Radiological Aspects of Coal Ash Practices in Israel

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Outline of the Presentation

In this presentation we will address some of the many radiological aspects of "coal ash practices":

• The basic features of the major "coal ash practices."
• The extent and distribution of the utilization of coal ash among practices.
• The radiological characteristics of the ash (the radioisotopes involved, the radioactivity concentrations, the parameters relevant for external and internal dose evaluations e.g. type of radiations, energy and frequency of photons and particles emitted, ALI and DAC values, etc.).
Outline of the Presentation (cont.)

- The exposures/doses encountered in the implementation of “coal ash practices” or caused by the products resulting from them.
- The implications of these doses to the legal, and administrative control framework to ensure the health and safety of the public on one hand while being simple, practical, efficient and not expensive on the other hand.
This presentation is partially based on earlier publication of the author:

International Workshop on Environmental and Health Provisions for Coal Ash Utilization

Radiological Aspects of Coal Ash Practices
(stack, transportation, storage and utilization in Infrastructure, building industry and agriculture) a statement of opinion
by
T. Schlesinger
July 2008

This statement of opinion was prepared for the Israeli National Coal Ash Board
“coal ash practices” active in Israel and related routes of exposure or products causing exposure

Handling of the ash:
- Stacking, transportation and storage of the ash - mainly external exposure (if industrial hygiene measures against dust, e.g. wetting and masks are used)

Utilization of the ash:
- Infrastructure
- The building industry
- Agriculture
external and internal exposure
The extent and distribution of coal ash utilization in Israel

1. bottom ash
bottom ash (cont.)

Bottom ash uses (thousands tons) in 2008

- **Cement**: 53.1% (68,423 tons)
- **Agriculture**: 32.8% (42,325 tons)
- **Infrastructure**: 10.9% (14,335 tons)
- **Building Products**: 3.1% (4,215 tons)
The extent and distribution of coal ash utilization in Israel

2. Fly ash

![Graph showing the extent and distribution of coal ash utilization in Israel from 1982 to 2008. The graph indicates a significant increase in the utilization of fly ash over the years, with a peak in 2008. The categories include Building Products, Infrastructure, Concrete, Disposal to sea, Landfill-Hadera Power Station, and Cement.]
Fly ash (cont.)

Fly ash uses (thousands tons) in 2008

- 58.8% (623,000 tons)
- 40.2% (426,000 tons)
- 1% (11,000 tons)

Cement
Concrete
Building Products
Radiological characteristics of coal ash produced in Israel

The radioisotopes present in coal ash:

- **Members of the $^{238}\text{U}$ series**
  - $\alpha$ emitters - $^{238}\text{U}, ^{234}\text{U}, ^{230}\text{Th}, ^{226}\text{Ra}, ^{222}\text{Rn}, ^{218}\text{Po}, ^{214}\text{Po}, ^{210}\text{Po}$.
  - $\beta$, $\gamma$ emitters - $^{234}\text{Th}, ^{234}\text{Pa}, ^{234}\text{Pa}, ^{214}\text{Pb}, ^{214}\text{Bi}, ^{210}\text{Pb}, ^{210}\text{Bi}$.

- **Members of the $^{232}\text{Th}$ series**
  - $\alpha$ emitters - $^{232}\text{Th}, ^{228}\text{Th}, ^{224}\text{Ra}, ^{220}\text{Rn}, ^{216}\text{Po}, ^{212}\text{Bi}, ^{212}\text{Po}$.
  - $\beta$, $\gamma$ emitters - $^{228}\text{Ra}, ^{228}\text{Ac}, ^{212}\text{Pb}, ^{212}\text{Bi}, ^{208}\text{Tl}$.

- **$^{40}\text{K}$ (0.12% of natural K)** - $\beta$, $\gamma$ emitter.

$^{238}\text{U}$ and $^{232}\text{Th}$ are in equilibrium with all their daughters.
Radiological characteristics of coal ash produced in Israel (cont.)

