Implications of Israeli Standard 5098 on uses of coal fly ash in the local construction industry

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Local Construction Industry: Last Restraints and New Trends

- Higher loads (lack of free land, long spans, more multistoried buildings)
- Improved durability required along the Mediterranean Sea coast, in dry/hot climates, near Dead Sea, sinkholes formation, etc.
- Higher strength and more cement required
- Lack of quartz sand
Lack of Quartz Sand

- Present annual consumption of sand - 12 mln tons
- Expected to reach 20 mln tons by 2020
- Sand reserves in the coastal plain have dwindled to ~20 mln tons - less than 2 years of current consumption
- The Government has established an inter-ministerial committee to prepare a national master plan for the supply of sand through 2020
- Sand in the Northern Negev Desert (mainly in the Rotem Plain) – a future reserve
Coal Ash in Local Construction Industry

- ~100% FA is utilized, ~1 mln tons in construction:
  - manufacture of pozzolanic cement
  - cement additive
  - sand substitute in concrete production

- The rest of FA is being used in:
  - ceramics industry
  - road embankment
  - for agricultural purposes

- IEC and Nesher came up with innovative technologies for the commercial utilization of FA and its disposal
Coal ash utilization forecast balance-sheet in Israel, offer and demand (thousand tones)

- Industrial demand is increasing
- Solves the utilization problem

<table>
<thead>
<tr>
<th>Feasible scenario</th>
<th>2003</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fly ash</td>
<td>Bottom ash</td>
</tr>
<tr>
<td>Cement</td>
<td>482</td>
<td>500</td>
</tr>
<tr>
<td>Concrete</td>
<td>497</td>
<td>700</td>
</tr>
<tr>
<td>Concrete products</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>Masonry blocks</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>141</td>
<td>140</td>
</tr>
<tr>
<td>Agriculture</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>Industry</td>
<td></td>
<td>450</td>
</tr>
<tr>
<td>Export</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td><strong>Total uses</strong></td>
<td><strong>1200</strong></td>
<td><strong>156</strong></td>
</tr>
<tr>
<td><strong>Produced</strong></td>
<td><strong>1232</strong></td>
<td><strong>137</strong></td>
</tr>
</tbody>
</table>
A Need to Introduce National Standard Regulating Radioactivity of Building Materials

- On the other hand, the increased demand (2.2 mln tones forecast for 2010) means higher radionuclide levels in building materials, increase in radiation exposure of the population, mainly to gamma doses
Enhanced Radioactivity of By-Products used for Construction

- Blast-furnace slag
- Peat fly ash
- Oil shale ash
- Phosphogypsum
- Coal fly ash
Activity Concentrations in Common Building Materials and Industrial By-products Used for Building Materials in the EU

<table>
<thead>
<tr>
<th>Material</th>
<th>Typical activity concentration (Bq/kg)</th>
<th>Maximum activity concentration (Bq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(^{226}\text{Ra})  (^{232}\text{Th}) (^{40}\text{K}) Ra-equivalent</td>
<td>(^{226}\text{Ra})  (^{232}\text{Th}) (^{40}\text{K}) Ra-equivalent</td>
</tr>
<tr>
<td>Most common building materials (may include by-products)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td>40 30 400 114</td>
<td>240 190 1600 635</td>
</tr>
<tr>
<td>Aerated and light-weight concrete</td>
<td>60 40 430 150</td>
<td>2600 190 1600 2995</td>
</tr>
<tr>
<td>Clay (red) bricks</td>
<td>50 50 670 173</td>
<td>200 200 2000 640</td>
</tr>
<tr>
<td>Sand-lime bricks</td>
<td>10 10 330 50</td>
<td>25 30 700 122</td>
</tr>
<tr>
<td>Natural building stones</td>
<td>60 60 640 195</td>
<td>500 310 4000 1251</td>
</tr>
<tr>
<td>Natural gypsum</td>
<td>10 10 80 30</td>
<td>70 100 200 228</td>
</tr>
<tr>
<td>Most common industrial by-products used in building materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phosphogypsum</td>
<td>390 20 60 423</td>
<td>1100 160 300 1352</td>
</tr>
<tr>
<td>Blast furnace slag</td>
<td>270 70 240 388</td>
<td>2100 340 1000 2663</td>
</tr>
<tr>
<td>Coal fly ash</td>
<td>180 100 650 373</td>
<td>1100 300 1500 1644</td>
</tr>
</tbody>
</table>
Release of U and Th in Coal Combustion

(after Alex Gabbard)

US: Research into the problems related to FA storage and disposal should become a priority because about 100 million tons of FA are produced each year in the US alone.
Coal Fly Ash

- When used as the main component of building material, may result in enhanced exposure to $\gamma$-radiation
- Radon emanation power is low
Radionuclides in Local Building Materials

