Presented to NSRP/ SP-3 – October 2007

Tank and Void - Remote Inspection Using Minimally Invasive Technology

What is Minimally Invasive Technology?

- Minimally Invasive Maintenance and Inspection (MIIM)
- A system or device used to deliver desired capability deep into the interior of a high value piece of equipment with little or no impact to its internals.
- Capabilities include visual inspection devices, NDT probes, cleaning equipment or foreign object retrieval tools.
- Systems deployed using existing openings in equipment, such as inspection ports, hatches, thermowells, inlet/outlet piping runs, etc; require minimal or no disassembly of unit.

What are Minimally Invasive Robotics?

- Remotely operated minimally invasive robotic systems
- Systems work in harsh and hazardous environments
  - High temperatures
  - Radiation
  - Submerged (oil and water)
  - High voltage
- Systems work in remote locations
  - Small access openings
  - Long, serpentine paths
  - Confined spaces

Tank and Void Inspections Using MIIM

- Goals of Using Minimally Invasive Technology for Tank and Void Inspections
  - Enable quick, cost-effective condition assessment to eliminate tanks with ‘condition unknown’
  - Eliminate ‘emergent work’
  - Make ‘blast/recoat’ versus ‘touchup’ decisions in advance
  - Evaluate temporary coating repairs
  - Detect and track problem areas early and often
  - Eliminate need for confined space entry requirements
  - Eliminate safety hazard associated with personnel entering tank

Desired Features of a Tank Remote Inspection Tool

- Under-fluid capability
  - Eliminates draining, gas-free, cleaning
  - Eliminates putting people in hazardous confined space
- High mobility/flexibility
  - Allows remote inspection of all areas
  - Get into all compartments
  - See behind ribs/stiffeners
- Ability to operate in empty, as well as fluid-filled, tanks

In-Oil Transformer Inspection System

- Inspection tooling for commercial utilities' oil-filled power transformers
- Transformers are essentially large tanks filled with murky oil
- The technical challenge was to
  - Create a visual system that could generate good visuals through murky fluids
  - Create a flexible, steerable system that could get to all the relevant areas of the tank
- Top-bottom pictures – tank inspection system

In-Oil Transformer Inspections

- Top: Debris at the bottom of a tank (oil in tank)

- Bottom: foreign object (electrical tape) at the bottom of a tank (oil in tank)

Traditional Tank Remote Inspection Method

- Camera on a stick with pan-tilt-zoom capability
  - Can operate in or out of fluid
  - Can only inspect first compartment
    - Low Mobility

