EXPERT OPINION

THE COVERING OF THE ALMÁSFÜZITÖ RED MUD TAILINGS POND VII WITH COMPOSTED HAZARDOUS WASTE BY TATAI (CJSC)

Client

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(06,50: Waste + Packaging, 06,60: Landfilling, 51,06 Technical Chemistry)

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1. REASON FOR SEEKING AN EXPERT’S OPINION AND COMMISSIONING

By the OFFICIAL NOTIFICATION 392-6/2010 dated April 22, 2010, the Regulatory Authority for Environmental Protection, Nature Protection and Hydrology for Northern Transdanubia (Hungary), after reviewing the IPPC licence, granted the **environmental operating licence** for the **red mud tailings pond no. VII** (plot number 03/30, 03/32 Almásfűzitő, and plot number 0704/31, 0704/32 Dúnaalmás) for the bioconversion by **composting** of **132,000 t/a of hazardous waste** and **280,000 t/a of non-hazardous waste** to the company **Tatai Környezetvédelmi Zrt.** (herein referred to as “**TATAI(CJSC)**”). The operating licence includes a list of altogether 161 hazardous waste types (from code 010304* to code 200137* of the Hazardous Waste List of the European Waste Catalogue (EWC) and 244 non-hazardous wastes (from code 010101 to code 200306 of the EWC).

The undersigned EXPERT (contractor) was tasked by **GREENPEACE AUSTRIA**, Mister DI Herwig SCHUSTER, Fernkorngasse 10, 1100 Vienna, Austria, e-mail: herwig.schuster@greenpeace.at (client), with writing an **EXPERT OPINION** regarding whether this kind of (biological) treatment of the waste materials specified in the official notification of permission represents the state of art.

In addition, the undersigned expert was asked to conduct a risk assessment for the red mud tailings pond VII at Almásfűzitő from an environmental engineer’s point of view.
2. DOCUMENTS AND LITERATURE USED


4.) ANONYMOUS (2011): DVD Film “Almásfüzitő”. Helicopter photographs of the red mud tailings pond VII with deposited “compost prisms”.


17.) **Wissenschaftlicher Beirat für Abfallwirtschaft und Altlastensanierung im BMUJF (1999):** Stellungnahme zur Vererdungsverfahren für Abfälle (statement on the soilification of waste materials).


3. SITE DESCRIPTION

The red mud tailings pond VII at ALMÁSFÚZITÖ operated by TATAI (CJSC) (Tatai Környezetvédelmi Zrt.), which is covered by “composted” (hazardous) waste for preventing dust emissions (http://www.kornyezet-tata.hu), is located directly on the bank of the Danube river (which is also the border river between Hungary and Slovakia here), approx. 15 kilometres to the east of the town Komarom, see fig. 1. The location is of historical interest (roman settlement, old church).

Fig. 1: Geographical location of ALMÁSFÚZITÖ

Fig. 2: Detailed photo of the red mud tailings pond no. VII at Almásfüzitö.
The local alumina plant was in operation from 1950 to 1997. In this period, over 12 million tonnes of red mud were deposited in the 7 red mud tailings ponds of Almásfüzitő on an area of approx. 200 hectares in the floodplain of the Danube river, immediately behind the flood protection dam (2, 3).

3.1 Geology and Hydrogeology of Almásfüzitő

According to Viczián (3), the local geomorphology and hydrogeology in the area of Almásfüzitő is characterised by limestone terraces with layers of sand in between them. The floodplain in the bank area of the Danube river is characterised by highly water-permeable alluvial sediments with a thickness of 15 to 20 metres, see fig. 3.

![Geology and hydrogeology of Almásfüzitő according to Viczián (3) in (2).](image)

An impermeable aquiclude composed of loamy layers can only be found in a depth of over 20 metres, below the layers of sand and gravel; the flow direction of the groundwater is determined by the water level of the Danube river (i.e. at low or medium water levels, the groundwater flows from the red mud tailings ponds to the Danube; at higher water levels, the flow direction of the groundwater reverses, and the groundwater flows from the Danube to the red mud tailings ponds located directly on the bank of the Danube.)

On the riverbank, the area facing the Danube is delimited by a flood protection dam, which has a length of 10 kilometres and, in some sections, also serves as a dam for the red mud tailings ponds. Below the alluvial layers of sand and gravel (i.e. 15 to 20 metres below the ground level) there are old meandering river branches forming preferred groundwater streams flowing towards the Danube.

Additionally, it is important to note that “red springs” contaminated with red mud also escape at the dam surface. When the red mud tailings ponds I to VII were built in the 1950s, only the top humus layer was removed, and the underlying water-permeable sand layer was compacted without creating a mineral base sealing.
The dams of the tailings ponds I–VII were built using only the locally available material. According to handwritten geotechnical reports, a kind of film was additionally applied under the dam of the red mud tailings pond VII (3). For this reason, red-coloured leachate escapes into both the groundwater and the Danube. During floods, the red mud tailings ponds form islands in the river. The 10-kilometre dam at the bank of the Danube, which has a double function (i.e. flood protection, dam for red mud tailings pond) is 6 to 7 metres high (see also (4)).

On the basis of the available data, (2) compiled a water balance for the red mud tailings pond VII in the year 2010. With an annual rainfall of 919.4 mm/a and an evaporation rate of 386 mm/a, approx. 405,384 m³/a of contaminated leachate (particularly: pH, conductivity, Na, F, heavy metals) flow from the red mud tailings pond VII, which is 76 hectares in size, via the groundwater into the Danube. Since the ground water flow fluctuates depending on the water level, an even greater release of pollutants from the red mud tailings pond is to be expected in practice. For all red mud tailings ponds (I to VII), a total discharge of over 1 million m³/a of leachate is to be expected (2).

