National Coal Ash Board
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Ministry of National Infrastructures
Ministry of Environment
Ministry of Interior
Israel Electric Company
National Coal Supply Corporation

Monitoring of trace elements in coal ash

A discussion of the scientific–professional team attended by international experts
Workshop on the environmental aspects of coal ash utilization
Tel-Aviv 16.12.2009

Participants (lecturers quoted herein): Dr. Ariel Metzger (Chairman), Prof. Uri Mingelgrin, Omri Lulav, Dr. Philip Kalson, Dr. Yaacov Nathan, Prof. Rami Keren, Dr. Hans A. Van der Sloot, Dr. Robert Finkelman, Dr. Ruud Meij

Background documents: Discussion platforms
Summaries of workshop's lectures
Presentations of workshop's lectures

Topics of Discussion:

A. The correlation between trace elements concentration in coal (laboratory ash) and their concentration in industrial ash, as a function of the coal's properties and combustion conditions.

In the framework of the understanding between the Israeli Electric Corporation (IEC) and the Ministry of Environmental Protection, it was agreed to develop a control mechanism on sources of coal that will allow a preliminary evaluation of the expected concentrations of trace elements in fly ash and leachates thereof, as well as verify their compliance with environmental criteria (according to the application of the ash). IEC regularly measures trace elements concentration in coal (measured in a laboratory ash obtained after the coal has been burned), in industrial ash (obtained by burning the coal in the production units) as well as in the industrial ash leachates (see section B below) compared to the environmental criteria defined for “Useable Ash”. Elements' concentrations in leachates depend on the conditions of combustion in the power plants furnaces (since these conditions affect the elements’ volatility) and, of course, also on the properties of the coal and ash themselves. By developing the transfer coefficients from trace element concentrations in coal to their concentrations in industrial ash leachates, IEC will be able to evaluate the introduction feasibility of new types of coal from the environmental and human health points of view, and in accordance with the regulations pertaining to ash applications. In this manner, it will be possible to estimate the expected concentrations in the leachate as soon as a new coal source is examined. For this purpose, a database of trace elements concentrations in coals, ashes and their leachates will be needed, as a function of the coal's source, and data of operating conditions during combustion.

Such a database was developed over many years in the Netherlands. This database served as a basis for the Kema Trace Model (KTM), developed by the KEMA Institute, which serves power plants in that country in evaluating new coal sources. Among the model's many uses, it can assist in forecasting the concentration of each of the elements in a leachate using the column test method (CEN/TS 14405, up-flow percolation test, L/S=10). The Dutch coal basket is similar to that of Israel, and the combustion technologies used in the coal power plants are also similar. Therefore, we can use the principles on which the Dutch database was founded as a basis for developing an Israeli database as well as a set of transfer coefficients.

B. A recommended Israeli method for environmental characterization of coal ash, and the connection thereof to various ash applications.

Currently, the determination of trace elements concentrations in coal fly ash for the purpose of environmental evaluation is conducted (as instructed by the Ministry of Environmental Protection) by analyzing the leachate obtained by the USEPA's TCLP1311 method, with a constant pH of 5. This method has several shortcomings:

1. For the purpose of environmental characterization: in reality, the pH of the ash's surroundings is not constant. It undergoes changes due to the innumerable environmental processes involved; for example, exposure to CO_2 originating from the atmosphere or from microbial decomposition occurring in the soil. Due to those processes, the pH decreases from a value of 11 or higher at the time of ash application, down to around 8 or 9 at equilibrium. Consequently, there are temporal changes in the rate of release of elements from the ash. Therefore, we recommend the European characterization method prEN 14429. In this method, leaching is done at varying pH levels.
2. In relation to complying with environmental criteria, one should bear in mind that leaching at pH=5 does not reflect real conditions in the environment, where the ash is exposed to rainwater whose pH is closer to neutral. A leaching test with a neutral pH should be used, as is done in EN 12457-2 (single leaching step for granular material, at L/S ratio of 10), since this better reflects Israel's natural environment.
3. Regarding leaching tests to be conducted on compacted embankments: since ash used in infrastructure applications is moistened and compacted, and consequently assumes properties of a monolith over time, the standard powdery ash leachate test will not apply in that case. A better leaching test would be NEN 7347 (CGLT – Compacted granular leach test). Its complexity leads to the conclusion that a set of adjustment coefficients between its measurements and those of powdery ash leaching tests should be developed.

C. Definition of a representative ash and the verification of its compliance with environmental criteria[1]: a semi-annual mixture of ash sources versus periodic samples of individual sources.