Camera-on-a-Stick

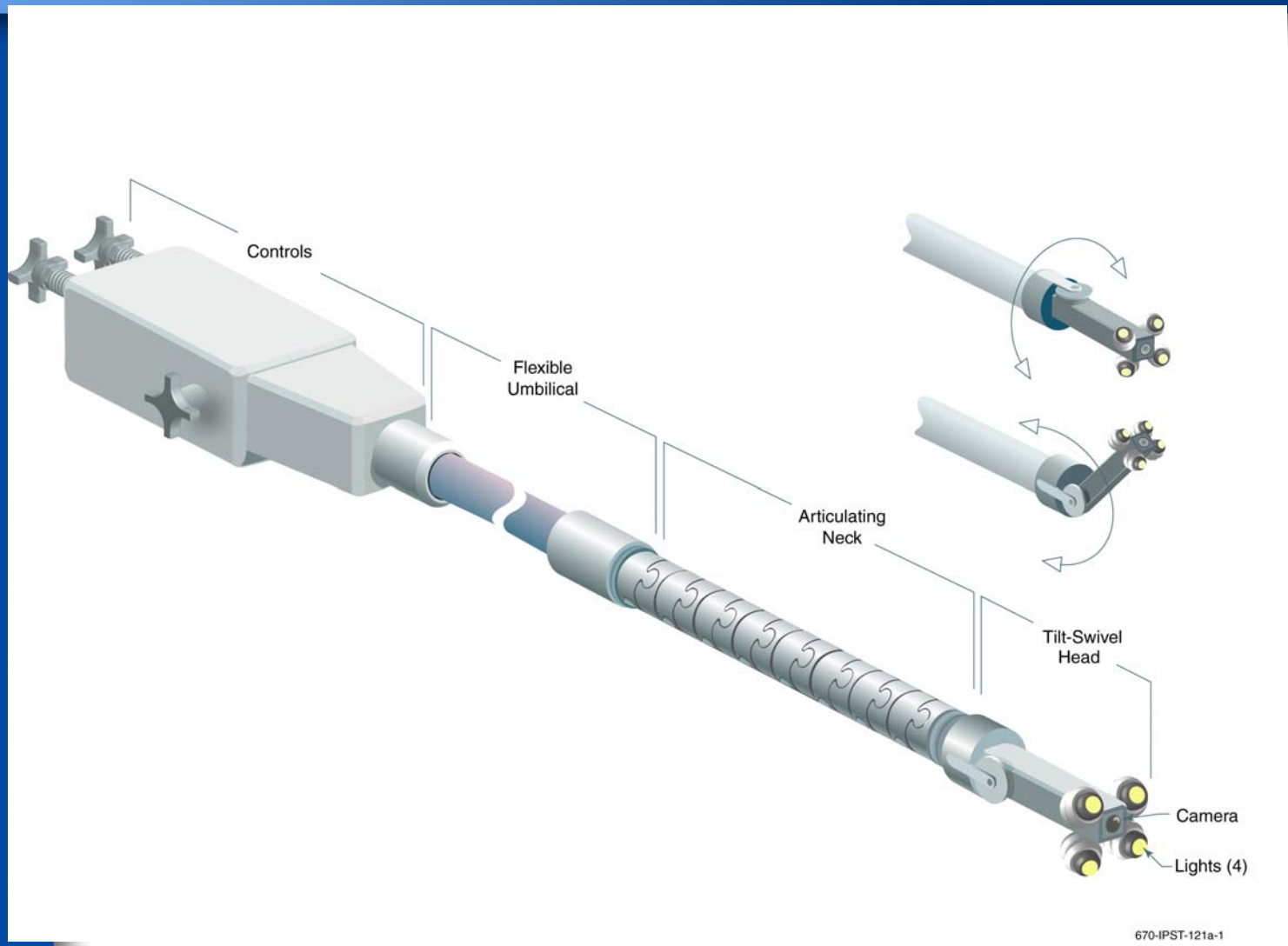
Traditional Tank Remote Inspection Method

- Remote Underwater Vehicle (ROV) ‘Swimmer’
  - Only for under-fluid applications
  - Risk of getting trapped; difficult to remove

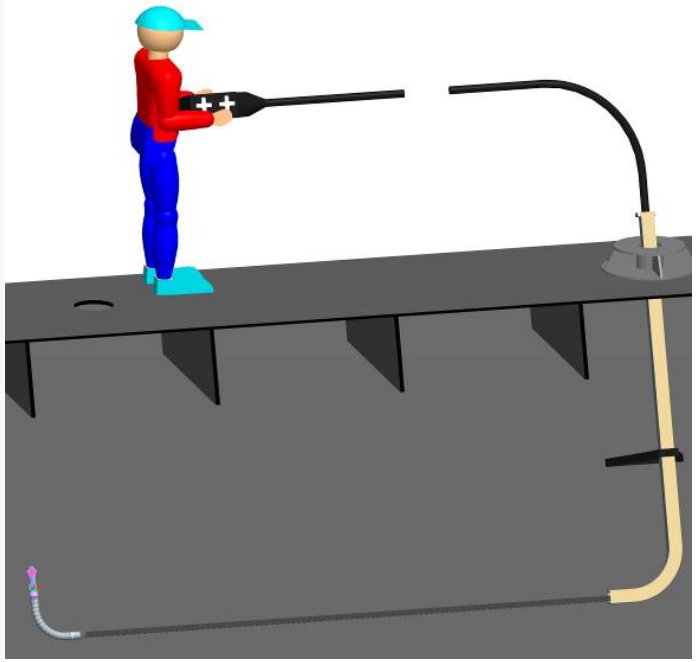
New Tank Inspection Method

- Flexible Tank Inspection Tool (Camera on a ‘snake’)
  - More mobility than the camera on a stick
    - Multi-compartment access from single entry
  - Under-fluid and empty tank capability
  - Can go through smaller access points than swimmer

