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Safeguards Tools for Geological Repositories: Passive Seismic Monitoring

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Applications of Safeguards to Geologic Repositories (ASTOR)

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Safeguards Goals

- Assure absence of (or identify) undeclared:
  - – Activities
    - Mining/tunneling, materials diversion, reprocessing
  - – Structures
    - Tunnels, buildings, …
  - – Equipment
    - …
  - – Materials
    - …

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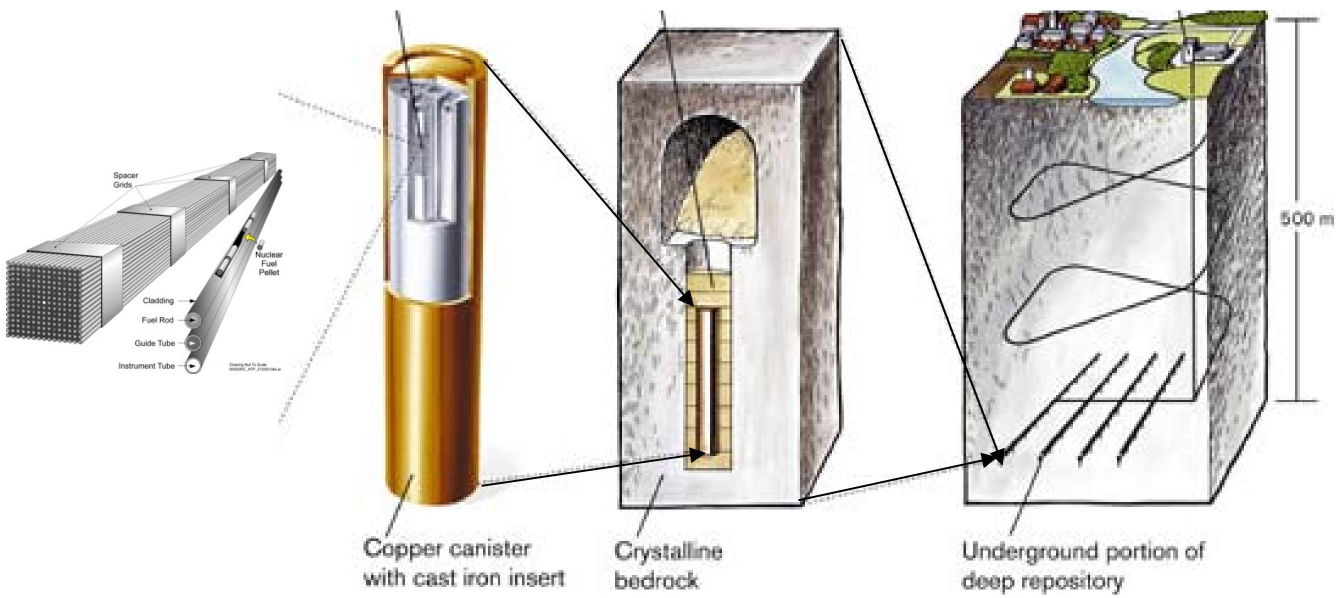
How to Maintain Continuity of Knowledge?
A Matter of Scale



C/S: Containment is only effective if it can be <u>verified</u>

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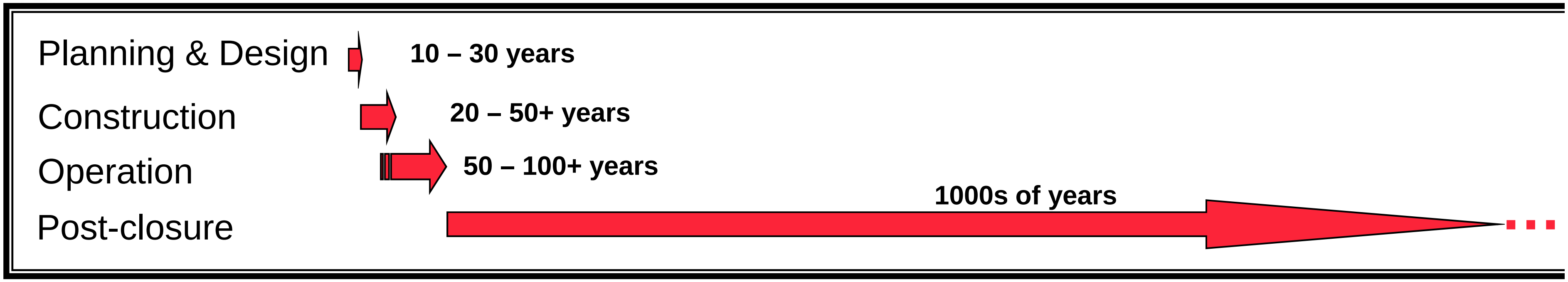
Major Repository Stages