The Israeli Electric Corporation conducts tests on semi-annually mixed ash samples based on daily sampling of industrial ash. These represent a mixture of all coal sources that are in use during the sampling period. Such a mixture apparently characterizes the ash accumulating in piles at power plants and remaining there until used. Concurrently, fly ash sampled from individual sources (the major sources) is tested. This is done each year. The introduction of a new coal for combustion necessitates an environmental safety approval, if the concentration of

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[1] "Useable ash" or "Designated use" "Maximum values" – as described in discussion platform

trace elements in the laboratory or industrial ash leachate (originating from this new source) meets the “Useable ash” criteria[1].

The main points raised in the discussions during the meeting are as follows[2]:

A. The connection between trace element concentrations in coal (laboratory ash) and their concentrations in industrial ash, as a function of coal properties and combustion conditions.

Dr. Ruud Meij (KEMA, The Netherlands)

The KTM model was applied on the data of several coal types corresponding with those used in Israel. This included coal from South Africa, Colombia and Indonesia. Trace elements composition was calculated for the coal types, (in the KTM database, elements’ composition is checked in the coal as is, without burning it, since some of the volatile[3] elements are released during the combustion), for fly ash, for bottom ash and for their leachates[4].

In evaluating environmental impacts, test results were compared with the threshold values used in the Netherlands for isolated applications, which are more stringent that those of non-isolated applications (as part of the Soil Quality Decree of 2007). The values in the following table indicate that the concentrations of certain elements in the fly ash leachates of the tested coals exceeded their maximal allowed threshold. They are represented in percentages of the threshold value.

Element mg/kg	Isolated applications		Non-isolated applications				
	Colombia – La Loma	Colombia - average	South Africa - Middelburg	South Africa - average	Colombia – La Loma	Colombia - average	Indonesia - average
Mo	123		349	379	1849	1053	323
Se	388	217		179	7751	4330	936
Ba				116			
Cr			335	341	185	350	214
Sb					154		
V							112
S							448

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[2] Parts of this discussion’s minutes appear in appendix 1. Originally in English and/or Hebrew. Transcripted from audio recording by Dan Shriki.

[3] Coal tested in the Netherlands according to the protocol of NEN-ISO 23380. In this method, the elements B, Cl, F, Hg, As, Sb and Se are not tested in the laboratory ash, but rather in a coal after digestion. The remaining elements may be tested in the laboratory ash after burning the coal at 500°C.

[4] Trace element concentrations in coal, fly ash and its leachates are given in appendix 2. This discussion did not address bottom ash testing.

As concerns Sulphur, its presence in the ash cannot be reliably predicted due to difficulties in measuring the element[5]. Among the remaining elements, the greatest exceedance was found in Molybdenum, Selenium and Chromium, for all coal sources in non-isolated applications. These findings explain why there is no such thing in the Netherlands as a permit for fly ash usage (of any coal source) in non-isolated applications.

Dr. Yaacov Nathan (Geological Survey of Israel)

The results of our coal tests are unreliable, since some of the trace elements evaporate during the combustion process (whereby the laboratory ash, namely the analyzed ash is obtained). This is especially true for sulphur and selenium.

Dr. Bob Finkelman (United States Geological Survey)

Unless the coal contains much Calcium, 90% of the Selenium in the coal will evaporate when it is burned at 200^{o}C, because Selenium is attached to Calcium. For this reason, ash containing more Calcium will probably contain more Selenium.

B. A recommended Israeli method for ash characteriziation and testing the leachates thereof with reference to various ash applications

Dr. Yaacov Nathan (Geological Survey of Israel)

I recommend the European characterization method prEN 14429, and the EN 12457/2 for compliance. This is due to several reasons:

1. It will be possible to compare between our results and those of other countries who employ the methods.
2. Leaching is done with water, not with acid (as in TCLP), and is therefore more realistic, even though no laboratory test can emulate natural conditions with 100% accuracy.
3. There are clearly defined regulations and thresholds, by which the compliance of each ash with certain applications can be readily established.

In selecting the method, we should make certain that the ratio L/S=10 is used, not L/S=2. The latter will not yield good results, due to the differences between the extents of water absorption exhibited by different sources of ash; this will make results comparison a cumbersome process.

We should continue studying the various types of ash, and in this endeavour rely on information abroad – especially as concerns Indonesian ash.

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[5] From the correspondence between Ruud Meij and Yaacov Nathan (post discussion): the coal is tested after undergoing digestion in an HNO_3-$HClO_4$-HF solution, which most trace elements can be measured in. By adding more HF after the digestion, it is possible to use ICP-AES to measure sulphur as well.

Another method, other than TCLP, whose results may be able to demonstrate the worst-case scenario as concerns the release of contaminants into the environment, is to dissolve the sample using hydrofluoric acid (HF).

Dr. Ariel Metzger (Israeli Electric Corporation)

The single-stage leaching process (L/S=10) is not a good choice for testing a material such as coal ash, since it does not faithfully simulate real conditions.

The advantage of TCLP is that it can demonstrate the worst-case environmental scenario, since the leaching process is done with an acid.