Radioactivity concentrations (Bq/kg):

**Fly ash** - $^{40}\text{K}: 130-450$ av-290
- $1.1 \text{ mgK} / \text{kg ash}$
- $^{238}\text{U}: 100-220$ av-150
- $12 \text{ mgU} / \text{kg ash}$
- $^{232}\text{Th}: 80-230$ av-150
- $37 \text{ mgTh} / \text{kg ash}$

**Bot. ash** - $^{40}\text{K}: 80-560$ av-230
- $0.9 \text{ mgK} / \text{kg ash}$
- $^{238}\text{U}: 80-190$ av-130
- $11 \text{ mgU} / \text{kg ash}$
- $^{232}\text{Th}: 75-190$ av-130
- $32 \text{ mgTh} / \text{kg ash}$

$^{238}\text{U}$ and $^{232}\text{Th}$ are in equilibrium with all their daughters.
Concentrations of $^{40}\text{K}$, $^{226}\text{Ra}$, $^{232}\text{Th}$ in the ash

<table>
<thead>
<tr>
<th></th>
<th>General</th>
<th>Rutenberg</th>
<th>Rabin B</th>
<th>Rabin A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>7-12/07</td>
<td>1-6/07</td>
<td>7-12/07</td>
<td>1-6/07</td>
</tr>
<tr>
<td>#</td>
<td>19</td>
<td>21</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>Weight (Bq/kg)</td>
<td>6-32</td>
<td>5-46</td>
<td>8,88</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>14</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>15</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>13</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
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<td>12</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>46</td>
<td>41</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Concentrations in Coal (Bq/kg):

- $^{226}\text{Ra}$: 16, 13 (Ra-226)
- $^{232}\text{Th}$: 12, 12 (Th-228)

Concentrations in Fly Ash (Bq/kg):

- $^{226}\text{Ra}$: 128, 142 (Ra-226)
- $^{232}\text{Th}$: 110, 120 (Th-228)

Concentrations in Bottom Ash (Bq/kg):

- $^{226}\text{Ra}$: 122, 117 (Ra-226)
- $^{232}\text{Th}$: 107, 104 (Th-228)

The concentrations are in Bq/Kg units on dry material basis.
Radiological characteristics of coal ash produced in Israel (cont.)

External Exposure - mainly due to gamma radiation
Relevant parameters for calculating dose rates – activity concentrations, radioisotope specific gamma dose rate constants (photon energy, photon frequency (per dis.), distance, shielding, etc.).
Use is made of photon transport theory using Monte Carlo calculations or other methods.
Radiological characteristics of coal ash produced in Israel (cont.)

Internal Exposure - mainly due to alpha radiation
Committed Effective Dose per unit activity intake (10^{-6} SV/Bq)
by inhalation (for 1\mu m in diameter non particles, adults, S and M types)

\begin{itemize}
  \item \textbf{\textsuperscript{238}U series} – \textsuperscript{238}U (7.3), \textsuperscript{234}U (8.5), \textsuperscript{230}Th (13.0), \textsuperscript{226}Ra (3.2), \textsuperscript{210}Po (3.0).
  \item \textbf{\textsuperscript{232}Th series} – \textsuperscript{232}Th (23.0), \textsuperscript{228}Ra (2.6), \textsuperscript{228}Th (39.0), \textsuperscript{224}Ra (2.9), \textsuperscript{226}Ra (3.2), \textsuperscript{210}Po (3.0).
  \item \textbf{\textsuperscript{40}K} - gamma radiation only (0.003)
\end{itemize}

Note: Internal doses following inhalation of beta and gamma emitters and internal doses due all type of radiations following ingestion are much smaller (1-3 orders of magnitude).
Radiological characteristics of coal ash produced in Israel (cont.)

ALI Values for Inhalation

<table>
<thead>
<tr>
<th>Radioisotope Series</th>
<th>ALI Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}$U in equilibrium</td>
<td>600 Bq</td>
</tr>
<tr>
<td>$^{232}$Th in equilibrium</td>
<td>340 Bq</td>
</tr>
<tr>
<td>$^{40}$K</td>
<td>$6.1 \times 10^5$ Bq</td>
</tr>
</tbody>
</table>

ALI values in terms of ash volume (for average radioactivity concentration values i.e. 150 Bq ($^{238}$U)/kg ash, 150 Bq ($^{232}$Th)/kg ash and 230 Bq ($^{40}$K)/kg ash))

<table>
<thead>
<tr>
<th>Radioisotope Series</th>
<th>ALI Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}$U series</td>
<td>4 kg ash</td>
</tr>
<tr>
<td>$^{232}$Th series</td>
<td>2.3 kg ash</td>
</tr>
<tr>
<td>$^{40}$K</td>
<td>2,650 kg ash</td>
</tr>
</tbody>
</table>

ALI for all the above concentrations together – 1.5 Kg ash.