**Tab. 1: Water balance for the red mud tailings pond at Almásfüzitő according to (2).**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Deposits I–VI</th>
<th>Deposit VII incl. hazardous waste</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area size</td>
<td>124 ha</td>
<td>76 ha:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>45.6 ha open</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>30.4 ha covered</td>
<td></td>
</tr>
<tr>
<td>Underground soil below</td>
<td>compressed floodplain soil (clay and sand)</td>
<td>compressed floodplain soil (clay and sand) plus some loam</td>
<td></td>
</tr>
<tr>
<td>Precipitation recorded at the weather station of Tata commune in 2010: 919.4 mm (litre/m³) of water</td>
<td>1,140,056 m³</td>
<td>698,744 m³</td>
<td>1,838,800 m³</td>
</tr>
<tr>
<td>Covered part:</td>
<td>279,498 m³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open part:</td>
<td>419,246 m³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaporation: 386 mm/year (period 1950–1990 at Tatabánya)</td>
<td>475,640 m³ evaporating</td>
<td>293,360 m³ evaporating</td>
<td></td>
</tr>
<tr>
<td>Water balance for 2010 = precipitation that drained through the red dross deposits</td>
<td>664,416 m³</td>
<td>405,384 m³ of water entering and leaching the waste deposit from the surface</td>
<td>1,069,800 m³ of water draining to the Danube</td>
</tr>
</tbody>
</table>

According to Viczián (3), the area of Almásfüzitő is located in a seismically unstable, earthquake-prone region. This is underlined by the presence of hot springs in the surrounding villages. Historical sources give evidence of several earthquakes of higher intensity in which buildings were destroyed, such as the earthquakes in Komárom in 1763 and 1783 and the earthquake in Dunalmás in 1815. In the immediate vicinity of the red mud tailings ponds there also younger fault lines which, according to (3), jeopardise the stability of the dams. According to Viczián (3), several sections of the dams, which were built directly above the old meandering river courses, show defects caused by slides and subsidences. By now, most of these defects have been repaired. Summarising, Viczián (3) is very critical of the stability and safety of the red mud tailings dams. (Literal quote: “So, the stability and safety of the deposits dikes is not sustained at all”). Some site characteristics of Almásfüzitő are summarised in the following fig. 4 (2).
Fig. 4: Site characteristics of Almásfüzitő (2).
4. ALMÁSFÜZITŐ SITE INFORMATION AND PHOTO DOCUMENTATION

Up-to-date on-site information with original photos of Almásfüzitő from reliable sources (4, 5, 6) are available to the undersigned EXPERT. This information helps to give a realistic representation of the site conditions. The pictures shown below (selected from a comprehensive photographic documentation) are recent photos taken in calendar week 7, 2011.

Fig. 5: Restored part of the red mud tailings ponds I–VII at Almásfüzitő. The surface is partially covered with soil and overgrown with grass and bushes. (5)
Fig. 6: Escape of dried-up red mud between the riverside riprap and the dam (above) and on the riverside slope of the dam of pond VII (below). (5)

Fig. 7: Escape of strongly alkaline leachate on the riverside slope of the dam of the red mud tailings pond VII (5).
Fig. 8: Accumulations of dead snails and slugs at the riverside base of the dam near the point where the leachate escapes (above). Vehicle-accessible top of the dam of the red mud tailings pond VII with the overgrown riparian zone facing the Danube river (on the bottom right). (5)
Fig. 9: Section of the red mud tailings pond VII where “composted hazardous and non-hazardous waste” is deposited in what are known as prisms to be allowed to rest and mature: (5).

Fig. 10: Prisms of “aerobic-biologically treated and composted” hazardous and non-hazardous waste deposited in the red mud tailings pond VII (5).
Fig. 11: Detailed view of the “aerobic-biologically treated and composted” material deposited in prisms (5).
Fig. 12: Escape of liquid from the piled up prisms (5).

Fig. 13: Detailed view: liquids escaping from the prisms deposited in the red mud tailings pond VII (5).
Fig. 14: Transition zone: deposited prism material and non-surface-covered red mud tailings pond VII. There is no intermediate layer visible. (5).

4.1 IR Thermographic Examination of Waste Prisms in Almásfüzitö

During the aerobic biological treatment of biodegradable organic waste (composting, soilification, MBT), temperatures of over 80 °C may be generated in the windrows in the thermophilic rotting stage. This is aimed at killing infectious microorganisms, which can be found also and particularly in organic waste. Below, the results of an IR thermographic examination of various prisms deposited in the red mud tailings pond VII are shown. The thermographic images were taken in calendar week 9, 2011 (6).
Fig. 15: IR thermographic image of the prisms deposited in the red mud tailings pond VII (6).

Tab. 2: Results of the thermographic examination of “prisms” deposited in the red mud tailings pond VII.

<table>
<thead>
<tr>
<th>Image no.</th>
<th>Lowest value</th>
<th>Highest value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-4.6</td>
<td>14.6</td>
</tr>
<tr>
<td>2</td>
<td>-1</td>
<td>8.6</td>
</tr>
<tr>
<td>3</td>
<td>-3.2</td>
<td>7.4</td>
</tr>
<tr>
<td>4</td>
<td>0.4</td>
<td>8.6</td>
</tr>
<tr>
<td>5</td>
<td>0.9</td>
<td>9</td>
</tr>
<tr>
<td>6</td>
<td>-11.2</td>
<td>14.4</td>
</tr>
<tr>
<td>7</td>
<td>-0.6</td>
<td>7.4</td>
</tr>
<tr>
<td>8</td>
<td>-5.4</td>
<td>9.9</td>
</tr>
<tr>
<td>9</td>
<td>-0.3</td>
<td>8.5</td>
</tr>
</tbody>
</table>
The analysed results of the IR thermographic examination of “prisms” in the red mud tailings pond VII of Almásfüzitő are summarised in table 2. The corresponding thermographic images 1–36 can be found in ANNEX I.

It should be noted that these images were taken at the beginning of March (calendar week 9) 2011, in the evening of a sunny, relatively warm day. The mean ambient temperature measured was approx. -3 °C. The heat radiated from the surface of the prisms reached a **mean temperature** of +9 °C (range: 2.6 to 17.6 °C).