Dr. Hans A. Van der Sloot (ECN, The Netherlands)

There are 3 important kinds of characterization tests: pH stat, column test and tank test. Materials behaving like monoliths should be tested using the tank test method. Characterization tests are conducted in a certain limited frequency, but since the Israeli ash does not vary significantly (for example its high alkalinity), test results will probably repeat themselves.

Prof. Rami Keren (Volcani Center for Agricultural Research)

In the methods mentioned by Van der Sloot there is a strong connection between the characterization and compliance test. However, this is not true in the TCLP method. Therefore, the latter cannot serve as a basis in deciding which type of coal to purchase.

C. Definition of a representative ash and the verification of its compliance with "Designated usage" criteria: a semi-annual mixture of ash sources in contrast with periodic samples of distinct sources

Dr. Ariel Metzger (Israeli Electric Corporation)

As regards the concentration of trace elements in the industrial fly ash of different countries (as of 2009), most of them show similarity between the semi-annual mixtures and those of this year. This is also true for the long period lasting from 1991-2009[6].

As for the purchase of new coals – the coals used nowadays are purchased under long-term contracts and are of a single type – low-sulphur bituminous coal (there are no FGD facilities in all the production units in Israel; there is only one in Ruthenberg). So it can be determined that the Israeli fly ash has uniform environmental quality. We can also add that it will be rather benign to the environment, since low-sulphur coal, in general, has low trace element content.

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[6] Further discussion on this point is given in appendix 3.

Fly ash quality may be modified in the future, when FGD and SCR facilities are introduced into all power plants.

Dr. Hans A. Van der Sloot (ECN, The Netherlands)

The fly ash's trace elements content will be significantly affected with the introduction of SCR and FGD facilities. Information on this subject exists from tests that were conducted in the USA. This information will be available from January 2010, and we would be wise to consult it.

Summary

A. The connection between trace elements concentrations in coal and their concentration in industrial ash, as a function of the coal properties and combustion conditions.

1. The nature of this connection will depend on the analytical methods used for measuring the concentration of trace elements in coal and its ash. In Israel, trace elements concentrations are measured after the coal has been burned. Therefore, the measured concentrations of those elements that are volatile (especially Sulphur and Selenium[7]) will be lower than their true values in the coal. In order to avoid this fallacy, we should consider preparing coal for testing by digesting it in a solution containing HNO_3, HF and H_2O_2. This will eliminate organic matter through oxidation by H_2O_2 and dissolve low-solubility salts (such as silicates), which cannot be fully dissolved by means of HNO_3 only. There is a European method that tests coal in this manner; it is (DD CEN/TS 15297-2006: Solid biofuels; Determination of minor elements).

2. The introduction of FGD and SCR facilities into power plant units may have a major impact on the future quality of ash. A significant impact can also occur if biomass is combined with coal in the combustion process, as is done in the Netherlands. We recommend that information be gathered from ash tests conducted in the USA and in Europe that may hint to the effects FGD and SCR facilities, as well as biomass combustion, on trace elements content and their availability in the ash.

3. It is recommended to continue accumulating information on Israeli ash (whatever its source), continue conducting tests and relying on international information that is available on the subject, especially as regards Indonesian ash, upon which information is currently deficient. Nevertheless, since the sources of coal used in Israel are rather constant, and since Israeli ash is mostly alkaline and uniform, we can set a limit on the frequency in which characterization tests will be conducted on Israeli fly ash.

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[7] It is possible to test sulphuric content in coal without burning the latter. This is done using Dutch method NEN ISO-23380. However, due to the lack of the required X-ray Fluorescence instrument, it cannot be performed at the present time by the Geological Survey of Israel.

B. A recommended Israeli version for the method of environmental characterization of coal ash, and its practical connection to various ash applications

1. The European characterization and compliance methods known as prEN 14429 and EN 12457/2, respectively, are most appropriate for us, since the environmental estimation they provide simulates very well the real conditions to which fresh fly ash is exposed in infrastructure and land applications.
   Note: Dr. Ariel Metzger believes that we should continue using the TCLP method, since the leaching of the elements in an acid represents a more stringent environmental scenario[8].

2. Fly ash that behaves like a monolith (for example, in road embankment applications) should be characterized using the tank test method[9].

C. Definition of a representative ash in order to test its compliance with environmental criteria

1. Israeli fly ash has a relatively uniform environmental quality, since the coal from which it is derived is purchased under long-term contracts and is prevalently of the low-sulphur bituminous type, due to the restriction on sulphur emissions. There is a similarity in trace elements concentrations of industrial ash from different sources, except for certain sources from Indonesia (Blend, LS Blend and Melawan) and Colombia (Cerrejon, LS La Loma and Calenturitas Blend). These latter coals have relatively high concentrations of Boron and Selenium, both in the material itself and in its leachates.

