SEDIMENTS AND SUBMARINES
INDIANA JONES AND ENVIRONMENTAL ENGINEERING

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Can UT prof neutralize Nazi sub threat?

Sunk in North Sea in 1945, U-864 still holds toxic payload

By Asher Price
AMERICAN-STATESMAN STAFF

Early in the final year of World War II, the German submarine U-864 was motoring through frigid waters just west of Norway on its way to Japan. The secret mission of the specially outfitted vessel: to deliver at least 60 tons of mercury to the Axis ally for use in explosives.

But the British military detected the sub's assignment through its code-breaking program and dispatched a submarine, the HMS Venturer, to intercept. U-864 and its cargo were sunk, and about 70 men were sent to their deaths.

Now, facing an environmental threat from the mercury, the Norwegians have turned to University of Texas environmental engineering professor Danny Reible to figure out a way to entomb the wreck.

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About 60 years after the sub, split into at least two portions, sank to the ocean floor, the Norwegian navy located the wreck and found troubling signs that the steel canisters that contain the mercury are corroding, raising the possibility of an environmental disaster. Should the mercury escape it could contaminate fishing stocks in the region.

See MERCURY, A10

AUSTIN = REPUBLIC OF TEXAS BIKER RALLY

Chrome on Congress
How do assess the risks of contaminated sediments?
- Should focus on what is or may be available to organisms - not bulk sediment concentration
- Our efforts – understand sediment-water exchange processes and evaluate interstitial water concentration of contaminants as indicator of availability

How do we manage those risks?
- Our efforts focus on in-place remedies - sediment capping
Contaminated Sediments
What are they?

- Sediments are the ultimate “sink” for many contaminants
  - Polynuclear aromatic hydrocarbons (e.g. naphthalene, benzo[a]pyrene)
  - Polychlorinated biphenyls (PCBs, banned in 1970’s but persistent)
  - Dioxin – similar to the PCBs
  - Metals (Cadmium, zinc, copper, lead, nickel and mercury)
  - **Refractory, sorbing contaminants**

- Historical sources largely controlled
  - Direct discharges to surface waters significantly reduced
  - Legacy of contaminated sediments an important source
  - Continuing sources, however, limit potential cleanup
    - Difficult to control point sources
    - CSO’s – Combined sewer overflows
    - Runoff from contaminated sites
Legacy of Contaminated Sediment

Duwamish Waterway
Seattle WA
Legacy of Contaminated Sediments
Grasse River, New York

Courtesy AnchorQEA/Alcoa Inc
Contaminated Sediments
Why are they so important?

- Lack of disposal options is a major impediment to harbor development
  - 95% of shipping trade passes through dredged ports
  - Dredging leads to resuspension, release of contaminants
  - NIMBY limits disposal of dredged sediment

- Significant impediment to unrestricted usage of waterways
  - Fish advisories throughout great lakes and other areas

- Widespread problem
  - Of 21,000 national sediment sampling stations (1996 survey)
  - 26% exhibit potential of adverse effects
  - Additional 49% exhibiting intermediate probability of adverse effects
  - About 30% of superfund sites involve contaminated sediments
Contaminated Sediments
Why are they so difficult?

- Sources often difficult to identify and control
- Sediments often reside in highly variable, dynamic systems
  - Tides, wave action, high flow events, propwash all contribute to uncertainty
- Large volume of sediment
  - Often greater than 1,000,000 m\(^3\)
  - Average Superfund site ex situ treatment - <30,000 m\(^3\)
- Large amounts of water
  - Dredged solids content often in range of 1-10%
- Often marginal contamination with incomplete exposure pathways and uncertain risks
- Mercury
  - Widely distributed
  - Cannot be degraded (although can be present in bioavailable forms)
  - Complex biogeochemical processes
Background

Mercury Contamination

WARNING!

Nearly all fish and seafood contain some amount of mercury and related compounds, chemicals known to the State of California to cause cancer, and birth defects or other reproductive harm. Certain fish contain higher levels than others.

Pregnant and nursing women, women who may become pregnant, and young children should not eat the following fish:

SWORDFISH • SHARK • KING MACKEREL • TILEFISH

They should also limit their consumption of other fish, including tuna.