### 4.2 Chemical Analyses of 5 Samples Taken from „Compost“ Prisms at ALMÁSFŰZITŐ

A total of 5 samples taken from the “compost” prisms of Almásfüzitő (see figs. 9, 10 and 11) were personally handed over to the undersigned EXPERT by an absolutely reliable source which will not be revealed in the present EXPERT OPINION and examined in the accredited environmental analysis laboratory of the Institute for Sustainable Waste Management and Technology (IAE) of the Montanuniversitaet Leoben (see figure 15). As shown in table 3, the following results were achieved.
Tab.3: Analytic results for 5 “aerobic-biologically treated and composted” material samples taken from compost prisms at the red mud tailings pond VII of ALMÁSFÚZITÖ, analysed by IAE-Laboratory at Montanuniversitaet Leoben.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># 1</td>
</tr>
<tr>
<td>DM [%]</td>
<td>87</td>
</tr>
<tr>
<td>LOI [% DM]</td>
<td>4</td>
</tr>
<tr>
<td>TOC [% DM]</td>
<td>2</td>
</tr>
<tr>
<td>AOX [mg/kg DM]</td>
<td>11</td>
</tr>
<tr>
<td>HC-Index [mg/kg DM]</td>
<td>&lt; 50</td>
</tr>
<tr>
<td>el. Conductivity [µS/cm]</td>
<td>350</td>
</tr>
<tr>
<td>pH [-]</td>
<td>10</td>
</tr>
<tr>
<td>XRF-Results</td>
<td></td>
</tr>
<tr>
<td>SiO2 [% DM]</td>
<td>86</td>
</tr>
<tr>
<td>Al₂O₃ [% DM]</td>
<td>5.5</td>
</tr>
<tr>
<td>Fe₂O₃ [% DM]</td>
<td>1.3</td>
</tr>
<tr>
<td>CaO [% DM]</td>
<td>0.9</td>
</tr>
<tr>
<td>MgO [% DM]</td>
<td>0.8</td>
</tr>
<tr>
<td>S [% DM]</td>
<td>0.05</td>
</tr>
<tr>
<td>Cl [% DM]</td>
<td>n.s.</td>
</tr>
<tr>
<td>Na [% DM]</td>
<td>0.5</td>
</tr>
<tr>
<td>K [% DM]</td>
<td>0.1</td>
</tr>
<tr>
<td>Cr [mg/kg DM]</td>
<td>n.s.</td>
</tr>
<tr>
<td>Zn [mg/kg DM]</td>
<td>n.s.</td>
</tr>
<tr>
<td>Pb [mg/kg DM]</td>
<td>14</td>
</tr>
<tr>
<td>Cu [mg/kg DM]</td>
<td>n.s.</td>
</tr>
<tr>
<td>Ni [mg/kg DM]</td>
<td>n.s.</td>
</tr>
<tr>
<td>Sb [mg/kg DM]</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

DM: Dry matter  
LOI: Loss on ignition  
TOC: Total organic carbon  
AOX: Adsorbable organic halogenes  
n.s.: not significant
The results displayed at table 3 are clearly showing, that the investigated samples are mainly of inorganic origin (TOC-values between 2-7.5 % only) and do not at all correspond to the typical composition of compost-like material. Another aspect is the highly significant difference in composition between the 5 samples, reflecting an extreme heterogeneity in their matrices. Remarkable are the high values for AOX (in solid sample) and for electrical conductivity in sample # 5, as well as the high concentration of sulfur in sample # 3. In any case, deposition of materials like these on low-standard landfills do contradict with state of art as well as environmental regulations in progressive EU countries. It also should be mentioned, that according to German Environmental Law, the mixing of hazardous wastes is strictly forbidden, because of possible increase in risk potential due to unwanted chemical reactions.

4.3 DVD Film: The Covering of the Red Mud Tailings Pond VII of TATAI (CJSC) at Almásfüzitö

A DVD was handed over to the undersigned EXPERT by an anonymous source (4) for free use. It contains a film shot from a helicopter and showing the activities performed by TATAI (CJSC) for covering the surface of the red mud tailings pond VII. Since this DVD shows very impressive images which can make an important contribution to assessing the overall situation of Almásfüzitö, it is enclosed in the EXPERT OPINION.

5. COMPARISON OF THE RED MUD TAILINGS POND VII’s SURFACE COVER WITH THE STATE OF THE ART

The site information available (see sections 4.1, 4.2 and 4.3) for the red mud tailings pond VII at Almásfüzitö is sufficient to allow the following comparison with the state of the art in which the facts relevant for investigating this case are presented.

5.1 Pollution Potential of the Red Mud Tailings Pond VII at Almásfüzitö

Red mud from the neighbouring alumina industry has been deposited in the red mud tailings pond VII at ALMÁSFÜZITÖ in Hungary (reported total quantity ponds I–VII approx. 12 mil. tonnes). According to the OFFICIAL NOTIFICATION 392-6/2010 issued by the regulatory authority and dated April 22, 2010 (1), this tailings pond, which is 76 hectares in total size, is to be covered with a layer of „artificial soil”, which has a thickness of 1.5 metres and is produced by on-site “aerobic biological treatment and composting” of a total of 161 approved hazardous waste types and 244 approved non-hazardous waste types, so that dust emissions at the surface are avoided. Red mud consists of very fine-grained (d95 < 100 µm) dried-up deposits (main components: Fe2O3: 24–50 %, Al2O3: 12–30 %, TiO2: 2–18 %, Na2O: 1–8 %, SiO2: 5–30 %, as well as traces of Cr, V, Ni, Ba, Cu, Mn, Pb, Zn, Ga, Sc, Zr, Y, etc.) and has a high alkalinity level (pH ≥ 12) and thixotropic properties, i. e. under mechanical stress (e. g. pressure), reversible changes in viscosity from solid to liquid, leading to the typical flow behaviour of red mud, occur in the fine-grained substance.
Due to the multitude of the specified waste codes, it is virtually impossible to limit the potential range of pollutants contained in the hazardous and non-hazardous waste deposited after “composting”. It encompasses an extremely broad range (from code 010304* to code 200137*) of the European Waste Catalogue (EWC) and the Hazardous Waste List (3) and includes both organic and inorganic substances with hazardous characteristics according to ANNEX 3 (H-criteria) of the Austrian Ordinance on the European Waste Catalogue (7).

For instance, also the hazardous waste with the EWC code 100329* “waste from treatment of salt slags and black drosses containing dangerous substances” is approved for the production of “artificial soil” by aerobic biological treatment and composting according to the aforementioned official notification.

It is to be noted that by the method of “bioconversion by composting” mentioned in the OFFICIAL NOTIFICATION 392-6/2010 issued by the regulatory authority (1), a method which is to be classified as a sort of “soilification”, most of the persistent pollutants contained in the waste materials specified in this official notification cannot be degraded nor immobilised, which leads to the potential danger of discharge into the environment.