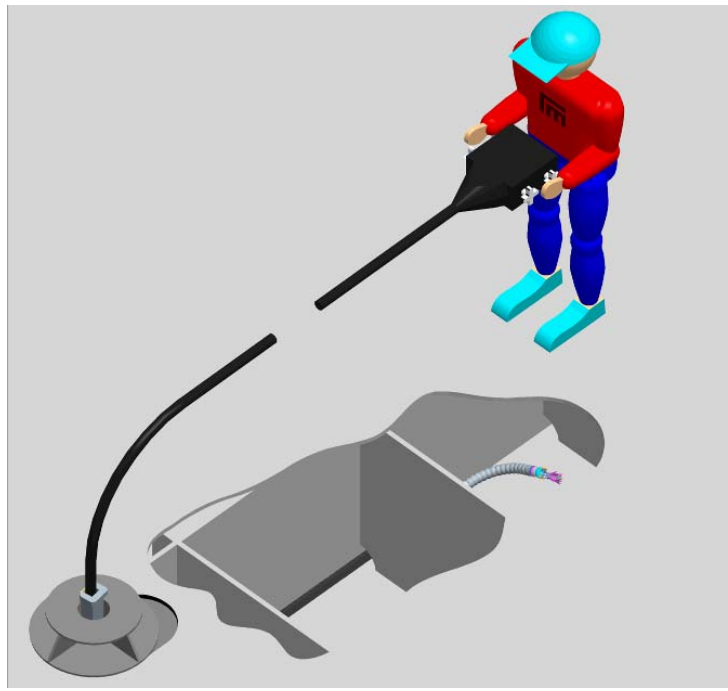
Flexible Tank Inspection Tool Overview



Flexible Inspection Tool Capabilities

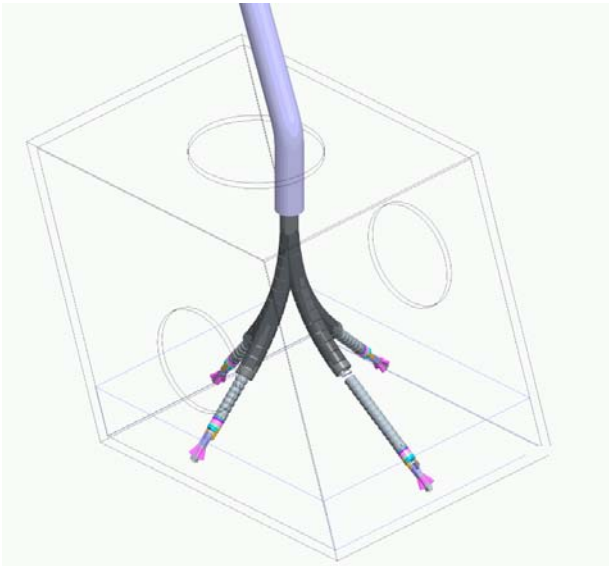


ClearShot - Inspecting a tank that has no compartments

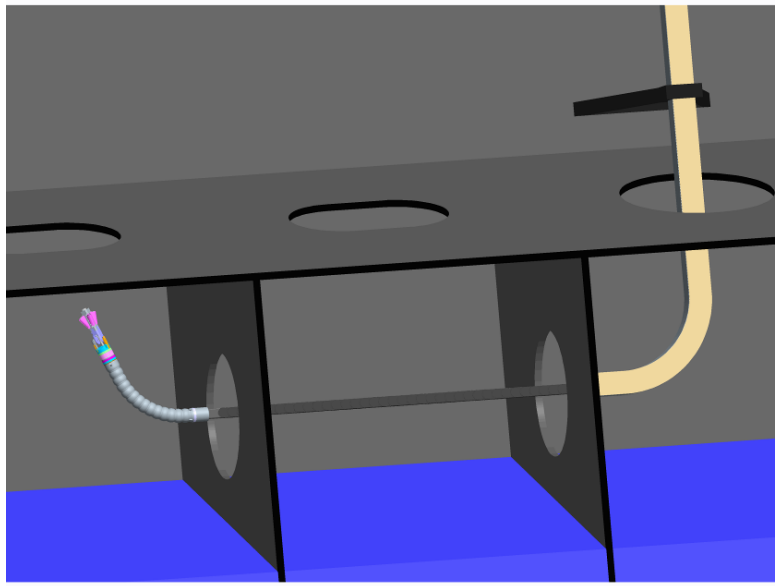


Inspection Probe Installed in Tank. Operated by person outside tank

Flexible Inspection Tool Capabilities



Articulating Distal End Flexes to Reach Multiple Locations in a tank

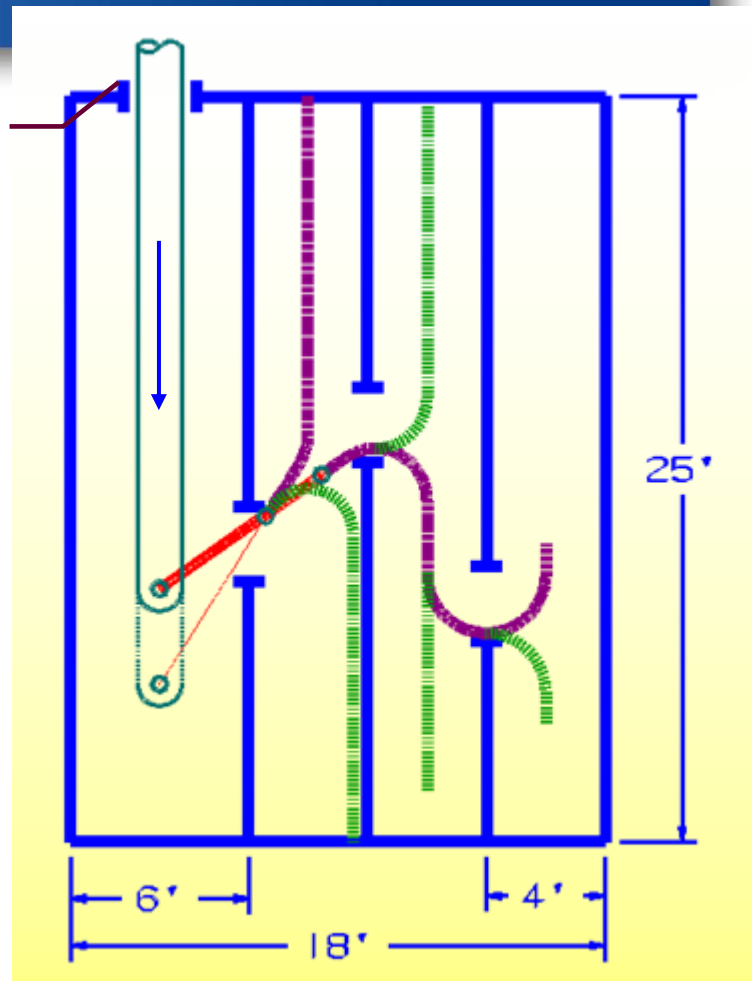


Flexible Probe Maneuvers Through Tank Compartments

Adapting Tool for Shipboard Tank Use

- Naval tank systems require longer lengths
  - Standard tool is 17 ft.
  - Naval applications require up to 50 ft.
  - 35 ft. design submitted to NAVSEA
- Naval system requires more mobility
  - Specially designed guides will provide needed mobility
- Naval system may require zoom capability
  - Tool can be modified to zoom
- Naval system may require enhanced lighting
  - Tool has about 24 W
  - Can add lighting to match requirements