(Joint Technion – Ministry of Environment Research, 1998)

![Bar chart showing radionuclides in different building materials.](image-url)
Effective Specific Radioactivity of Local Building Products

Effective Specific Radioactivity of Aggregates Available in Israel

- Pumice (Italy)
- LWA from expanded clay (Norway)
- Pumice (Greece)
- LWA from CFA
- Tuff
- Basalt
- Dolomite
- Limestone
- River gravel (limestone-dolomite-flint)
- Quarry waste sand (dolomite)
- Sea sand (quartz)
Effective Specific Radioactivity of Building Binders and Industrial By-Products Available in Israel
Reference Levels for Radioactive Elements in Building Materials in EU

- **European Commission:**
  - Radiation Protection 112
    - "Radiological Protection Principles concerning the Natural Radioactivity of Building Materials", 1999,
    - Directorate-General Environment, Nuclear Safety and Civil Protection
Controls can be based on a lower dose criterion if it is judged that this is desirable and will not lead to impractical controls. Controls should be based on a dose in the range 0.3 – 1 mSv a$^{-1}$. This is the excess gamma dose to that received outdoors.
$^{226}\text{Ra}/300 + ^{232}\text{Th}/200 + ^{40}\text{K}/3000 < 1$

The activity concentration index shall not exceed the following values depending on the dose criterion and the way and the amount the material is used in a building:

<table>
<thead>
<tr>
<th>Dose criterion</th>
<th>0.3 mSv a$^{-1}$</th>
<th>1.0 mSv a$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials used in bulk amounts, e.g. concrete</td>
<td>$I \leq 0.5$</td>
<td>$I \leq 1$</td>
</tr>
<tr>
<td>Superficial and other materials with restricted use: tiles, boards, etc.</td>
<td>$I \leq 2$</td>
<td>$I \leq 6$</td>
</tr>
</tbody>
</table>
The activity concentration index should be used only as a screening tool for identifying materials which might be of concern. Any actual decision on restricting the use of a material should be based on a separate dose assessment. Such assessment should be based on scenarios where the material is used in a typical way for the type of material in question. Scenarios resulting in theoretical, most unlikely maximum doses, should be avoided.
The purpose of controls is to restrict the highest individual doses. Therefore, the dose criterion used for national controls should be chosen in a way that the majority of normal building materials on the market fulfill the requirements. Usually measurements of activity concentrations are needed only in cases where there is a specific reason to suspect that the dose criterion for controls might be exceeded. The Member States should require, as a minimum, the measurement of types of materials which are generically suspect.
Radiation Protection 112

- The use of industrial by-products containing natural radionuclides in building materials which could result in activity concentration indices exceeding the values specified in these recommendations should be justified on a case by case basis by Member States. It is expected that such justification would include non-radiological criteria.
Some traditionally used natural building materials contain natural radionuclides at levels such that the annual dose of 1 mSv might be exceeded. Some of such materials may have been used already for decades or centuries. In these cases, the **detriments and costs of giving up the use of such materials should be analyzed and should include financial and social costs.**
Reference Levels for Radioactive Elements in Building Materials in Israel

**Israeli Standard 5098 (Nov. 2002):**

- The Ministry of the Environment suggested to limit the exposure to 0.3 mSv/y for the practice, not exceeding the exposure to the public from the building material 0.45 mSv/y, assuming an average current exposure from existing building materials (background) of 0.15 mSv/y. Following this criteria a methodology to link activity concentration of the sample and annual dose was developed by the experts from the Soreq Nuclear Research Center.
IS-5098

- Considers the contribution of $^{222}\text{Rn}$
- Requires testing $^{222}\text{Rn}$ exhalation rate, if $|I| > 1$

Test of radionuclides ($^{226}\text{Ra}$, $^{232}\text{Th}$, $^{40}\text{K}$)

$^{222}\text{Rn}$ emanation is maximum ($e=0.05$)

- $|I| \leq 1$
- $|I| > 1$

Test of Rn exhalation
Israeli Standard 5098

- IS-5098 is the strictest standard on radioactivity of building materials in the world
- Many building products hardly meet IS-5098
- In fact, it covers now masonry blocks ONLY
- Concrete products have been excluded from the standard scope until 1.12.2005
- Implications on uses of FA in construction???
IS-5098: Influence of Thickness and Density


EC RP-112:
I = 0.58
- must be < 1 (1.0 mSv/y)
- must be < 0.5 (0.3 mSv/y)
Concrete, Density = 2400 kg/m³

Radioactivity index

Relative index

Concrete [22, 1, 35]
Ceramic Tiles
IS-5098 vs. EC RP-112

Ceramic Tiles, Density = 2600 kg/m³

- Made in Italy [243, 76, 1131]
- Made in Israel [46, 48, 776]