- Planning and Design
  - Establish baseline information
- Construction
  - *Concurrent with Operation*?
  - Design Information Verification (DIV)
- Operation
  - *Concurrent with Construction*?
  - Receiving, conditioning, disposal/emplacement
    - Verify waste container identity & integrity after weld-closure & emplacement
- Post-closure
  - Monitor site activities
  - *Passive Seismic application*

Remote-Sensing Methods

- Seismic
  - Active
    - Detect structural features (sharp contrasts; e.g., floors & walls)
    - Verify repository design
    - Monitor rock stress fields (elastic wave computerized tomography, EWCT)
  - Passive
    - Emission tomography (PSET)
      - Monitor mining activities (explosions, TBM, …)
    - Transmission tomography (PSTT)
      - Verify repository design
- Electromagnetic
  - Active
    - Locating metal canisters/waste containers
  - Passive
    - Monitor electrical power consumption

Remote-Sensing Methods (cont'd)

- Ground-Penetrating Radar (GPR)
  - Active EM: variations in conductivity/dialectric
  - Detection of contrasting objects; e.g. waste packages
    - Potentially sensitive to small objects (1 - 3 m)
- Radiometric
  - Passive: detection of radionuclide-decay emissions (γ rays, neutrons)
    - e.g., passive NDA
  - Active: detect changes in density, porosity, water content, etc.
    - Calibrate against background/initial conditions
  - Monitor mining activities, movement/diversion of waste packages
- Thermal Monitoring
  - Thermal variations/perturbations
  - Monitor SNF decay heat
  - Calibrate against background & initial conditions (?)
- Acoustic monitoring (acoustic emission detection)
  - Mining activities
  - Rock stress & strain (fracturing & deformation)

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Remote-Sensing Methods (cont'd)

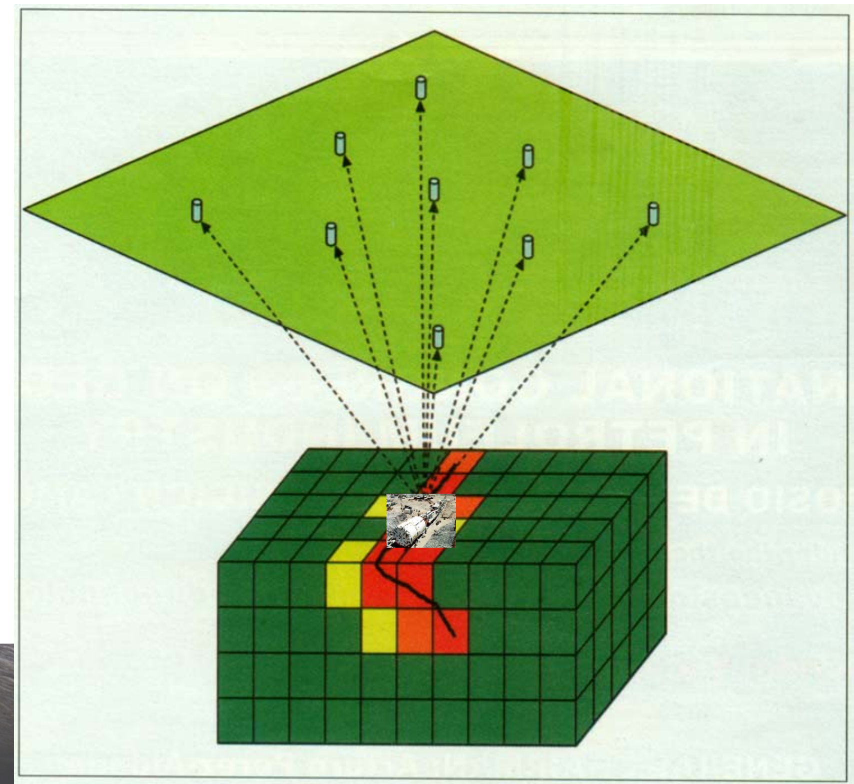
- Electrical
  - Monitor changes in resistivity (rock stress fields)
    - Electrical Resistivity Tomography (ERT)
  - Monitor changes in repository characteristics (???)
    - Reveal undeclared activities: movement, mining
- Magnetic surveys
  - Local/near-surface (3 – 4 m) detection of ferrous objects
  - Detect undeclared near-surface facilities
    - e.g., reprocessing, hot cells,
  - Limited SG applicability
- Gravity surveys
  - Density variations/perturbations
  - relatively shallow features (depth?)
  - Limited SG applicability (?)