5.2 Hazard Potential of the Red Mud Tailings Pond VII at Almásfüzitő

Most importantly, the barriers in place to prevent the transport of pollutants from the landfill to the environment need to be evaluated so that the hazard potential of landfills and deposits (for existing subjects of protection) can be properly assessed.

According to the state of the art, landfills are designed as multi-barrier systems which have to show the following main barriers:

- **Natural site** (geological/hydrogeological subsoil)
- **Inert behaviour of the waste**
- **Technical landfill structures**
- **Monitoring**

- **Natural Site Barrier**

The requirements for a landfill site in accordance with the state of the art are specified in section 5 of the Austrian Landfill Ordinance 2008 (8).

The landfill/red mud tailings pond VII at ALMÁSFÜZITŐ is located directly at the Danube river, and is separated from the river bank only by a dam consisting of mainly piled, soil-like material (earth, partially red mud). It is located within the flood zone of the river, in an earthquake-prone region (see sections 3 and 3.1 as well as (2), (9) and (3)).

According to Viczián (3), the local geomorphology and hydrogeology of the site of Almásfüzitő is characterised by limestone terraces with layers of sand and gravel in between them.

The subsoil of the red mud tailings pond VII situated in the floodplain contains highly water-permeable alluvial sediments with a thickness of 15 to 20 metres; a largely impermeable aquiclude composed of loamy layers can only be found in a depth of over 20 metres, below the layers of sand and gravel.

By today’s standards, this kind of landfill site is absolutely unsuitable (i.e. the local conditions disqualify the site as a possible landfill location) and would not obtain a landfill construction permit according to the Austrian Landfill Ordinance 2008 (8). It is obvious that
an exchange between the leachate and the groundwater (bank filtrate) is taking place; the
direction of flow fluctuates and depends on the respective hydraulic gradient and hence on
the water level of the Danube river (see also photo documentation in chapter 4). Based on
the existing orography and the unfavourable geological/hydrological local conditions, it can
safely be assumed that no effective natural site barrier is in place. What the danger of
earthquakes and floods means for a risk structure at a risk spot, can be seen from the
example of FUKUSHIMA, Japan.

- **Internal barrier (degree of waste inertisation)**

The most important barrier of a landfill is what is known as “internal barrier”, i. e. the degree
of inertisation of the deposited waste. With regard to red mud, the following is to be noted:
Due to the causticity typical of this residue (i. e. BAYER process), the depositing of red mud
leads to the formation of very strongly alkaline leachate ($\text{pH} \geq 12$) over time. Then again, the
solubility of heavy metals in red mud (exceptions: anion formers such as arsenate,
vanadate, chromate or amphoteric metals such as copper, zinc and lead) is low, which is
also due to its zeolite-like properties. Regarding the (partially hazardous) waste deposited
directly above the red mud (without an intermediate layer) and pre-treated by “composting”
or, more precisely, “soilification”, the following is to be noted: Persistent pollutants (e. g.
heavy metals, PAHs, etc.) cannot be degraded nor immobilised using this (aerobic) pre-
treatment method (see section 4.2). Moreover, persistent organic pollutants and inorganic
anions are not retained by the red mud deposit layer located directly below the surface
cover. This results in a significant environment-relevant pollutant mobilisation potential
(which depends on the types and quantities of the aerobic-biologically pre-treated waste
deposited to form a covering layer).

The state of the art for composting and soilification is, inter alia, defined in (10, 11).
A comparison with the method used for producing “artificial soil” in Almásfüzitő reveals the
following differences:
Aerobic treatment of biogenic waste (composting) proceeds through the following three
stages shown in figure 16:

![Temperature development in a compost windrow](image)

Temperatureentwicklung in einer Kompostmiete = Temperature development in a compost windrow
Fig. 16: Typical temperature course during the three stages of composting

- **Degradation (or thermophilic) stage**
  At the beginning of this stage, which lasts approx. 3 to 4 weeks, mesophilic microorganisms (their optimal working temperature is approx. 40 °C) convert the readily degradable substances such as proteins and simple carbohydrates (starch, sugar). Since the rapid conversion initially results in an accumulation of organic acids, the pH-value initially slightly decreases. At the same time, a large amount of energy is released, and the temperature rapidly increases to a range of 60 to 80 °C. As a consequence, the mesophilic microorganisms die and thermophilic fungi and bacteria begin to thrive. Now, the degradation of cellulose and hemicellulose already sets in. (Cellulose is the main component of plants.) Cellulose-decomposing moulds may cover the compost with a white-grey mycelium very early on. The pH-value increases, alkaline and alkaline earth ions are released, and organic acids are metabolised by microorganisms.

- **Conversion (or mesophilic) stage**
  When the readily degradable compounds are largely degraded, the temperature decreases to approx. 40 to 45 °C again, and the mesophilic microorganisms (fungi, bacteria) continue the cellulose conversion process. The cell wall component lignin (which comprises approx. 30% of the wood structure) is degraded by special fungi (called Basidiomycota or basidiomycetes), forming humic substances together with protein components. The mineral nutrients and the humic acids associate to form what is known as the humus complex. The compost becomes **brown in colour** and obtains a **crumbly structure**. At this stage, it has the greatest fertilising effect. (However, due to its low level of plant compatibility, it cannot be used in practice yet.)

- **Development (or maturation or cooling) stage**
  Temperature further decreases until reaching the ambient temperature. The transition to the maturation stage is seamless. At this maturation stage, the stable humus fraction gradually develops. The longer the compost is allowed to mature, the more similar to soil it becomes. The nutrients are bound more and more tightly to the clay-humus complex; the fertilising effect gradually decreases, while the (soil developing) humus effect and the level of plant compatibility increase.

Due to the degradation processes and the evaporation of water, the mass of the originally used materials is reduced by approx. 30 to 50%. (This is known as “rot loss”.) In the composting process, stable humus complexes are generated along with carbon dioxide, water and heat, which fulfil a number of important functions in the soil:

- storage of nutrients and water;
- stabilisation of the crumbles (no washout);
- buffering (pH-value stays neutral or close to neutral);
- detoxification of the soil by binding heavy metals and organic pollutants.