Fish and seafood can be an important source of nutrients and an important part of a balanced diet. However, the federal Food and Drug Administration advises pregnant and nursing women, women who may become pregnant, and children to limit their weekly consumption of fish.

Fish that tend to have little or no mercury include shrimp and scallops. Mercury levels in tuna vary. Tuna steaks and canned albacore tuna have higher levels of mercury than canned light tuna.

For more information about the risks of mercury in fish and about the levels in various types of fish consult the following websites:

U.S. Food and Drug Administration (“FDA”)  www.cfsan.fda.gov
U.S. Environmental Protection Agency  www.epa.gov/ost/fish
or call the FDA toll-free at 1-888-SAFEFOOD 1-888-723-3366).
Bioaccumulation in the Food Web
Northwest Atlantic Food Web

Mercury → Methyl Mercury → Benthic Org. → Fish → Humans
Chemist/Engineer’s View of a Food Web

Mercury → Methyl Mercury → Benthic Org. → Fish → Humans
Background

1. Mercury source & movement to sediments
2. Mercury availability
3. Conducive Hg speciation
4. Conducive biogeochemistry
5. Food web transfer
Conceptual model – Amendments (Task3)

• To reduce Hg in food
  • control aqueous speciation – reduce bioavailability
  • sorbing amendments – reduce available Hg
  • isolate from biologically active zone – capping
  • Remove Hg from environment – dredging??

Solid phase  Aqueous phase

FeOOH  OM  FeS  K_{FeS}  Hg^{2+}  Hg(1)Hg(2)

Non-bioavailable  Bioavailable

CH_{3}Hg^+  SO_{4}^{2-}  HS^{-}

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Bioaccumulation in Food Web
Managing Risks of Sediments
What are the Options?

- Monitored Natural Recovery
  - Part of all remedies
  - May be an integral part of active remediation

- Dredging
  - Need to recognize impacts and limitations
  - Triggers a variety of onshore activities

- Capping
  - Clean sediment/sand layer over contaminated sediment
  - Can be rapidly implemented with minimal impact
  - Need to assess long-term protectiveness
Response to Remedial Approaches

**Risk Relative to Reference Conditions**

- Natural Recovery
- Dredging
- Capping (without maintenance)

**Time/yrs**

0 5 10 15 20 25 30 35 40 45 50

**Major cap breach without maintenance**
Is Dredging a Good Idea?

Dredging conducted early 2005 near outfall 001

[Bar chart showing total PCBs (ppm lipid) across different locations: Background Stretch, Near Outfall 001, Near Unnamed Tributary, Mouth of River. The chart includes data from years 1998 to 2005.]
Reduce risk by:

- Stabilizing sediments
- Physically isolating sediment contaminants from benthos
- Reducing contaminant flux to benthos and water column

Sand surprisingly effective for strongly solid associated contaminants

“Amended caps” for other situations
Objective of Capping: Physical Containment

- Clean Cap Layer
- Erosion
- Hyporheic Exchange
- Advective or Diffusive Transport
- Contaminated Sediment
- Benthic Activity
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Chrome on Congress
Unterseeboot -864 (U-864)

- **U-864**
  - Commander: Korvkpt. Ralf-Reimar Wolfram
  - Commissioned 9 Dec 1943
  - Used for training throughout most of 1944
- **Assigned to Operation Caesar late fall 1944**
  - Transferring military technology and supplies to Japan
  - **Cargo of U-864**
    - 65 tons of elemental mercury
    - Jet engine components from Me-262
    - V-2 missile guidance systems
    - German and Japanese scientists and engineers
- **Plans intercepted by code breakers at Bletchley Park**
- **HMS Venturer sent to intercept**

Source: en.wikipedia.org
Venturer vs U-864

**Venturer**
- Royal Navy V Class
- 545 tons, 206 ft in length
- 3” gun, 8 torpedoes (4 bow tubes)
- 13 knots (surface) 9 knots (submerged)
- Crew of 37

**U-864**
- German IXD class
- 1616 tons, 287 ft in length
- 105 mm (~4”)/45 mm (~2”), 24 torpedoes (4 bow, 2 stern)
- 19.2 knots (surface), 6.9 knots (submerged)
- Crew of 73 (including scientists for transport to Japan)
U-864 runs aground January 1945 and routed to Bergen for repairs