Additional Methods

- Satellite
  - Imagery (IR, visible, etc.), GPS (elevation changes), …
- Hydrological
  - Changes in water-table levels, flow paths
- Chemical
  - Changes in groundwater chemistry
- Atmospheric
  - Monitor emissions
    - radioactivity, aerosols, chemistry, …
- Containment & Surveillance
  - Seals, cameras, …
- On-site Inspections

Monitoring with Passive Seismic Arrays

- Tunnel Boring Machines
  - Yucca Mountain, Nevada
  - Boston, Massachusetts



- Mining Activities

Identify activity source & location

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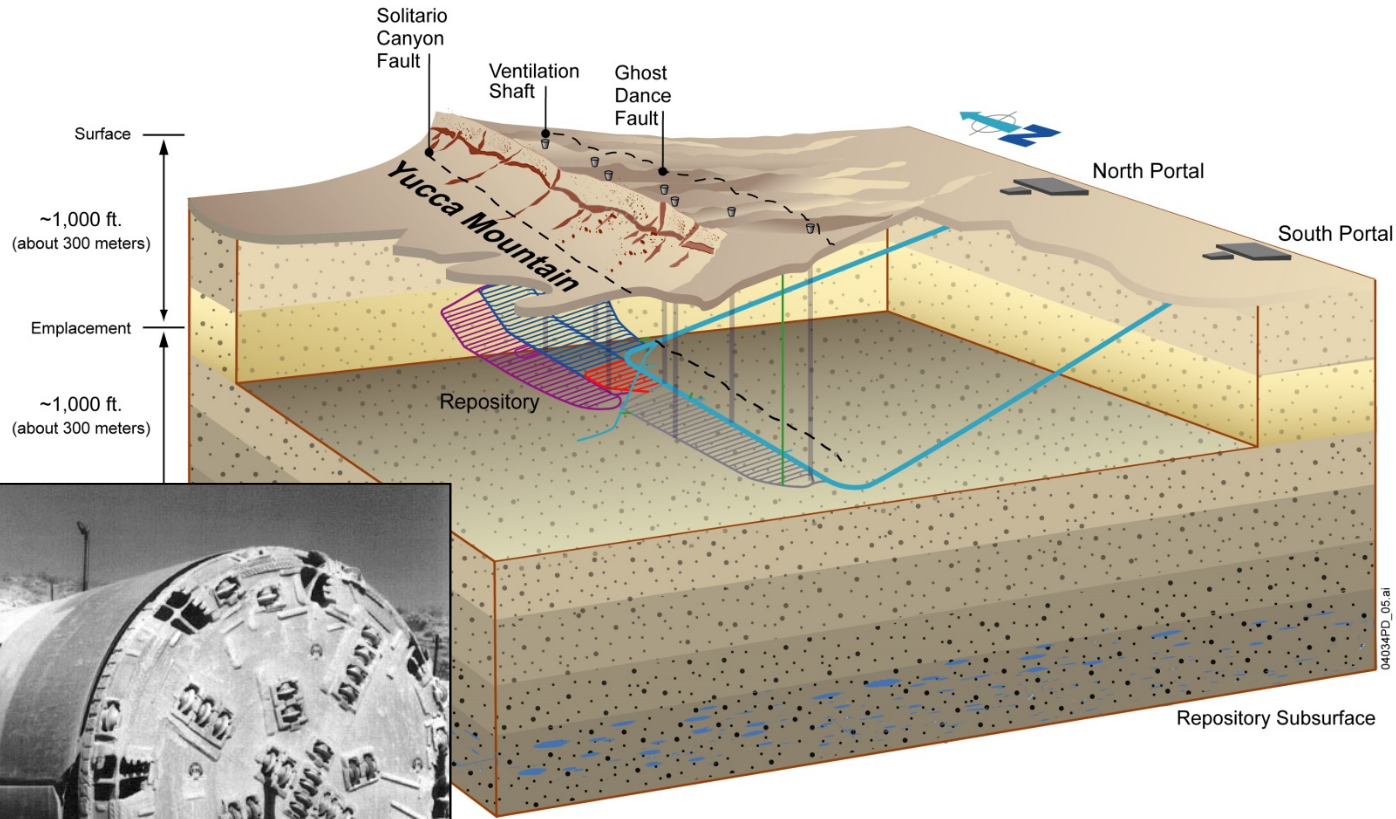
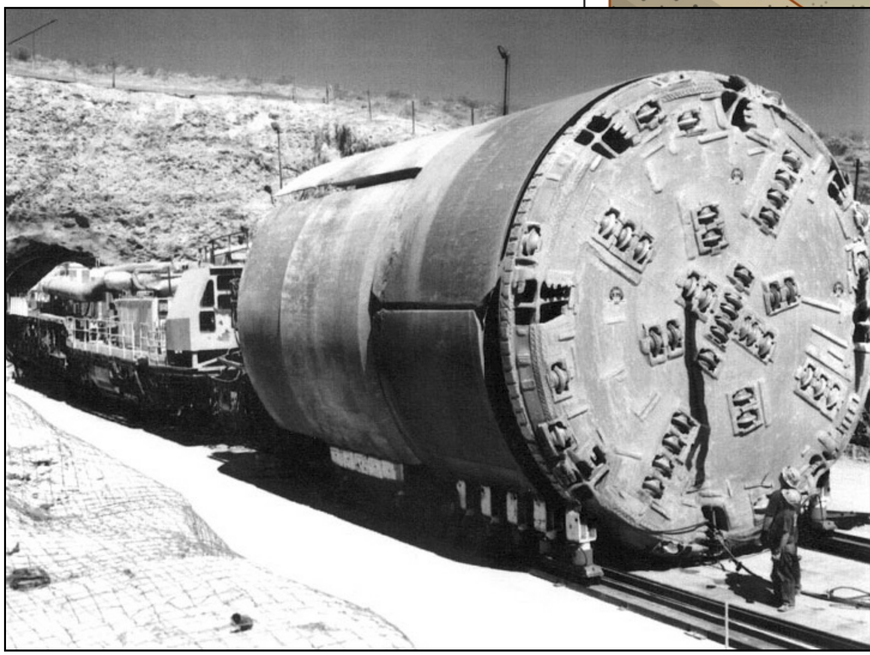
TBM Monitoring at Yucca Mountain, Nevada