2. Semi-annual ash mixtures, which represent all coal sources combined during the period in question, reflect the predicted condition of ash utilization in large-volume infrastructures. This is because the supply of ash to such applications will necessitate its accumulation in large piles for prolonged time periods.

3. New coal sources intended for use in Israel are only approved after verifying that the trace elements concentrations in their laboratory or industrial ash are within the historical IEC ranges and that their concentrations in TCLP leachates complies with

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[8] From an EPA review of TCLP (http://www.ehso.com/cssepa/TCLPfaqs.htm): the method presents a theoretical scenario in which municipal solid waste is mismanaged by placing it in an unlined landfill. In this method, the acetic acid is designed to simulate the results of the reaction of the waste with rainwater infiltrating the landfill, and then leaching through the waste to the soil and beyond. The threshold values were set at levels that would ensure that groundwater quality under the landfill is preserved and prevent it from posing a threat to human health and the environment.

[9] A review of the testing method most suitable for ash in infrastructure applications, CGLT, appears in the summary of the discussion platform on road paving and infrastructures.

“Useable ash” criteria. With the transition to the European leaching methods, the leachates will be examined against updated criteria[10].

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[10] A proposal for a new criterion is discussed in appendix 4.

Appendix 1

Selected parts of the protocol of the meeting on trace elements monitoring

A. Metzger (Chairman): The meeting will discuss ways for improving the system of monitoring trace elements in coal and coal ash. Current as well as proposed coal ash testing and monitoring methods will be examined.

R. Meij: I will use the KEMA Trace Model (KTM) to present an estimatation of trace element concentrations in Israeli fly ash. First I would like to note the origins of coal used in the Netherlands, then proceed with some background information on KTM, and finally present its results. The coal origins used in the Netherlands are similar to those used in Israel, so test results we obtained for coal ash from these origins, are valid for Israel. However, it varies from year to year (in trace elements composition). For example, the mean annual concentration of Arsenic in coal used in the USA has been steadily declining (during 1981-2003), while the concentration of Boron in Indonesian coal has shown an increase. More Indonesian coal means more Boron. So if we know there is a problem with Boron because of its uptake by plants, it may be preferable to avoid that type of coal.

KTM receives coal data as an input, and calculates the ash composition and emissions into the air. The model is based on 42 mass balance studies I conducted from 1980 on. Since 1986, FGD was included. The model can estimate the concentration of 55 trace elements in the leachate, as well as its radioactivity. Based on the mass balance studies, we calculated enrichment factors (by dividing the element's concentration in the ash by its concentration in the leachate, and multiplying the result by the percentage of ash in the coal) for the different types of ashes. Based on that we classified the trace elements to 3 categories, with respect to their volatility. The model is used by power plants in the Netherlands prior to purchasing new types of coal; and in that way we are able to see if there is a problem with the coal, and decide whether to burn it or not.

As regards the implementation of KTM on Israeli coal – we used the data of coal imported to the Netherlands from South Africa, Colombia and Indonesia. I took as a reference the mean values of all samples I have in the database. We calculated the composition of fly ash and bottom ash leachates (represent leaching according to the percolation test method, using an L/S ratio of 10). I compared the results with Dutch threshold values for ash applications according to the Dutch Soil Quality Decree, as it refers to isolated applications from the environment, (dry condition) which are more stringent for non-isolated applications from the environment, (wet condition). The results are given in percentages of the aforementioned threshold values; any given concentration will be considered excessive if it is above 30% of the threshold value. It is immediately apparent that Sulphur could be problematic, since its content exceeds the accepted value in Indonesian and Colombian bottom ash in non-isolated applications. However, it must be said here that the prediction of Sulphur concentration in the ash is rather uncertain.

As for the results of the fly ash tested – in all cases the concentrations of the elements chromium, molybdenum and selenium exceed their accepted values in non-isolated applications. Hence, in the Netherlands it is forbidden to use fly ash in infrastructure without insulation. This is why fly ash is used in the Netherlands only as a raw material for cement and other such applications, since the situation there is different than in Israel: there is much more precipitation there, and the groundwater level is very shallow.

A. Metzger: IEC regularly checks concentrations of 16 trace elements and 3 radionuclides in coal, fly ash and bottom ash. The tested batches consist of semi-annual mixtures of all the types of coal that is burned in any given power plant, and they are collected on a daily basis. The concentrations of trace elements in industrial fly ash originating from coal imported from various countries during 2009, alongside those concentrations in semi-annual mixtures collected in the period of 1991-2009, show similar results among the various countries; these results are within the range of the semi-annual mixtures' concentrations. In 1998 we decided to start measuring trace element concentrations in fly ash leachates (using the TCLP method; starting November 2009 we began using the European leaching method EN 12457/2). Recently, industrial fly ash has been regularly sampled and tested by the National Coal Ash Board (trace elements in ash and TCLP & EN 12457/2 leachates); this is in contrast to the laboratory ash we used to test in the past, and which was obtained by burning the coal in the laboratory at high temperatures (so-called HTA- High Temperatures Ashing). The problem with this ash was that some of the elements were volatilized during the combustion process. Therefore we prefer to test the industrial ash that is sampled at the power plant (during the burning of specific coal types).