Radioactivity index

- IS-5098, <0.01 m
- EC RP-112 (0.3 mSv/y)
- EC RP-112 (1 mSv/y)
Granite Tiles
(in the meanwhile - out of scope in IS-5098)
IS-5098 vs. EC RP-112

Granite Tiles [75, 46, 5090], Density = 2300 kg/m³

Radioactivity index

Thickness, m

Relative index

Relative index

IS-5098
EC RP-112 (0.3 mSv/y)
EC RP-112 (1 mSv/y)
Concrete Mix Design

- Strength
  - B40 and higher (Cement = 450 kg/m³)
  - B30 (Cement = 230; 270 kg/m³)
- Portland cement CEM II 42,5 (Nesher)
- Dolomite coarse aggregate – represents ~50% of Israeli quarries
- Fossil silica sand (Rotem) – today’s and tomorrow’s local sand resource
- FA = 0; 150 kg/m³
<table>
<thead>
<tr>
<th>⁴⁰K</th>
<th>²³²Th</th>
<th>²²⁶Ra</th>
<th>Mix Constituent</th>
<th>Code/Source</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>180.9</td>
<td>245.8</td>
<td>230.4</td>
<td>FA</td>
<td>South Africa</td>
<td>1</td>
</tr>
<tr>
<td>5.9</td>
<td>1.0</td>
<td>25.1</td>
<td>Coarse Agg.</td>
<td>VD-6</td>
<td>2</td>
</tr>
<tr>
<td>257.1</td>
<td>9.3</td>
<td>7.8</td>
<td>Coarse Agg.</td>
<td>KP-23</td>
<td>3</td>
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<tr>
<td>90.9</td>
<td>4.3</td>
<td>4.5</td>
<td>Sand</td>
<td>SA-10</td>
<td>4</td>
</tr>
<tr>
<td>147.7</td>
<td>12.9</td>
<td>21.3</td>
<td>Sand</td>
<td>SR-11</td>
<td>5</td>
</tr>
<tr>
<td>263.7</td>
<td>11.5</td>
<td>7.4</td>
<td>Coarse Agg.</td>
<td>VC-9</td>
<td>6</td>
</tr>
<tr>
<td>11.2</td>
<td>1.4</td>
<td>25.8</td>
<td>Coarse Agg.</td>
<td>VK-3</td>
<td>7</td>
</tr>
<tr>
<td>21.9</td>
<td>1.1</td>
<td>42.0</td>
<td>Coarse Agg.</td>
<td>FA-19</td>
<td>8</td>
</tr>
<tr>
<td>25.0</td>
<td>1.9</td>
<td>40.5</td>
<td>Coarse Agg.</td>
<td>HR-14</td>
<td>9</td>
</tr>
<tr>
<td>9.8</td>
<td>1.1</td>
<td>32.2</td>
<td>Coarse Agg.</td>
<td>HC-17</td>
<td>10</td>
</tr>
</tbody>
</table>
### Radionuclides’ content in concrete with and without FA, Bq/ kg