The following factors are important for an optimal composting process:
- **oxygen supply**;
- CO₂ content (indicator of biological activity)
- water content
- temperature
- pH-value
- diversity of organisms (living conditions)
- composition of the used materials (substrate and structural materials)
- homogenisation (mixing).

The temperature course over time is an important indicator of the development or progress of the composting process (see figure 17).

![Temperature Course in Composting Trial at Pátio](image)

**Temperaturverlauf bei Kompostiersversuch Pátio**

- Temperaturverlauf bei Kompostiersversuch Pátio = Temperature course in the composting trial at Pátio
- Temperatur [°C] = temperature [°C]
- Rottedauer [Tage] = rotting time [days]
- Temperatur in Miete = temperature in windrow
- Außentemperatur = outside temperature

**Fig. 17: Example of temperature curves of a composting trial. Adapted from (12)**

According to the state of the art, in the aerobic process of composting, a fundamental distinction is made between the following two systems or methods:
- **Natural aeration** (in open windrows, which are re-stacked or turned)
- **Forced aeration** (in closed systems)
Fig. 18: Re-stacking of open triangular windrows according to KOMPTECH.  
www.komptech.com

In open windrow composting, the waste to be composted in the triangular windrow is re-stacked for aeration over a period of 10 weeks. In the first week, it is re-stacked 2 to 3 times, afterwards (from week 2 to week 10) it is re-stacked 1 to 2 times per week. Apart from aeration through re-stacking, rotting time and compost quality are influenced by controlled irrigation.
Fig. 19: Forced aeration in a closed system covered with a tarpaulin (Lorber, 2011)

Alternatively, forced aeration in the closed system is used according to the state of the art, see figure 19.

After the rotting stage, which last approx. 10 weeks, when the temperature in the windrow has decreased to the ambient temperature again, the compost is allowed to mature and is then sieved for homogenisation, see figure 20.
A comparison with the method used in Almásfüzitő for aerobic biological treatment and composting of hazardous and non-hazardous waste, for producing “artificial soil” (i.e. soilification), reveals the following fundamental differences:

**Method description (1)**

- **Technological process of composting using hazardous waste with a low oil content (5 to 7 % TPH):**
  - Add hazardous and non-hazardous waste with a low oil content in prisms (typical dimensions: 20–40 x 5–6 x 2–3 metres) and homogenize the materials
  - Set the moisture content of the prism to approx. 35 %
  - Allow the material to rest and mature for 1 to 2 months, aerate and stir it when half of the maturation period has passed
  - Check the material and apply it

- **Technological process of composting using hazardous waste with a high oil content (15 to 20 % TPH):**
  - Add hazardous and non-hazardous waste with a high oil content in prisms (typical dimensions: 20–40 x 5–6 x 2–3 metres) and homogenize the materials
  - Set the moisture content of the prism to approx. 45 %
  - Inoculate the material with oil-degrading microorganisms
  - Allow the material to rest and mature for 4 to 6 months, stir and aerate it when half of the maturation period has passed
  - Check the material and apply it

It is to be noted that after “adding” hazardous waste in prisms and after setting the moisture content (to approx. 35 % and 45 %, respectively), the material is aerated and stirred only once after half of the “maturation period” (lasting 4 to 8 weeks and 16 to 24 weeks,
respectively), although the form of the prisms is significantly more disadvantageous with regard to natural aeration than the form of triangular widrows.

This definitively does not represent the state of the art. Obviously, the temperature course of the rotting stage is not monitored, either. This monitoring may not be necessary because supposedly (?) no thermophilic stage occurs. The results of the thermographic camera (see section 4.1 and Annex I) indicate this (According to the method description, the waste, after being added in prisms, is deposited in the red mud tailings pond to be allowed to “rest and mature”, see also section 4).

**Fig. 21: Sludge-like, earthy structure of the material deposited in the prisms to be allowed to rest and mature**

Because of the obvious absence of a thermophilic stage (60 to 80 °C), the infectious microorganisms (bacteria, pathogenic germs) contained in organic waste cannot be destroyed as required.

A comparison between figure 20 and figure 21 reveals considerable differences in the structure of the materials deposited for maturing. While the sieved municipal waste compost (in fig. 20) shows the characteristic crumbly structure of compost, the material deposited in the prisms clearly has a sludge-like consistency (see fig. 21).
Moreover, it certainly cannot be expected that by **stirring and aerating the material only once** after half of the maturation period, a significant aerobic degradation of the organic substances can take place, let alone a degradation or immobilisation of the pollutants present in the added hazardous and non-hazardous waste. The facts considered here suggest that a **soilification of waste through dilution** is to be achieved, which does not represent the state of the art. Hence, the effectiveness of the “internal barrier” is **not in place** or is greatly reduced due to the (potential) mobilisability of the “biologically pre-treated” waste, and is generally to be **called into question** due to the broad range of hazardous and non-hazardous waste types specified in the official notification of permission (1) and used for the production of the “artificial soil” for covering the surface of the red mud tailings pond VII.

- **Technical barriers**
  The state of the art of landfill technology is described in detail in section 6 of the Austrian Landfill Ordinance 2008 (8). Technical barriers are landfill structures such as:
  - base sealing,
  - surface cover,
  - leachate collection and treatment system, and
  - landfill gas collection and recovery/treatment system.

  In accordance with the state of the art, the following landfill structure (from bottom to top) would be required for the site of Almásfüzitő (8):
  - Rough formation using soil material with a low permeability (technical compensatory measure for a missing or inadequate site barrier).
  - **multi-part** (e. g. 3 x 25–30 cm) **mineral sealing layer** with a low permeability \(k_f \leq 1 \times 10^{-9} \text{ m/s}\)
  - HDPE film with a thickness of 2.5 mm
  - * protection fleece (geotextile)
  - * 50 cm drainage layer (gravel 16/32 mm) with leachate collection pipes
  - * protection fleece (geotextile)
  - landfill body (here: red mud disposal)
  - not applicable when a suspension of red mud is deposited in the water retention basin.
  - HDPE film with a thickness of 2.5 mm
  - * protection fleece (geotextile)
  - * 50 cm drainage layer (gravel 16/32 mm) with infiltration water collection pipes
  - * protection fleece (geotextile)
  - * topsoil (1 m) as a recultivation layer
  - recultivation with autochthonous plants (e. g. acacias, grass).
Fig. 22: Protection fleece over HDPE plastic film (Lorber, 2011)
For the disposal of hazardous waste, very rigorous base and surface sealing systems as well as the indoor storage or roofing-over of the waste for keeping the rainwater out are required, see figure 24.
A comparison with the situation at the red mud tailings pond VII at Almásfüzitő reveals the following fundamental differences:

The red mud tailings ponds I–VII at Almásfüzitő were build as of 1950. The top humus layer was removed, and the underlying water-permeable sand layer was compacted without creating a mineral or synthetic base sealing. The dams of the tailings ponds I–VII were also built using only the locally available material, i.e. dried-up river mud (see photo documentation in section 4).