Israeli fly ash has a rather uniform environmental quality. This is due to several reasons: Our custom is to purchase coal in long-term contracts, and we have not employ FGD in most of the power plants units in the last 15 years. So we purchase only low-sulphur bituminous coal of low sulphuric content due to the restrictions on Sulphur, and this benefits us, since low-sulphur bituminous coal is also characterized by a low content of trace elements, in particular Mercury. Although this is not true for all the trace elements, it is for most of them.

A deterioration in coal ash quality can be avoided, since new coal types are tested at IEC in order to determine their operational as well as environmental parameters. In the future we intend to add FGD and SCR facilities to all coal units, and this will have an effect upon ash quality. One of these, for example, will be the concentration of Ammonia in the ash, originated from the Ammonia injected into SCR with the purpose of having it react with Nitrogen oxides in order to reduce their concentration in flue gases. So in such a state of excess Ammonia (what remains of it after the aforementioned reaction), if the SCR is situated before the electrostatic precipitators, you can enrich the fly ash in Ammonia. In some cases the use of fly ash in concrete might be impeded due to the smell; its more a matter of a hygienic problem than an environmental one, and it has no effect on the trace elements.

Another possibility to change the ash quality in the future is use of alternative fuels. Till now the Ministry of Environmental Protection has forbidden the burning of biomass together with coal in Israel's power plants (as is done in the Netherlands). But after installation of FGD and SCR facilities, we may try to burn biomass as well, and this may have an effect on the ash's trace elements content.

There is a similarity between trace element concentrations in fly ashes originating from coals of different countries. Nonetheless, there are some differences; for example the Colombian ash's higher concentration of selenium in comparison with that of the South African coal, and the concentration of this element in the leachate prepared using the European method exceeded the criterion for non-hazardous waste in the European Landfill Directive. But this is not to say that fly ash should be considered hazardous, since it behaves as a monolith in infrastructure applications. Moreover, not all countries include Selenium in their drinking water standards.

B. Finkelman: In ash, selenium associates with calcium, so calcium-rich ash will contain more Selenium, and arsenic as well. We can adjust the concentration of these two trace elements by means of a controlled mix of coal or ash from different sources (power plants in Israel do not do this).

A. Metzger: In its chemical properties, selenium is very similar to sulphur, and the gypsum created in the process of sulphur removal from flue gases in the FGD apparatus, will also contain Selenium. So, the selenium which will not be retained in the ash will be found in the gypsum, and, subsequently, not be emitted to the environment.

P. Kalson: There are two changes which can potentially have an effect on coal ash utilization and its effects on the environment: A) installation of SCR apparatus after the boiler, for NOx removal from flue gases, and B) massive changes in the combustion conditions (in the boiler, in the grinders and in the burners). Such changes may have three effects: 1. The residual Ammonia in the ash which may affect our ability to utilize the ash freely in any application. I think we lack sufficient knowledge to understand how different ashes will react to Ammonia residual in the flue gases. 2. Changes in the fly ash resulting from the operational changes mentioned above. 3. Secondary changes in the concentrations of some trace elements, in the ash fraction passing through the FGD apparatus.

H. A. Van der Sloot: I think that SOx removal apparatus (FGD) and NOx removal apparatus (SCR) will have a major effect on the trace elements in the ash (at least from results that I've seen from the USA). This information will be available, I believe, from January 2010. It should include test results for a large number of ashes that have been studied from different flue gas treatment processes, and this information will be extremely useful for you to at least know what you may be facing.

A. Metzger: We shall be glad to receive that information. However, we are currently focusing on the problem of ammonia remains in fly ash. Our goal is that the Ammonia residue in the ash will not exceed 100 ppm, as this would ensure that there will be no effect on the use of ash in concrete.

R. Meij: I conducted two mass balance studies which include SCR. We saw no differences, and barely detected any Ammonia in the fly ash. Also, when we purchase a new type of coal in the Netherlands, it is analyzed only once. And if it is done properly, there should be no need to analyze the ash too. However, we should discuss your method for testing coal. We analyze it not after ashing, since after ashing volatile elements are lost during the combustion process. In order to test trace elements content in coal, the tested batch undergoes a digestion process in an HF solution.