5.15 m diameter tunnel
Tuffaceous (volcanic) host rock

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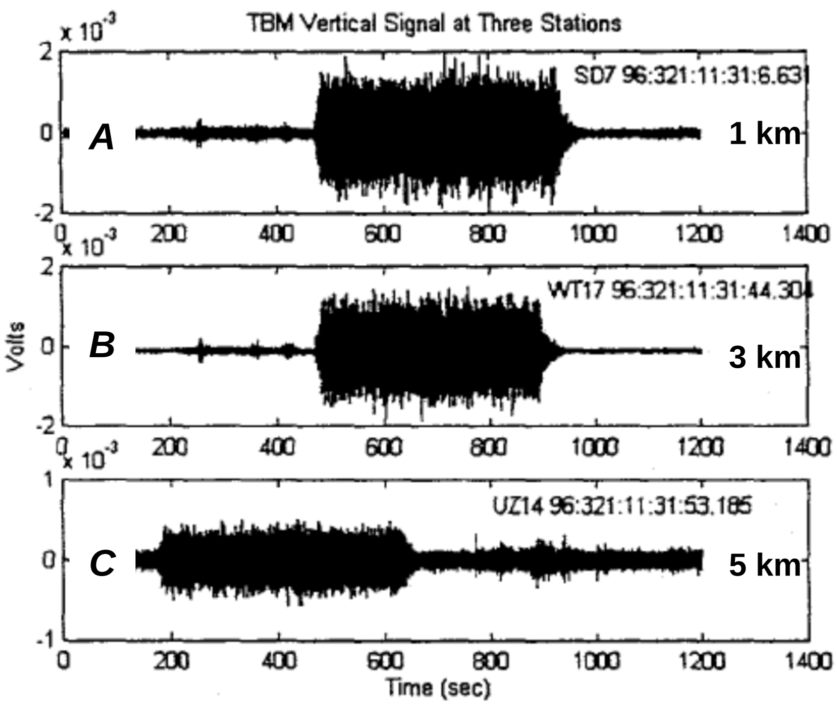
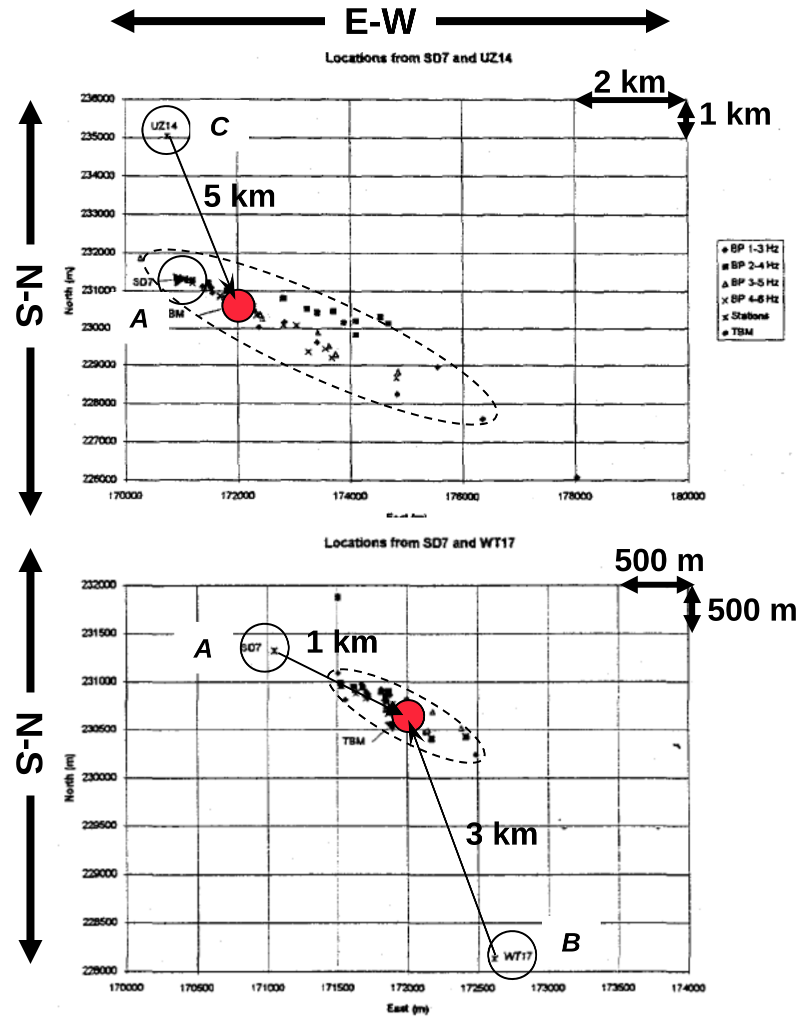
TBM Monitoring at Yucca Mountain, Nevada

Seismic signal



A,C: 3-element array of vertical sensors
B: Orthogonal 3-component system



Location Identification
(back azimuth)