According to unconfirmed reports, the red mud tailings pond VII is the only pond where a kind of synthetic film was applied; the film is said to have been applied under the dam, but not to the base of the tailings pond (2, 3, 13).

The escape of red-coloured leachate from the tailings ponds into the groundwater can be observed. According to (2), the annual volume of leachate expected to leak from pond VII is up to 405,384 m³.

Apart from the fact that deposited red mud has a reduced permeability ($k_f$ value: $1 \times 10^{-7}$ to $1 \times 10^{-9}$ m/s), no technical barriers, such as the base sealing or the surface cover, exist at the landfill of Almásfüzitő, as mentioned earlier, i.e. the groundwater is not protected against the entry of pollutants from the landfill body (by convection/advection and/or diffusion/dispersion).

Since the surface of the landfill is covered – only partially – with deposited “composted” (hazardous) waste, and is entirely exposed in some places in the form of dried-up red mud, it is not possible to speak of an effective surface cover either. Due to the absence of a surface drainage, contaminated surface water is stored in the covered area of pond VII, as shown in figure 25.

Fig. 24: Hazardous waste stored in a roofed structure at the SDAG landfill at Aszód (Lorber, 2011)
It remains to note that at present, the red mud tailings pond VII at Almásfüzitö virtually has no effective technical barriers, and thus definitely does not represent the state of the art (see 2, 9, 5, 3, 13).

- **External monitoring and control barrier**
  Environmental monitoring constitutes the outer component of the multi-barrier system of a landfill. According to the state of the art, environmental monitoring should be so designed that the escape of pollutants from the landfill body into the surrounding environment (in case the other barriers should fail) is detected in time so that appropriate countermeasures to avert dangers can be taken.

This includes, e.g., an adequate number of groundwater probes, which have to be sampled and analysed at regular intervals. According to the **OFFICIAL NOTIFICATION 392-6/2010** issued by the regulatory authority for the operating licence of pond VII at Almásfüzitö (1), the following requirements specified in **paragraph IV, points 33 to 37**, have to be fulfilled:
33. The monitoring shall be performed for all tailings ponds. For the purpose of the corresponding examinations, the wells I–VII, K2, NA1–NA3 and NA4/A as well as well 9695, which serves as a background well, shall be kept in operation.

34. The water level in the wells shall be measured monthly. The samples used to determine the water quality shall be taken semi-annually and, if possible, at the same time, taking into account the water levels of the Danube river as well as the highest and the lowest water levels.

35. The components to be examined include: water temperature; pH; sodium; specific electrical conductivity; COD; total hardness; iron; manganese; chloride, sulphate, nitrite, nitrate, ammonium, phosphate, cyanide and fluoride ions; molybdenum, barium, total chromium, nickel, copper, zinc, cadmium, lead, mercury, arsenic.

36. The TPH content of the water samples shall be determined once a year, the date of the analysis shall be adjusted to coincide with the other examinations. The PAH and PCB content of the water samples shall be checked if the TPH content exceeds 1 mg/l.

37. Once a year, the toxicity of the water samples taken shall also be examined using the daphnia short-time test. This analysis shall be performed at the same time as the determination of the mineral oil content.

42. In case of exceptional incidents, the necessary measures shall immediately be taken. In addition, the regulatory authority and the competent authorities shall be informed.

According to information from (5), observation wells for analysing groundwater samples can be found in a few places at the astern outer base of the dam of the tailings pond VII. Measuring points for collecting and recording geophysical and soil mechanical data for the purpose of assessing the stability of the dam are not in place. On the basis of the visual impression, the stability of the dam is to be called into question. The toxic sludge disaster at the MAL Zrt. alumina plant on October 4, 2010, which affected Devecser and Kolontár, has shown very dramatically that there is a real risk of dam failures at the older red mud tailings ponds located in Hungary. In the case of ALMÁSFÜZITŐ, this would have a direct impact on the Natura 2000 site located along the Danube river, which forms the border between Hungary and Slovakia here. In Almásfüzitó, the external monitoring barrier exists in a rudimentary form. However, in view of the aforementioned risks related to the site, a semi-annual to annual sampling interval for monitoring the quality of the groundwater seems to be nowhere near adequate, and the monitoring of the dam’s stability is missing entirely.

5.3 Summary Comparison with the State of the Art

As mentioned at the beginning, landfills are established according to what is known as the “multibarrier principle”, which represents the state of the art. This is based on the consideration that if one of the 4 main barriers fails, the resulting environmental hazards can be prevented or mitigated by the other barriers, which work independently from one another. In ALMÁSFÜZITŐ, the fundamental problem lies in the fact that the location selected for the red mud tailings pond VII is absolutely unsuitable for a landfill according to today’s criteria (EU Landfill Directive). Now, one would expect that the resulting safety deficit is compensated by the other 3 barriers, as mentioned above. But unfortunately, this is not the case at all because:
• There are no effective base sealing, no adequate leachate collection and treatment system, and no surface cover in place – i. e. in practice, virtually no technical barrier exists (2, 9, 3, 13).

• The “internal barrier” is based on the inert properties of the deposited waste. This is aimed at preventing or reducing the release (i. e. mobilisation) of pollutants. In the case of ALMÁSFŰZITŐ, the situation is such that on the one hand, strongly alkaline leachates are formed and released by the red mud, which was deposited first. On the other hand, the additional disposal of “composted” hazardous waste results in a significant increase in the pollution potential.