A. Metzger: We do not use that method in Israel.

R. Meij: That explains the differences we found. That's why much less Selenium is found in laboratory ash, since its greater part is lost when the coal is burned in the laboratory. Our results too refer to low-sulphur coal, since that is the type of coal we regularly purchase, despite the fact that FGD apparatus are found in all power plants in the Netherlands. Selenium is a toxic element whose value range is rather narrow; in contrast, other elements have wide ranges. As for the FGD and SCR operation, combining them removes around 90% of potential emissions into the atmosphere. In biomass combustion, the removal of Mercury from flue gases is even greater, due to the increased oxidization of the element.

Y. Nathan: I suspect that our coal testing results are incorrect, since some of the trace elements, and I do not know exactly which, have evaporated before we analyzed the coal (since the analysis was conducted on laboratory ash received from burning of the coal). I know that because most of the measurements we made on sulphuric content in the coal were incorrect, since Sulphur is highly volatile. Hence I fear that also our Selenium test results are unreliable.

B. Finkelman: In our studies we volatilized around 90% of the coal's Selenium at 200^{o}C, unless there was calcium in the coal, because Calcium captures the Selenium.

Y. Nathan: The reason we want to have our test methods as similar as possible to commonplace methods, with preference to European methods, is so that we will be able to compare our results with those of others. In addition, European methods use water, not acids, for leaching (as is done in TCLP, for example). In our case, there are two testing methods: the characterization test, and the compliance test. We will not change the L/S ratio we use in the characterization test, only the pH. As for the compliance test, one uses a ratio L/S=2 and one L/S=10; we choose the latter, since the lower ratio gives not so good results, due to differences in the amount of water absorbed by the ash.

It is important to state that there is no laboratory test that can duplicate the natural conditions. We simply need to find a way to overcome this gap. We recommend that the compliance test we choose be as close as possible to the European method EN 12457/2, since this latter simulates real conditions very well. We should abandon the TCLP method used hitherto, since the fact that it uses an acid for leaching rather than water. At the time there was no other method that included threshold values, and that is why we adopted TCLP. But now that we have, we should choose it.

A. Metzger: I would like to comment on what Yaacov said here. I totally agree with Van der Sloot that the single-stage leaching test is not suitable for testing a material such as coal ash in all situations. So if the single-stage test is eventually adopted as a replacement for TCLP, I don't really see the progress in it.

Y. Nathan: Ariel, you are confusing between the characterization test and the compliance test. The compliance test is a single-stage test which has clear regulations (European Landfill Directive for wastes), according to which we can establish where ash can be used and where it cannot. I agree with your claim that the compliance test will not give a good idea on what will happen to the ash in the field. For this purpose we have the characterization method, used with different pH's. We have to accumulate much data and learn more about the various coal ash sources, in particular the Indonesian one, about which we have very little information, including relying on knowledge from others abroad.

H. A. Van der Sloot: There are 3 important kinds of characterization tests: pH stat, column test and tank test. Materials behaving like monolith should be tested using the tank test method. It is important to discern between characterization test and compliance test. Characterization tests are conducted with a certain limited frequency, and since Israeli ash does not vary significantly (for example its high alkalinity is rather constant), test results will probably repeat themselves.

R. Keren: There is a strong connection between characterization and compliance tests mentioned by Van der Sloot. In contrast, with the TCLP method, there is barely any such connection. Hence, TCLP cannot serve as a basis for purchasing a new type of coal.

A. Metzger: However, the advantage of TCLP is that it represents the worst environmental case scenario, since it uses an acid for extraction. Consequently, more trace elements are released than under natural conditions. Additionally, TCLP includes threshold value criteria.

Y. Nathan: We could use an HF solution, for example, in order to check the worst case scenario. The problem with Indonesian ash is that when it is mixed with water and its pH measured immediately, it will show a rather acidic value around 5, and it will rise to around 7-8 after two or three minutes.

U. Mingelgrin: To summarize, it can be said that currently there is no consensus regarding the proposed modifications in the environmental conditions (i.e. requirements) for the use of fly ash. However, most of the issues were covered, and the discussion on the environmental conditions will continue at a later time.