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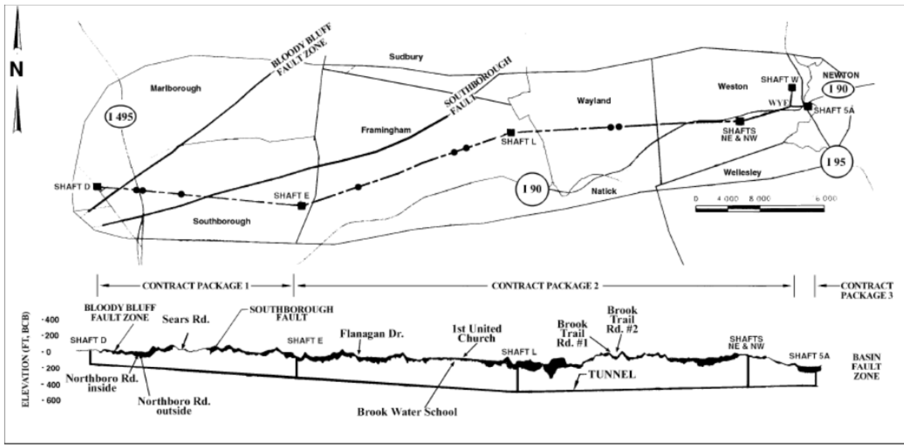
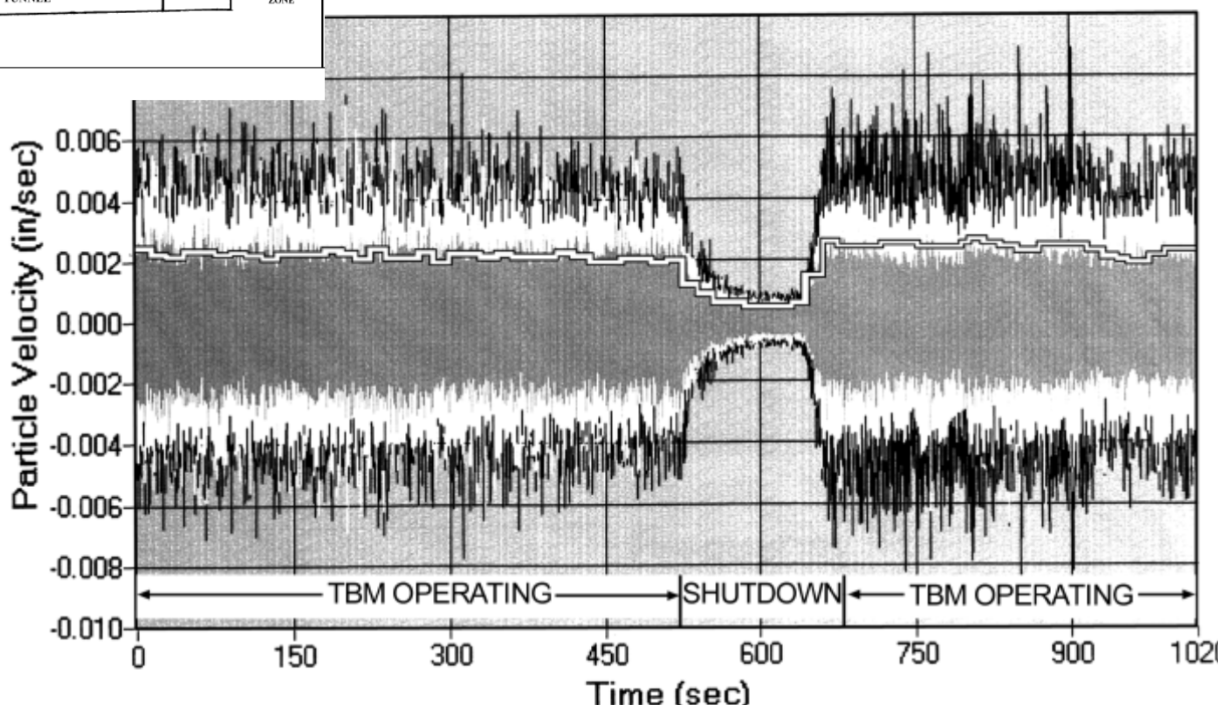
Source: Garbin et al. (1997) SAND97-1668c.

TBM Monitoring
MetroWest water supply tunnel, Boston



125 m deep, 5.15 m diameter tunnel
granitic & metamorphic host rocks

about 40 total hours of TBM activity recorded



Source: Greaves et al. (1999) LA-UR-99-5027.