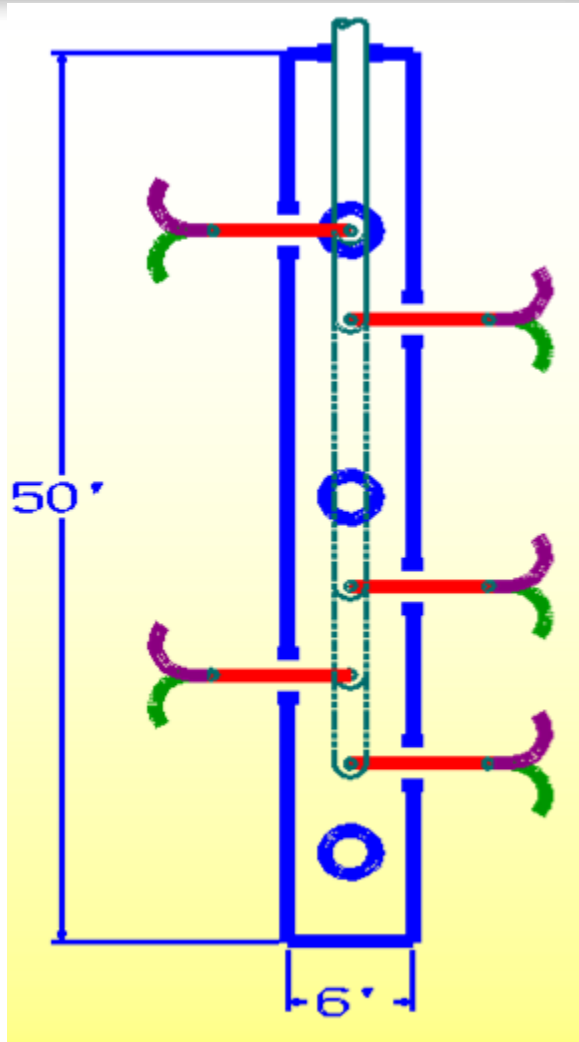
Flexible Inspection Tool Adaptations: Enhanced Mobility



- General layout of multi-chamber tank concept
  - Rigid guide for 1st chamber
  - Moveable arm for subsequent chambers
  - Can cover up to 4 chambers with this technique
  - Technique works whether dry or fluid-filled
  - Zoom camera provides inspection capability

Flexible Tool Adaptations: Enhanced Mobility

- Damage Control Void
  - Very deep (~50 ft)
  - Dry
  - Side compartments
- Concept for control void
  - Use adjustable length, rigid guide
  - Use flexible arm to get into compartments
  - Use articulation for multi-directional viewing
  - Use zoom camera for close-up inspection capability



Moving Forward

- With detailed data available on tank layouts of systems can be designed for specific style tanks
- Use as much as possible of existing tank inspection work done as a basis for the tool

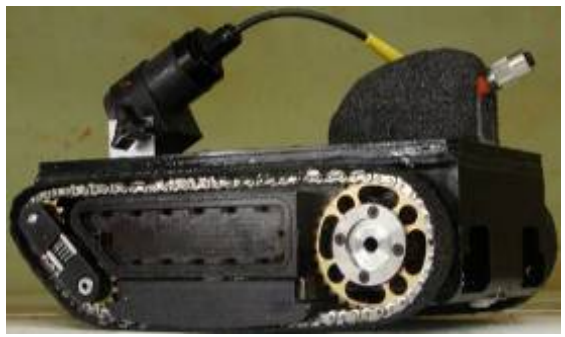
Tanks, Hulls and Voids Inspection Using Miniature Crawler

- Miniature Crawler- submersible, high powered, miniature, ferro-magnetic wall crawling vehicle
- Autonomous, Semi-autonomous and Manual Operation Modes
- Small – (~10” x 7” x 4”) vehicle capable of climbing vertical/overhanging steel structures
- Live visual inspection as well as DVD recording capability
- Easy to use operator control unit

High Power, Small Size with Obstacle Avoidance

Tethered or Autonomous Versatile Payload Carrier

Visual inspection capability



Autonomous, Submersible, High Powered, Miniature, Ferro-Magnetic Wall Crawling Vehicle