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Cement content, kg/m³</th>
<th>FA content, kg/m³</th>
<th>Mix Code</th>
<th>Coarse Agg. Source</th>
<th>Fine Agg. Source</th>
<th>226Ra</th>
<th>232Th</th>
<th>40K</th>
<th>238U</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>450</td>
<td>0</td>
<td>VD-0</td>
<td>VD-6</td>
<td>SR-11</td>
<td>53.9</td>
<td>7.6</td>
<td>34.0</td>
<td>34.0</td>
<td>VD-0</td>
</tr>
<tr>
<td>2</td>
<td>450</td>
<td>0</td>
<td>VK-0</td>
<td>VK-3</td>
<td>SR-11</td>
<td>55.2</td>
<td>8</td>
<td>32.9</td>
<td>32.9</td>
<td>VK-0</td>
</tr>
<tr>
<td>3</td>
<td>450</td>
<td>0</td>
<td>HR-0</td>
<td>HR-14</td>
<td>SR-11</td>
<td>57.3</td>
<td>8.4</td>
<td>34.0</td>
<td>34.0</td>
<td>HR-0</td>
</tr>
<tr>
<td>4</td>
<td>450</td>
<td>0</td>
<td>HC-0</td>
<td>HC-17</td>
<td>SR-11</td>
<td>45.7</td>
<td>9.8</td>
<td>34.4</td>
<td>34.4</td>
<td>HC-0</td>
</tr>
<tr>
<td>5</td>
<td>450</td>
<td>150</td>
<td>VD-150</td>
<td>VD-6</td>
<td>SR-11</td>
<td>67.3</td>
<td>16.0</td>
<td>43.9</td>
<td>43.9</td>
<td>VD-150</td>
</tr>
<tr>
<td>6</td>
<td>450</td>
<td>150</td>
<td>VK-150</td>
<td>VK-3</td>
<td>SR-11</td>
<td>52.0</td>
<td>12.8</td>
<td>38.4</td>
<td>38.4</td>
<td>VK-150</td>
</tr>
<tr>
<td>7</td>
<td>450</td>
<td>150</td>
<td>HR-150</td>
<td>HR-14</td>
<td>SR-11</td>
<td>56.0</td>
<td>12.9</td>
<td>37.6</td>
<td>37.6</td>
<td>HR-150</td>
</tr>
<tr>
<td>8</td>
<td>450</td>
<td>150</td>
<td>HC-150</td>
<td>HC-17</td>
<td>SR-11</td>
<td>53.3</td>
<td>15.4</td>
<td>40.2</td>
<td>40.2</td>
<td>HC-150</td>
</tr>
<tr>
<td>9</td>
<td>230</td>
<td>150</td>
<td>VD-150-2</td>
<td>VD-6</td>
<td>SR-11</td>
<td>69.2</td>
<td>11.9</td>
<td>32.8</td>
<td>32.8</td>
<td>VD-150-2</td>
</tr>
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<td>10</td>
<td>230</td>
<td>150</td>
<td>VK-150-2</td>
<td>VK-3</td>
<td>SR-11</td>
<td>67.7</td>
<td>12.2</td>
<td>32.6</td>
<td>32.6</td>
<td>VK-150-2</td>
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<tr>
<td>11</td>
<td>270</td>
<td>150</td>
<td>HR-150-2</td>
<td>HR-14</td>
<td>SR-11</td>
<td>54.5</td>
<td>11.6</td>
<td>37.8</td>
<td>37.8</td>
<td>HR-150-2</td>
</tr>
<tr>
<td>12</td>
<td>270</td>
<td>150</td>
<td>HC-150-2</td>
<td>HC-17</td>
<td>SR-11</td>
<td>55.5</td>
<td>11.3</td>
<td>42.1</td>
<td>42.1</td>
<td>HC-150-2</td>
</tr>
</tbody>
</table>
Radon Exhalation

- Radon emanation coefficient $\approx 0.05$ for all types of concrete
Discussion

- Index for 4 concrete mixes containing 150 kg/m³ of coal fly ash is higher by ~20% than that of zero-FA mixes
- Almost all the mixes, even without FA, do not meet the Israeli standard
- At the same time, they meet easily the requirements in Europe, even those based on the strictest value of the allowable dose (0.3 mSv/year), such as Danish regulations
The Problem

- Concrete is the main building material in the region. Therefore, this situation is absurd and contradicts the principle (23) in RP-112: "The dose criterion used for national controls should be chosen in a way that the majority of normal building materials on the market fulfill the requirements"

- Urgent revision of IS-5098 is needed
What We Expect from Standards?

Example 1:
- “Environmentally-educated” consumer wants strict standard
- Authorities/Producers are not able to ensure the controls, which cost money

Example 2:
- “Economically-driven” consumer wants cheap product
- Producers agree (less limitations)
- Authorities are not always agree
What We Expect from Standards?

- Standard is always a compromise between desirable and achievable

Consumer

Government

Producer
How Much Standards Cost?

Example 1: IS-4466, Pt 3 “Steel for the reinforcement of concrete”
- Elongation (minimum) = 12%
- Cyclic tests: no fracture at 4% elongation (3 cycles)

Controls = Wasted money!
Example 2: IS-5098

- Masonry blocks
- Concrete
- Gypsum
- Natural stone
- Ceramics

Hardly applicable standard!
How to Solve the Problem?

- Professionally
  - Learning experience of foreign countries
  - Fundamental research
  - Applied research
  - Legislation (last step!)

- Unprofessionally
  - Public pressure
  - Strikes of port workers
  - Media intervention
Justification of FA Uses

- Alternative energy production costs?
- Alternative ways of FA disposal/utilization?
- How much the benefits of using FA cost?
  - Improved workability of fresh concrete
  - Improved durability of hardened concrete
- How much the society is ready to pay for higher radiation doses?
How Much Does it Cost to Decrease Annual Radiation Exposure for the National Budget?

- Preventing 1 mSv/y in Israel is equivalent to the increase of personal income by ~2%
- $1 \text{ mSv/y costs } 6 \text{ mln} \cdot 15 \text{ k}$ \cdot 0.02$

= $1.8 \cdot 10^9$
Conclusions

- Coal FA is valuable industrial by-product having a potential to be re-used in construction, however the problem of its contaminants has to be addressed.

- In view of this, there is a need in introducing environmentally safe and economically reasonable standard regulations, which should be based on justified radiological, social and economical legislation concepts.
Thank you!