TBM Passive Seismic Monitoring

- Application to very long-term monitoring at the repository (km) scale
- Low-amplitude, long-duration signal
  - Low signal-to-noise ratio
- TBM seismic signal depends on:
  - Host rock, TBM size, Array geometry/locations, monitoring duration, other factors
  - Signal decays as approximately the inverse of the squared distance between TBM and receivers
- Location Identification
  - conventional hypocenter location combines back-azimuth and P-wave first arrival
  - location error depends on …
    - sensor location, back-azimuth measurement, picking error of P-wave first arrival times
    - depth range and number of geophones in an array can also influence error distribution
- Ambient noise interference (reduced S/N)
  - Human activities (e.g., construction), micro-temblors, …
  - Evaluate *ratio* of time-averaged long- and short-term signals
- Additional factors evident from covert TBM operation
  - Muck and groundwater removal
    - satellite imagery, hydrogeology
  - Ventilation: diesel/fuel exhaust, dust, exhaust-air temperature
    - Atmospheric monitoring, Satellite IR imaging
  - Fuel/air supplies to TBM

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Conclusions

- How to maintain continuity of knowledge (CoK) from disposal canister through emplacement and repository closure?
  - Wide range of time and length scales
    - meter- to kilometer and days to millennia
  - Containment & surveillance (C/S) post-emplacement and post-closure
- Passive seismic most promising for long-term monitoring of covert mining & TBM activities
  - Repository post-closure (> 100 years)
- Near-term monitoring more problematic
  - Concurrent construction and operation
    - may swamp seismic signal(s) from undeclared activities
  - Combine with additional methods, including on-site inspections, satellite
- Successful repository safeguards will encompass full range of time & length scales
  - System-wide approach for C/S, CoK, near- and long-term monitoring

Additional Slides
for Q & A

Experimental Details: Yucca Mtn.

- Data collected for 42 days
- Three seismic data acquisition stations
  - SD7 (A)
    - ~1 km from TBM
    - 3-element array
      - vertical spring-mass seismometers (model GS-13)
    - 50 m gauge separation
    - Located on edge of butte
  - WT17 (C)
    - ~3 km from TBM
    - Orthogonal 3-component system
      - Two horizontal components aligned E-W and N-S
    - Located on relatively flat land
  - UZ14 (B)
    - ~5 km from TBM
    - 3-element array of vertical sensors
    - ~100 m gauge separation
    - Located on drilling pad in NW-trending valley

All sensors placed n 1-m deep, sand-filled holes

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Experimental Details: Boston

- Fourteen (14) seismic stations
  - Deployed both in and near the tunnel
  - Short-period and broadband instruments
  - Second-closest broadband site:
    - Array aperture of 60 m
  - Short-period and broadband pair situated <u>inside</u> tunnel for 8 hr work shift
    - ~35 m behind TBM

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Some TBM characteristics

- TBM performance
  - Utilization
    - fraction of time the TBM spends cutting
      - Reduced by maintenance & repair
  - Penetration rate
    - instantaneous penetration per unit time or per cutter-head revolution
  - Advance rate
    - Equals *utilization* times *penetration rate*
- Tunnel slope
  - TBM downward slopes usually less than 18°
    - up tp 30° slopes w/ improved muck removal, sensor modifications
      - Replace smooth conveyor w/ pleated
- Manpower requirements
  - 4 to 8 man crew
- TBM noise levels
  - vibrations are ½ to 100X lower than blasting
  - vibrations characterized as being similar to moderate-to-heavy street traffic
  - advanced tunneling technologies may have lower (and different) noise character
- Unforeseen adverse geologic conditions are the principal impediment to tunneling
  - excessive faulting/fracturing can reduce advance rates
  - potential repositories will likely be well characterized, better preparing potential tunnelers.

Other Tunneling methods

- Drill-and-blast methods typically achieve advance rates of 2.5 m/day to 5.0 m/day
  - Numerous technological advances
- Water-jet cutting
  - Significantly reduced noise compared w/ TBMs & drill/blast
  - Application to salt repositories?
  - Muck & pump rates?
- Subterrene Penetrator
  - TBM that melts and displaces rock
    - electrically heated, refractory metal head
  - Significantly reduced noise w/r/t TBM
  - Energy intensive
    - Increased (monitor-able) electrical fields?