- What makes miniature crawler unique?
  - Capabilities - Submersible and Operation up to 300’ depths
  - User Friendly Operator Control Unit- Easy and Quick Set Up/Use (<5 min).
  - Powerful - Towing Capacity up to 50 lbs
  - Smart- Obstacle Avoidance Behaviors
  - Versatile-Multiple Payload Capability
  - Upgradeable- Self Detaching System
  - Awareness- Localization and Position Tracking

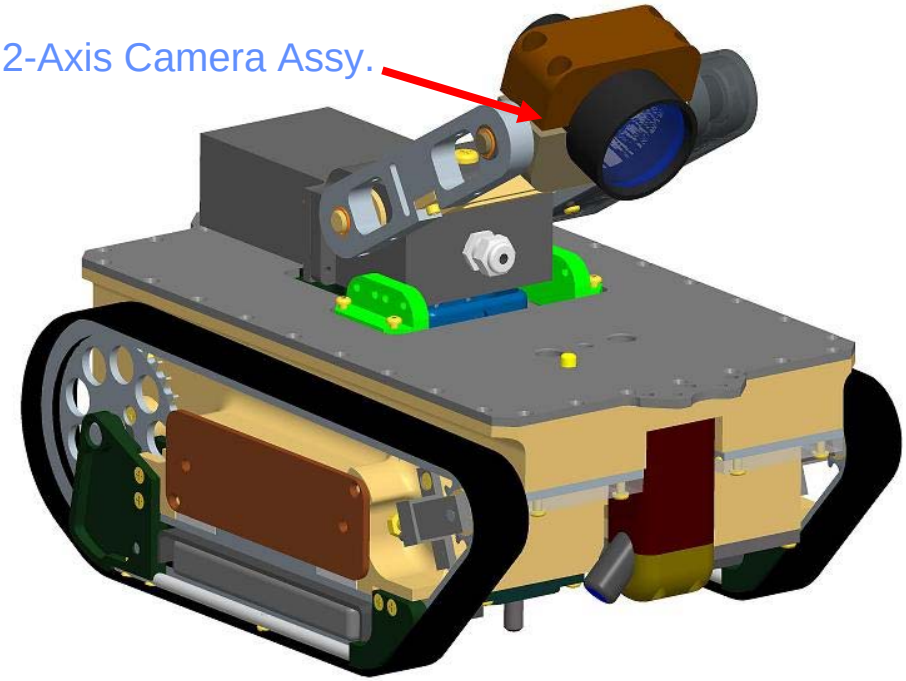
Operates On-Scale Underwater to 300”

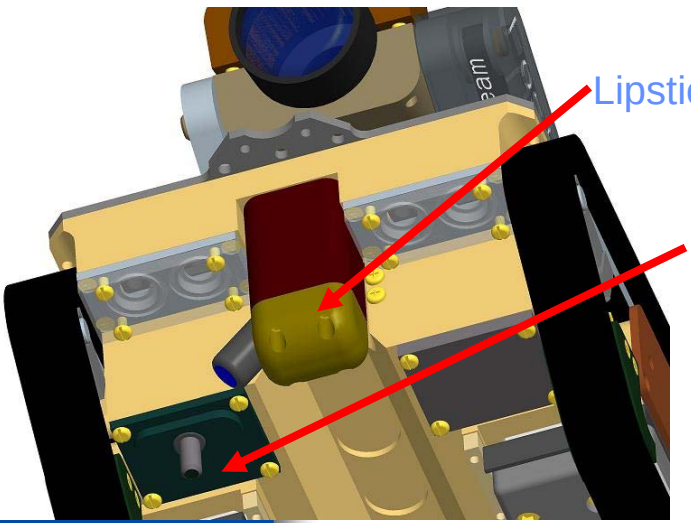
Miniature Crawler OCU

Miniature Crawler Potential Application Areas

- Visual Inspections and Delivery of NDT or other Tooling
  - Tanks and Voids
  - Ducts
  - Hulls
  - Cranes
  - Other hard to reach, hazardous areas
- Multiple Applications with the Same Crawler
  - Inspection (Live Visual, NDT or Other)
  - Payload Carrying and Utilization
    (Sensors, Actuators, Cleaning Heads, Manipulators etc.)
  - Laser Decoating
  - Reconnaissance