Appendix 2

Prediction of trace element content using the KTM model

Element (conc. in mg/kg)	South Africa Middelburg			South Africa average (~26 samples)			Colombia La Loma			South Africa average (~13 samples)			Indonesia average (~13 samples)		
	Coal	Fly ash		Coal	Fly ash		Coal	Fly ash		Coal	Fly ash		Coal	Fly ash	
	Content	Content	Leachate	Content	Content	Leachate	Content	Content	Leachate	Content	Content	Leachate	Content	Content	Leachate
As	1.60	10.90	*0.03*	2.3	15.41	*0.05*	4.4	58.21	*0.17*	2.8	28.79	*0.09*	3.4	35.9	*0.11*
B	21	78.0		35	131.1		28.0	203.0		41	231.0		93	546	
Ba	253	1724	19	340	2317	25				121	1231	14	53	561	6
Be	1.55	10.53		1.8	12.09		0.7	9.36		0.6	5.80		0.7	7.26	
Br	1.08	0.74	0.32	0.9	0.58	0.26	0.7	0.87	0.38	1.3	1.30	0.57	0.9	1.00	0.44
Cd	0.05	0.36	*0.001*	0.07	*0.5*	*0.001*	0.5	6.26	*0.019*	0.19	1.94	*0.006*	0.05	*0.5*	*0.002*
Ce				19			1.6			5.2			5.0		
Co	8.76	59.7	*0.04*	6.8	46.3	*0.03*	3.0	39.6	*0.02*	2.8	28.6	*0.02*	4.3	45.3	*0.03*
Cr	30	203	2.2	29	196	2.2	8.0	106	1.2	20	200	2.2	11.5	122	1.3
Cs	1.13	7.70		1.1	7.24		0.5	5.94		0.8	8.01		0.7	7.31	
Cu	9.95	67.8	*0.02*	11.0	75.1	*0.02*	7.1	93.6	*0.03*	8.5	85.8	*0.03*	8.7	92.6	*0.03*
Eu	0.50	3.41		0.6	3.95		0.1	1.80		0.2	2.08		0.3	3.53	
F	200	218	22	235	256	26	35	74	7	64	104	10	47	80	8
Ge				15						8.0			19		
Hf	2.13	14.5		2.1	14.5		0.4	5.1		0.7	7.1		1.3	14.1	
Hg	0.07	0.27	*0.001*	0.10	0.39	*0.002*	0.05	0.39	*0.002*	0.07	0.37	*0.001*	0.07	0.41	*0.002*
I				2.3			3.0			1.9			3.0		
La	19.9	136		3	20		2.5	33		5.3	53		5.1	54	
Mn	37.2	254		57	386		14.6	192		43	440		16.3	174	
Mo	1.55	10.56	3.5	1.7	11.48	3.8	4.3	56.02	18.5	3.1	31.9	10.5	0.9	9.80	3.2
Ni	24.5	167	*0.05*	16	106	*0.03*	10.2	134	*0.04*	12.4	126	*0.04*	13.1	139	*0.04*
Pb	11.2	76	*0.08*	9	64	*0.06*	2.3	30	*0.03*	3.0	30	*0.03*	3.1	33	*0.03*
Rb	4.80	32.7		5.5	37.7		4.0	53.2		9.3	94.3		6.2	65.6	
Sb	0.23	1.55	*0.02*	0.36	2.44	*0.03*	1.7	22.36	*0.25*	0.8	7.83	*0.09*	0.3	*3*	*0.03*
Sc	5.30	36.1		5.7	38.8		2.8	37.2		2.6	26.1		4.5	47.7	
Se	0.53	2.50	0.08	1.9	8.97	0.27	6.3	58.13	11.63	4.6	32.5	6.50	0.9	7.02	1.40
Sm	3.07	20.9		3.3	22.8		0.6	7.7		0.9	9.1		1.6	16.7	
Sn	4	*27*	*0.14*	1.6	*11*	*0.05*	2.1	*28*	*0.14*	(1.1)	*12*	*0.06*	1	*11*	*0.05*
Sr	184	1254		414	2822		52	684		108	1099		81	860	
Te	0.40	*3*		0.8	*6*		1.7	*22*		2.0	20.0		0.5	5.33	
Th	8.27	56.4		7.9	53.8		0.9	11.8		1.6	16.1		1.7	17.6	
Tl				0.5			1.3			0.8			1		
U	2.35	16.02		2.3	15.86		0.6	7.56		0.8	7.93		0.4	3.89	
V	32	218	1.1	28	189	0.9	20	265	1.3	25	250	1.2	38	405	2.0
W	1.11	7.56		1.2	7.87		0.3	3.31		0.4	3.89		0.7	7.90	
Zn	12.90	87.9	*0.07*	12	84.2	*0.07*	17	218.8	*0.18*	18	182.6	*0.15*	16	168.1	*0.13*

Values in *italic* – below the limit of detection for concentration in the leachate. This includes: As, Cd, Co, Cu, Hg, Ni, Pb, Sn and Zn.

Appendix 3

Note: the following table presents IEC (Israel Electric Corporation) data of minimal and maximal concentrations of trace elements in semi-annual mixtures taken from 2005-2009, as well as NCAB (Israel National Coal Ash Board) data for individual fly ash sources sampled during the same period.

Element in ash	Minimum (ppm)		Maximum (ppm)	
	NCAB	IEC	NCAB	IEC
As	7	9	65	32
B	40	125	880	550
Ba	110	1000	5000	3075
Be	4	5	24	12
Cd	0.2	0.2	3	1.3
Co	20	26	65	50
Cr	75	80	260	165
Cu	55	48	145	90
Hg	0.03	0.04	0.34	0.1
Mn	70	260	860	530
Mo	5	6	43	26
Ni	55	55	125	100
Pb	14	29	75	55
Sb	1	1	15	9
Se	<2	<2	40	18
V	115	<2	310	250
Zn	75	80	250	210

In general, there is fairly good correlation between IEC's values and those of NCAB. However, there are significant discrepancies in some trace element concentrations in TCLP leachates, as the following table shows. This table too shows minimal and maximal concentrations of trace elements in the leachates of semi-annual mixtures and individual fly ash sources (again, during the years 2005-2009).

