollutants is due to urban pollution and which is natural. It is quite clear that the pollutants of the group come from the east, probably the Dead Sea area.

Another interesting observation is that when the wind blows all night from the west there is sometimes dust in the air and the concentration of the group decreases to a minimum. On these days, some of the individual elements go to their maximum. It is known that dust from the Sahara Desert reaches the Middle East and it is quite possible that this is the source of the dust and the individual elements.

Generally, it takes about 4 days for each pollutant to be cleared out, no matter how long it

takes to reach the peak. The dust generally piles up within about 8 days; other elements, in particular industrially released Br, reach a peak very quickly.

The fact that days of heavy dust were not days of particular wind conditions leads to the conclusion that the dust might be created far away from the area. This might agree with the fact that dust from the Sahara Desert is brought by the wind to the Middle East.

Another observation is that on dusty days the temperature was about 10 °C or more higher than the days before and afterwards.

As for the urban pollutants, they can be created by industry or transportation. The main pollutant is Br, whose concentration has a peak every 16 days. The rise is sudden but the fall is within 4 days. It is interesting to note that in some cases, when the air is loaded with dust, Br concentration drops to a minimum, as if the dust cleans the bromine from the air. Another element which is probably due to industry is Hg, used in another chemical plant in the area. A thorough investigation of the sources of urban pollution is still needed.

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## ИЗМЕРЕНИЯ ЗАГРЯЗНЕНИЯ ВОЗДУХА В ПОЛУЗАСУШЛИВОЙ ЗОНЕ С ИСПОЛЬЗОВАНИЕМ НЕЙТРОННОГО АКТИВАЦИОННОГО АНАЛИЗА


Для измерений загрязнений воздуха в полузасушливой зоне использовался нейтронный активационный анализ. После тщательного отбора воздушных фильтров пробы воздуха были профильтрованы в городе Беер-Щева на юге Израиля. Отбор производился в течение двух месяцев с периодом для каждого отбора, продолжавшимся два дня. Пробы облучались потоком термических нейтронов интенсивностью порядка $10^{13}$ n/cm$^2$ сек в течение одного часа, после чего несколько раз измерялся гамма-спектр. Концентрация элементов выводилась из анализа гамма-спектров. Комбинированием погодных условий с результатами измерений был получен ряд следствий.

Источники загрязнения воздуха могут быть разделены по своей природе: пыль определенного происхождения, содержащая Fe, Co, Cr, Sc, Th и Na (вероятно, из области Мертвого моря); другие источники пыли, содержащие Sb, Eu и Hf; загрязнения городского происхождения благодаря промышленности и транспорту с Br и Hg. Загрязнение воздуха имеет свои минимумы и максимумы в соответствии с погодными и промышленными условиями. Для очищения от загрязнений требуется 4 дня. Найдены и другие связи с условиями погоды.