The method of aerobic biological treatment and composting of hazardous and non-hazardous waste for the production of the artificial soil used for covering the surface of the red mud tailings pond VII specified in the official notification 392-6/2010 of the grant of the operating licence (1) is not state of the art (11, 17). It is based on the controversial method of soilification. In the present case, the pollutants are not degraded to a significant degree or not degraded at all and are not immobilised, either. Instead, they are diluted by adding soil-like material to them so that limit values can be achieved. By applying this method, it is possible to reduce the concentration of pollutants; the load of pollutants, however, remains the same. The method of “soilification” does not represent the state of the art and is not in line with the principle of sustainability (“dilution of pollution is no solution”) (17). Using this method unnecessarily results in a dramatic increase in the pollution potential, and thus also in the hazard potential of the risk spot of pond VII, Almásfüzitő.

Persistent organic pollutants and inorganic anions (e. g. arsenate, chromate, vanadate and amphoteric elements such as Pb, Cu, Zn, etc.) cannot be retained by the red mud deposited between the waste layer and the soil.

This means that the important “internal barrier” in the case of Almásfüzitő has to be regarded as “ineffective”, particularly as the continued disposal of “composted” (hazardous) waste leads to an additional entry of pollutants which will increase over time – all the more so, as the list of hazardous waste types (161 EWC codes in total) and non-hazardous waste types (244 EWC codes in total) approved according to the official notification contains a virtually unfathomable range of pollutants.

• Monitoring as an “external barrier” exists in a rudimentary form as far as leachate control is concerned. However, geophysical and soil mechanical monitoring and control of the dam’s stability, which would be important in the case of ALMÁSFŰZITŐ, is not taking place.

**Summary and conclusion:**
Due to the complete absence of both the “natural site barrier” and the “technical barrier” in conjunction with the completely inadequate “internal barrier” and the only rudimentary existence of the “external barrier”, the hazard potential of the landfill of ALMÁSFŰZITŐ is to be classified as “extremely high”. A massive release of pollutants into the environment, and thus hazards to subjects of protection (human health, groundwater, Natura 2000 site, etc.) are to be expected, especially under extreme environmental conditions (maximum precipitation, floods, earthquakes).

From the undersigned’s point of view, it is indispensable to adopt appropriate measures; there is an immediate need for action within the meaning of “danger in delay”.

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6. THE RISK FACTOR OF DAM STABILITY

The sparse geotechnical documentation (2, 9, 3, 13) does not clearly indicate the construction method (e.g. water retention type?) by which the red mud tailings dam at Almásfüzitő, which in some places also serves as a flood protection dam of the Danube river, was built of locally available materials in the years following 1950.

![Diagram of a tailings dam](image)

**Figure 1. Water-Retention Type Dam for Tailings Disposal**

What is more, the available documentation does not specify what material (power plant ashes?) the impervious core of the dam (if it exists at all, see fig. 26) is made of, nor does it specify whether dam is equipped with a drainage system at its base (????), which can prevent a dam from being washed out. This is important particularly in the case of red mud given the fact that this waste type is highly thixotropic (i.e. it is known to flow under pressure). The additional disposal of “composted” (hazardous) waste implies an increase of the superimposed weight and favours the thixotropic behaviour of the deposited red mud, leading to an increased risk of dam failure. Monitoring and controlling the dam’s stability is essential to the proper safety management of the landfill of ALMÁSFÜZITŐ, and all the more so after the toxic sludge disaster at Devecser and Kolontár.

According to the long version of (3), called “diploma study” (chapter II/14), Viczián tells us that below the dried-up, hardened top layer of the red mud tailings ponds at Almásfüzitő (which he calls “cassettes”), red mud is said to be present in liquid/pasty form. This is the result of examinations of core drills.

Below, a translation of this diploma study by Viczián is quoted in excerpts:¹

“Red mud loses its water content only slowly. Decades after the disposal, material with a water content of 30 to 40 % was still found in deep drillings. In winter, the high water content leads to an increase in size (volume); after thawing, the size goes down again.

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¹ Translation from the German by V. N.
In dry periods, red mud loses moisture and decreases in size (volume). In summer, the surface of the landfill is littered with drought cracks, and the area of the lake (water surface) covering large part of cassette VII decreases.

In periods of high precipitation, these cracks disappear, and the waste absorbs vast amounts of water. The changes in the size (volume) of the red mud produce considerable stresses in the landfill dams, thus accelerating damage to them.

Mainly after periods of high precipitation, when the excess water accumulates in the landfill area, this infiltration line grows (channel formation), and water escapes at the base of the dam slope. The formation of springs reduces the stability of the dams and causes them to slide. The water level of red mud depends on the groundwater level, which, in turn, is influenced by the Danube, and on the precipitation in this area. The covering of the landfills with an impervious layer would reduce the amount of water infiltrating the red mud and washing it out. A cover would have a positive effect on both the amount of the leaching polluted water and the condition of the dams. The dams are also weakened by the tunnels made by moles and other digging animals, which serve as stream lines (escape channels) for landfill waters. ...”

In literature (18), extensive data about the construction of embankments for tailings ponds exist. There are also in-depth analyses of the causes of dam failures (18, 19). Table 4 gives a comparison of different embankment types.
Tab. 4: Comparison of different embankment types for tailings ponds (18).

As regards the topic of “dam stability”, the undersigned refers to the literature available and quoted in excerpts here (18, 2, 9, 3, 13, 16, 30). Against the background of the dam failure disaster of Devecser and Kolontár on the 4th of October 2010, also the stability of the dam of the red mud tailings pond VII at Almásfüzitö is, in any case, to be called into question.

Source: [Vick1983]
7. SUMMARY AND CONCLUSION WITH RECOMMENDATIONS

The aerobic biological treatment and composting of hazardous and non-hazardous waste for the production of “artificial soil” used for landfill covering practised by the company Tatai Környezetvédelmi Zrt. (TATAI (CJSC)) and approved by OFFICIAL NOTIFICATION 392-6/2010 dated the 22th of April of 2010 does not represent the state of the art, and, what is more, is no sustainable solution for the red mud tailings pond VII at Almásfüzitő.

As the technological process used by TATAI (CJSC) is based mainly on the dilution of pollutants, pollutants cannot be sufficiently degraded nor immobilised. Hence, the site-specific hazard potential is significantly increased.

From the undersigned EXPERT’s point of view, a risk technology is used at the risk spot of Almásfüzitő, which clearly runs against environmental interests. Risk reduction measures such as:

- **no further disposal** of “composted” hazardous waste by TATAI (CJSC) in the red mud tailings pond VII;
- **application of a surface cover with a drainage system** in accordance with the state of the art;
- **checking and monitoring of the dam’s stability** by using geophysical and soil mechanical techniques, are urgently required.