Element in leachate	Minimum (ppb)		Maximum (ppb)		Threshold value	
	NCAB	IEC	NCAB	IEC	EPA	Usable ash
Ag	<0.2	<0.2	3	7	5000	150
As	1.1	6	1260	565	5000	2000
B	1410	3615	28625	19950	*	20000
Ba	130	125	1300	790	100000	*
Cd	0.4	0.4	36	16	1000	100
Cr	12	21	885	415	5000	2000
Hg	<0.02	<0.02	0.35	<0.2	200	25
Mn	<2	<2	2700	2050	*	5000
Mo	100	115	1175	440	*	2000
Pb	0.2	0.2	7.3	1.6	5000	150
Se	14	28	1275	480	1000	700
V	15	320	2330	1250	*	5000

In comparing the concentrations it becomes evident that semi-annual ash sampling moderates the maximal values, especially in the case of arsenic, selenium, boron and, to a certain extent, molybdenum. As a result of this, elements that are checked in individual sources and exceed the threshold value (boron and selenium, marked red in the table), do not exceed these values in the semi-annual mixtures.

Appendix 4

Suggested threshold values according to the European criteria for non-hazardous waste

The following table shows maximal values suggested for “Designated use” criteria for coal ash, according to the European Directive for Non-hazardous waste (ENH). These values, which represent leachate concentrations that were obtained according to the Israeli variation of the elution method EN 12457/2 (for individual ash sources during the years 2007-2009), have been chosen on the basis of the following :

Use as a structural filler in road paving according to the specifications of the Israeli National Roads Company or similar specifications:

- 70% of the maximum allowed value for the definition of a material as non-hazardous according to the European criteria (ENH).
- An exception of up to 90% of the ENH will be permitted, if conditions (climate, soil and groundwater) that prevail in the area of application permit, conditioned on the approval of the Israel Water Authority.

Use in other filler applications:

- The existing “Rules of thumb” will remain in effect without change:
  - Reasonable values, taking into consideration the differences between ENH values and the average values found in leachates of the fly ash of coals imported to Israel.
  - Maintaining an order of magnitude difference between ENH values and maximum allowed values, when the above mentioned differences allow for it.
  - Half of the ENH value, and in any case no more than 70% of it, when these differences are too small to enable an order of magnitude difference.
  - Twice the maximum value found in the leachate of ashes in studies performed on ash, for elements that are not included in the ENH list.

Stabilization and improvement of soil (agriculture and infrastructures)

- The percentage of the ENH maximum values will be site specific and will depend on the percentage of clay in the soil, as detailed in the platforms for discussion on the environmental conditions for the application of coal ash in agriculture, in infrastructure and in road paving.

						Threshold values modified based on "Rules of thumb", in accordance to ENH			
Element (mg/kg dry matter)	**Minimal value**	**Maximal value**	**Average**	**EN threshold for non-hazardous waste (ENH)**	**Difference between ENH and average**	**EN*0.1**	**EN*0.5**	**EN*0.7**	**Maximal value * 2 (for non-ENH elements)**
Ag	<0.002	<0.01	0.005						0.02
As	≤0.002	1.4	0.15	2	1.85	0.2		1.4	
B	<0.2	446	76.31						892
Ba	0.75	59.57	12.97	100	87.03	10	50	70	
Cd	0.002	0.076	0.13	1	0.87	0.1	0.5	0.7	
Cr	0.48	5.7	2.50	10	7.5	1	5		
Cu	<0.001	0.1	0.09	50	49.91	5		35	
Hg	<0.0002	<0.0009	0.0003	0.2	0.2	0.02		0.14	
Mn	<0.02	0.09	0.025						0.18
Mo	1.9	28.8	6.02	10	3.98	1	5	7	
Ni	<0.1	1.05	0.14	10	9.86	1		7	
Pb	<0.001	0.03	0.007	10	9.99	1		7	
Sb	<0.001	1	0.082	0.7	0.62	0.07	0.35	0.49	
Se	0.05	8.75	1.49	0.5	-0.99	0.05	0.25	0.35	
V	0.07	5.2	0.99						10.4
Zn	0.1	1.35	0.59	50	49.41	5		35	

It can be seen that the average values of some of the elements exceed (marked in red) the threshold values calculated as one tenth of ENH, but they do comply with the threshold values calculated as one half of ENH (marked in blue). Exceptions to this are the elements **selenium and molybdenum.**