NDT System for Measuring Wall and Coating Thickness

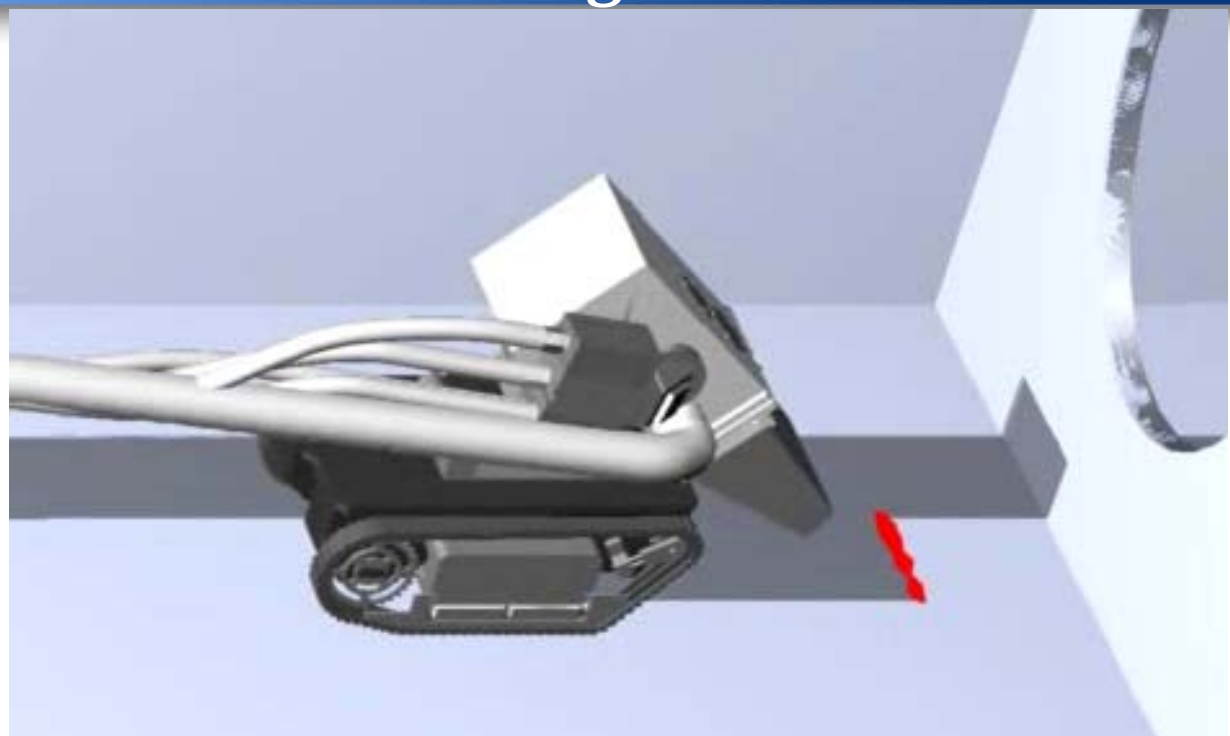




Data-Logging Ultrasonic Coating & Wall Thickness Gauge

1. NDT Sensing Module easily installs on existing Crawler.
   - Measures both coating and wall thickness from one side
   - Locates pitting and corrosion
2. Lipstick Camera Module attaches to allow for visual assessment of area to be measured.
3. 2-Axis Camera Assembly allows for gross inspection of surrounding area.

Tank and Hull Maintenance – Laser Decoating



Robotic Delivered
Laser Decoating Technology

Benefits of Minimally Invasive Inspection for Tanks and Voids

- Provides reduced down time for meeting scheduled maintenance requirements
- Supports accurate decision making
- Provides conclusive diagnosis and documentation of existing problems - ongoing trend analysis
- Eliminates safety and health risks associated with personnel entering confined space, contaminated space or any hazardous areas