A **surface cover** of the red mud tailings pond VII at Almásfüzitő representing the STATE OF THE ART would consist of the following elements (from bottom to top):

1. Covering of the surface with a **2.5 mm HDPE sheet**
2. Application of a **protection fleece** (geotextile)
3. Application of a **50 cm area drainage layer** (gravel 16/32 mm) with installed rainwater collection pipes
4. Another **protection fleece**
5. **1 m recultivation layer** of topsoil material
6. Recultivation with **autochthonous plants** (e. g. grasses, acacias).

It is strongly recommended to have the **dam stability** checked and assessed by a recognised international expert.

8. DECLARATION

The undersigned EXPERT hereby confirms that the present FINDINGS and the present EXPERT OPINION were drawn up to the best of his knowledge and belief and in compliance with STATE-OF-THE-ART TECHNOLOGY and SCIENCE.

Leoben, May 25, 2011

(O. Univ. Prof. Dipl.-Ing. Dr. techn. Karl E. Lorber)
9. ANNEX

ANNEX I: Photo documentation – Images taken with an IR Thermographic Camera
PROPERTIES OF TAILINGS DAMS

What are tailings?

Tailings are the residue of the milling process used to extract metals of interest from mined ores or to clean coal. During this process, ores are milled and finely ground, and then treated in a flotation and/or hydrometallurgical plant. The extracted metal represents a small percentage of the whole ore mass and so, the vast majority of the mined material ends up as a finely-ground slurry. Tailings contain all other constituents of the ore except for the majority of the extracted metal. These consist of heavy metals and other substances at concentration levels that can be toxic to biota in the environment. Moreover, tailings contain the chemicals added during the milling process, although these levels and types are generally not of major concern. After milling, these contaminants are better available for dispersion into the environment than in the original ore because of their finer particle size and higher surface area. Furthermore, the mechanical stability of the tailings mass is poor because its small grain size and high water content.

Tailings impoundments

Most mill tailings produced worldwide are dumped in large surface impoundments ("tailings dams"). In other cases, tailings are processed for use as backfill in underground mine workings. The embankments of these large impoundments are typically constructed as earth-fill dams. Although water-retention dams are suitable for use, their cost is too high.

Unlike water-retention dams, tailings dams usually are not initially constructed to completion but rather, are raised sequentially as the impoundment fills.

Types of sequentially raised tailings dams
UPSTREAM TAILINGS DAMS

Upstream-type embankments are the most popular embankments for tailings dams: new parts of the embankment are built on top of the slurries impounded during the previous stage - the dam crest thus moving "upstream".

Because of its low cost, the upstream method is used with most tailings dams worldwide, but it must be built and operated with great care and attention as it has the highest risk of failure of all the methods. Dam stability is of great concern with this type of tailings embankments:

- The phreatic surface is critical for dam stability. Dam failure can occur, if the beach width between the decant pond and the dam crest becomes too small - from flood inflow, or from improper mill operation. While the determination of phreatic surface location is important for upstream-type embankments, it is more complex for this method than for any other type of tailings-retention structure.

Phreatic Surface in Upstream Tailings Dams

Influence of beach permeability variation for nonhomogeneous embankments

Influence of beach width for homogeneous, anisotropic embankments

$k_i$ = permeability at the edge of the ponded water at the slimes zone
$k_0$ = permeability at the spigot point (dam crest)
$k_F$ = permeability of foundation
$k_i / k_v$ = anisotropy ratio (horizontal vs. vertical)
- Upstream dams are highly susceptible to **liquefaction** under severe seismic ground movement. This may result from earthquakes, from mine blasting, or even from the movement of heavy equipment.
- Upstream dam stability is endangered if the **rise-rate** of the dam is too high. Raising rates greater than 15 m/yr can be hazardous as the tailings particles need time to consolidate to their highest permeability. If the particles do not settle sufficiently, this can produce excess pore pressure within the deposit, decreasing stability.

<table>
<thead>
<tr>
<th>Comparison of Surface Impoundment Embankment Types</th>
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<tr>
<td><strong>Water Retention</strong></td>
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<td>Relative Embankment Cost</td>
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Source: [Vick1983]
BIBLIOGRAPHY


[The textbook on the subject! A reprint was published in 1990 by BiTech Publishers Ltd., Richmond B.C., Canada (ISBN 0-921095-12-0)]


[Provides overview of various methods used to dispose tailings and types of impoundments used. Describes basic concepts to design impoundments including site-specific variables of concern. Discusses embankment stability and water management. Includes a case study on a lined tailings impoundment. The report relies on Vick's book (see above). Be careful: Figures 8-11 are mixed up!] http://www.epa.gov/emaqwer/other/mining/techdocs/tailings.pdf


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• Tailings Dams - Design of drainage, Bulletin 97, International Commission on Large Dams, 1994; 120 pages bilingual (French/English).

• Tailings Dams and Seismicity: Review and Recommendations, Bulletin 98, International Commission on Large Dams, 1995; 60 pages bilingual (French/English).

[According to ICOLD, almost 200 tailings dams "have failed during earthquakes, releasing liquefied tailings that have led to serious damage and loss of life... Tailings dams are very susceptible to earthquake damage." The brochure explores reasons for these failures and suggests solutions to strengthen current dams and build more stable ones. Aspects covered: "Seismic performance; seismicity assessment; geotechnical evaluation; design and construction; seismic stability analysis; and remedial measures to improve safety."]


  Full text available through ADAMS, Accession No. ML003740223 (1M TIFF)

  Full text available through ADAMS, Accession No. ML003740229 (0.6M TIFF)

• International Commission on Large Dams - http://www.icold-cigb.net/
  Commission Internationale des Grands Barrages, 151, boulevard Haussmann 75008 Paris, France, Tel: +33-1-40425438, Fax: +33-1-40426071

• United States Society on Dams - http://www.ussdams.org/
  (formerly United States Committee on Large Dams - USCOLD) http://www.ussdams.org/c_tail.html

• Australian National Committee on Large Dams - http://www.ancold.org.au/

• Canadian Dam Association - http://www.cda.ca/

• http://www.tailings.info