- Delayed by RAF bombing on 12 January
- Cleared area by 6 February but had to turn back with engine problems
- Escort arranged for 10 February but periscope seen by Venturer on 9 February
- Venturer follows to sink upon surfacing but ultimately fires 4 torpedoes in 3-D firing solution to avoid U-864 escape
- 4th torpedo strikes U-864 more than 3 minutes after firing
- Only instance of submarine sinking another submarine while both submerged
60 Years Later

- Late 1990’s- amateur historians and declassification of war documents leads to a renewed search for U-864
- Discovered by Norwegian Vessel Tyr in Spring 2003 in 150 m (~500 ft) of water after a nearly 5 year search

Source: www.history.navy.mil
Location of U-864
U-864 Resting on the Bottom
U-864 Mercury

- Front (bow) of sub
- Back (stern) of sub

- Mercury stored in containers in ship’s keel.

Robert Calzada  AMERICAN-STATESMAN
1,857 Mercury Canisters

Two Located
One Empty

One intact but initial 5 mm wall reduced to 1 mm
Sediment Sampling
U-864 Sediment Mercury Levels

<table>
<thead>
<tr>
<th>I</th>
<th>II Moderately polluted</th>
<th>III Significantly polluted</th>
<th>IV Severely polluted</th>
<th>V Extremely polluted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background &lt;0.15 mg/kg</td>
<td>0.15-0.6 mg/kg</td>
<td>0.6-3 mg/kg</td>
<td>3-5 mg/kg</td>
<td>&gt;5 mg/kg</td>
</tr>
<tr>
<td>Old guidelines (which the Figure is based on)</td>
<td></td>
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</tr>
<tr>
<td>&lt;0.15 mg/kg</td>
<td>0.15-0.63 mg/kg</td>
<td>0.63-0.86 mg/kg</td>
<td>0.86-1.6 mg/kg</td>
<td>&gt;1.6 mg/kg</td>
</tr>
<tr>
<td>New guidelines (valid from February 2008)</td>
<td></td>
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</table>
Mercury in the Environment

65 tons of mercury
Equivalent to enough Mercury to contaminate Norway’s total fish catch for 30 years
Observations only account for 3-15 tons of 60 tons believed to be in the submarine

Where is the remainder?
- Dispersed at time of sinking?
- Dispersed subsequent to sinking?
- Retained within keel of submarine?

Remote vehicles to confirm but withdrawn when sediment showed instability
Options

- Salvage submarine?
  - Can submarine be raised intact without loss of mercury?
  - 60 + years of corrosion - ability to support its own weight?

- Entomb submarine?
  - Material selection?
  - Ability to place and retain with confidence?
  - Long term effectiveness?
  - Potential for encouraging mercury methylation?
Effects of Capping

Physical Sequestration

- Clean Cap Layer
- Contaminated Sediment

Biogeochemical Changes

Pre-Cap

- Organic Matter

Post-Cap

- Organic Matter
Will capping increase methylation?

• Observed a ~50% increase in MeHg in test sediments (Lavaca Bay), but what about North Sea sediments?
  • Similar sulfur/sulfide concentrations but less organic matter which drives microbial activity causing sulfate reduction

• Can mercury and methyl mercury retention be guaranteed in perpetuity?
  • Perpetuity difficult to predict but increased methylation modest and expected to remain buried below cap
  • Mercury mobility low and can be further reduced through amendments

• Capping/Entombment Feasible!
Teams of experts evaluated all approaches/factors
- Entombment/capping
- Salvage
- Submarine corrosion
- Geotechnical considerations on sea bottom

Recommendation for burial/capping in place to Norwegian Coastal Authority – Fall 2008

Spring 2009 – Exploration of removal
Plans - 2009

- Salvage submarine and remove contents
  - Driven by fishing /environmental community concerns
  - Public perception- “Just remove it”

- Approach
  - Grappler structure to place submarine pieces on a platform and the platform raised to the surface and placed on submerged barge
  - Originally planned for summer 2010

- Likely need to remediate contaminated sediment remaining
  - Dredging
  - Capping
Current Status

- Salvage decision “tabled”
  - Cost, liability and feasibility concerns
  - Reassessment of decision currently ongoing
  - More detailed evaluation of other options ongoing

- Prognosis?
  - Likely some sediment removal where possible
  - Entombment of remainder including submarine