Note: The annual occupational hygiene limit for inhalation of dust is 0.004 kg.
### Average annual doses to the world population from all sources of Radiation (UNSCEAR 2000)

<table>
<thead>
<tr>
<th>Source</th>
<th>Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Natural</strong></td>
<td></td>
</tr>
<tr>
<td>Cosmic</td>
<td>0.4</td>
</tr>
<tr>
<td>Gamma rays</td>
<td>0.5</td>
</tr>
<tr>
<td>Internal</td>
<td>0.3</td>
</tr>
<tr>
<td>Radon</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>Artificial</strong></td>
<td></td>
</tr>
<tr>
<td>Medical</td>
<td>0.4</td>
</tr>
<tr>
<td>Atmospheric nuclear testing</td>
<td>0.005</td>
</tr>
<tr>
<td>Chernobyl</td>
<td>0.002</td>
</tr>
<tr>
<td>Nuclear power</td>
<td>0.0002</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2.8</strong></td>
</tr>
</tbody>
</table>
Exposure of man to natural and artificial ionizing radiation
2.8 mSv / y (UNSCEAR 2000)

Figure 1: The different contributions to the average annual dose

- Natural cosmic: 14%
- Natural internal: 11%
- Natural external: 18%
- Natural radon: 43%
- Medical: 14%
- Nuclear: 0.3%
Dose limits ICRP 103 2007
constraint for prolonged exposure of the public 0.3 mSv/y

ICRP Publication 103

Table 6. Recommended dose limits in planned exposure situationsa.

<table>
<thead>
<tr>
<th>Type of limit</th>
<th>Occupational</th>
<th>Public</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective dose</td>
<td>20 mSv per year, averaged over defined periods of 5 yearsf</td>
<td>1 mSv in a yearf</td>
</tr>
<tr>
<td>Annual equivalent dose in:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lens of the eyeb</td>
<td>150 mSv</td>
<td>15 mSv</td>
</tr>
<tr>
<td>Skinc,d</td>
<td>500 mSv</td>
<td>50 mSv</td>
</tr>
<tr>
<td>Hands and feet</td>
<td>500 mSv</td>
<td>–</td>
</tr>
</tbody>
</table>

a Limits on effective dose are for the sum of the relevant effective doses from external exposure in the specified time period and the committed effective dose from intakes of radionuclides in the same period. For adults, the committed effective dose is computed for a 50-year period after intake, whereas for children it is computed for the period up to age 70 years.
The doses encountered in these practices or caused by the products resulting from them (NCAB 2008)

Stacking and transporting (occupational annual dose, 2000 h)*

External: 180 μSv (18 mrem)
Internal: radon-200 μSv (20 mrem)
ash particles- 500 μSv (50 mrem)

If industrial hygiene protection measures (wetting, masks, etc.) are applied the internal dose value is reduced by an order of magnitude and the total annual dose is estimated to reach a maximal value of 250 μSv (25 mrem), less than 25% of the annual dose limit to members of the public

* The dose values were calculated assuming a maximal concentration in the ash of 200 Bq/kg, 200 Bq/kg and 600 Bq/kg for $^{226}$Ra, $^{232}$Th and $^{40}$K respectively
The doses encountered in these practices or caused by the products resulting from them (cont.) (NCAB 2008)

Infrastructure refill material in road and railway construction (occupational annual dose, 2000 h)*

External : 300 μSv (30 mrem)

Internal : negligible (open space, no penetration to underground water)
The doses encountered in these practices or caused by the products resulting from them (cont.) (NCAB 2008)

**construction**
Refill of 3 m of bottom ash (covered by 1.5 m of soil) Under the floor of dwellings in residential construction Project (occupational annual dose to construction workers and background gamma level in dwellings)*

**External**: non detectable

**Internal**: radon emanation from the ground lower than before the filling
The doses encountered in these practices or caused by the products resulting from them (cont.) (NCAB 2008)

**Agriculture**

Substrate for growing herb plants (uptake of NORM in the plants via the roots).

Concentration of all natural radioisotopes in the spices well under WHO limits.
The doses encountered in these practices or caused by the products resulting from them (cont.) (NCAB 2008)

Agriculture
Substrate (10-30 cm thick) for playgrounds and football lawns.
(annual dose to members of the public from staying on lawn)

External Dose to members of the public
20-50 μSv (for 500 hours per year standing or laying on lawn).
The doses encountered in these practices or caused by the products resulting from them (cont.) (NCAB 2008)

Building products (i.e. concrete)
Concrete may contain up to 7% (by weight) fly ash (as a replacement of sea sand).
A typical concrete has a density of 2,300 kg/m$^3$.
For an average concentration in the ash of 150,150 and 290 Bq/kg (as) of $^{238}$U, $^{232}$Th and $^{40}$K, respectively, the contribution of the ash to the radioactivity concentration in the concrete is 10.5, 10.5 and 20.3 Bq/kg (con) of $^{238}$U, $^{232}$Th and $^{40}$K, respectively.
The doses encountered in these practices or caused by the products resulting from them (cont.) (NCAB 2008)

Concrete (cont.)
These values should be compared with radioactivity concentrations in conventional concrete in Israel (with no ash added) of 25,8 and 75 Bq/kg (con) of $^{238}\text{U}$, $^{232}\text{Th}$ and $^{40}\text{K}$, respectively (schles 2002).
This adds about 30% to the gamma dose to residents of a concrete building.
However the significant reduction (about 5 fold) in the radon emanation in concrete made with ash counterbalances the additional gamma dose.
The doses encountered in these practices or caused by the products resulting from them (cont.) (NCAB 2008)

concrete (cont.)
The net dose increment to residents of a standard concrete dwelling due to the incorporation of coal ash in the concrete (7%) is evaluated to reach 30 -100 μSv/y (7000 h)
Doses – Summary

• **Handling of the ash** - Up to 250 uSv/y (occupational).

• **Utilization of the ash** -
  - *Infrastructure* – up to 300 μSv/ y (Occupational).
  - *Agriculture* – up to 50 μSv/ y (members of the public).
  - *The building industry* – up to 100 μSv/y (members of the public).

All doses well under the dose limits and constraints for occupational exposure and exposure of members of the public.
Optimized control System

an optimized framework can be developed by a sophisticated use of the concepts of exclusion, and exemption:

• Based on table 2 and Pa. 5.4 of IAEA Safety Guide RS- G-1.7 (IAEA 2004) coal ash could be classified as “non radioactive substance” or (if classified as ”radioactive substance”) can be exempted from the requirements of notification and authorization.

• The exposures encountered in “coal ash practices” (or caused by products which are result of these practices) can/shall be controlled within the framework of the enforcement of occupational hygiene and/or radiation protection regulations.
RADIONUCLIDES OF NATURAL ORIGIN

4.2. The values of activity concentration for radionuclides of natural origin, derived using the exclusion concept (paras 3.2–3.3), are given in Table 1.

4.3. The values have been determined on the basis of consideration of the worldwide distribution of activity concentrations for these radionuclides. Consequently, they are valid for the natural decay chains in secular equilibrium; that is, those decay chains headed by $^{238}\text{U}$, $^{235}\text{U}$ or $^{232}\text{Th}$, with the value given to be applied to the parent of the decay chain. The values can also be used individually for each decay product in the chains or for the head of subsets of the chains, such as the subset with $^{226}\text{Ra}$ as its parent.

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Activity concentration (Bq/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{40}\text{K}$</td>
<td>10</td>
</tr>
<tr>
<td>All other radionuclides of natural origin</td>
<td>1</td>
</tr>
</tbody>
</table>
Optimized control System (cont.)

RADIONUCLIDES OF ARTIFICIAL ORIGIN

4.4. The values of activity concentration for bulk amounts of material containing radionuclides of artificial origin, derived using the exemption concept (paras 3.4–3.7), are given in Table 2.

4.5. For noble gases, the exemption levels provided in Schedule I of the BSS [1] should be used. Further discussion is provided in Ref. [11].

MIXTURES OF RADIONUCLIDES

4.6. For mixtures of radionuclides of natural origin, the concentration of each radionuclide should be less than the relevant value of the activity concentration given in Table 1.

4.7. For material containing a mixture of radionuclides of artificial origin, the following formula should be used:

\[
\sum_{i=1}^{n} \frac{C_i}{(activity\ concentration)_i} \leq 1
\]

where \( C_i \) is the concentration (Bq/g) of the \( i^{th} \) radionuclide of artificial origin in the material, \( (activity\ concentration)_i \) is the value of activity concentration for the radionuclide \( i \) in the material and \( n \) is the number of radionuclides present.

4.8. For a mixture of radionuclides of both natural and artificial origin, both conditions presented in paras 4.6 and 4.7 should be satisfied.
International Workshop on
Environmental and Health Provisions for Coal Ash Utilization
Tel Aviv, Israel December 15th – 16th 2009

References


References (cont.)


References (cont.)