Robotics for Inspection and Decommissioning of Nuclear Power Plant

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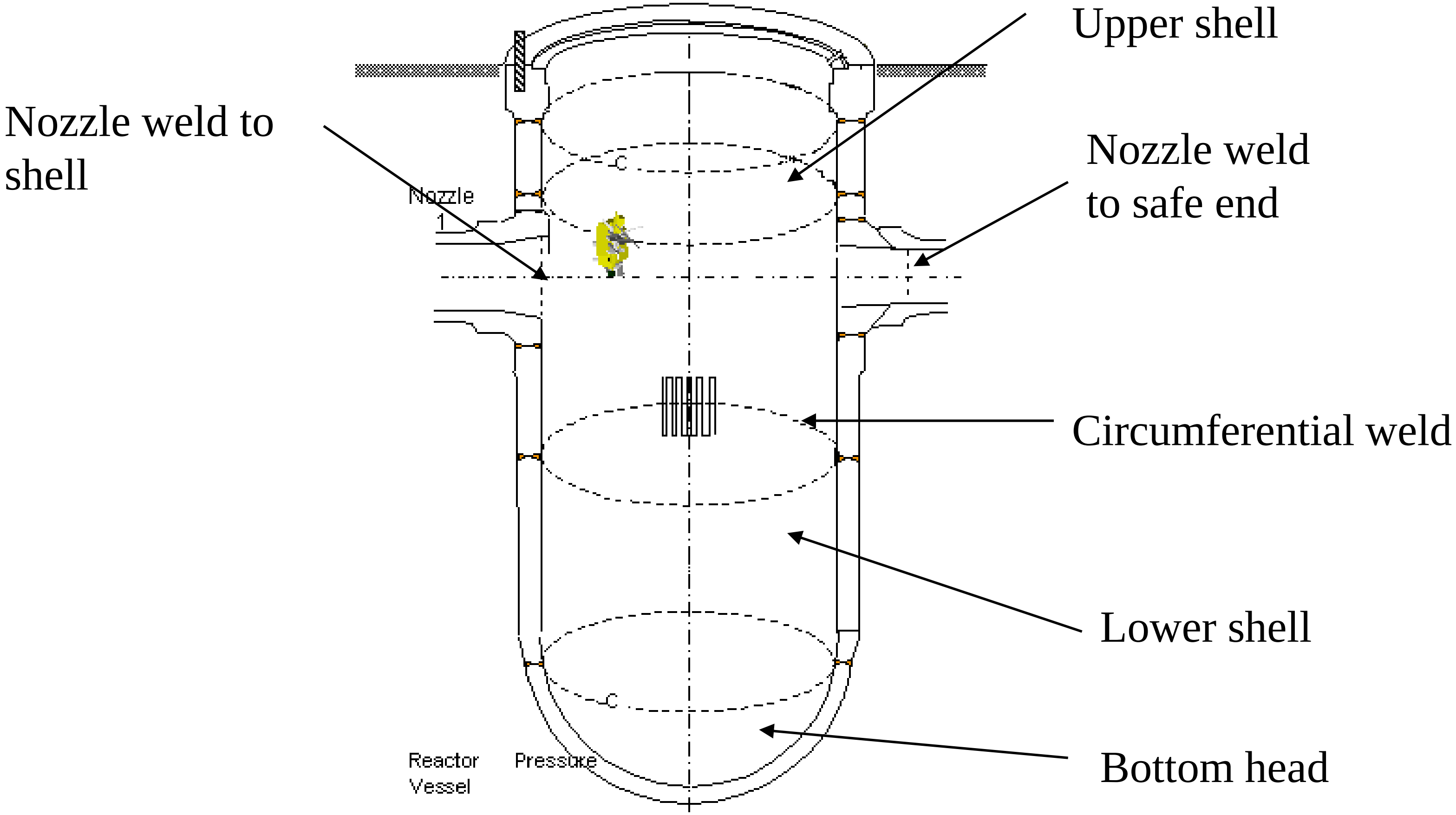
Robots developed by LSBIC to

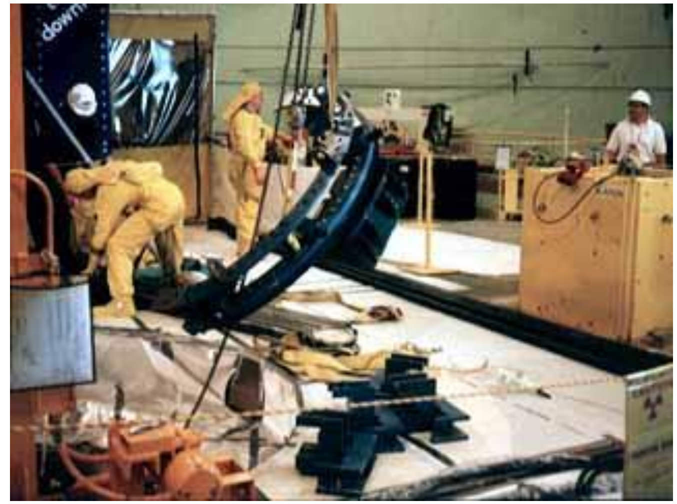
1. Inspect Pressure Vessel shell and nozzle welds
2. Inspect nozzle welds in the primary circuit of nuclear power plant
3. Inspect radiation cells, stacks, buildings
4. Cut steel objects for nuclear decommissioning

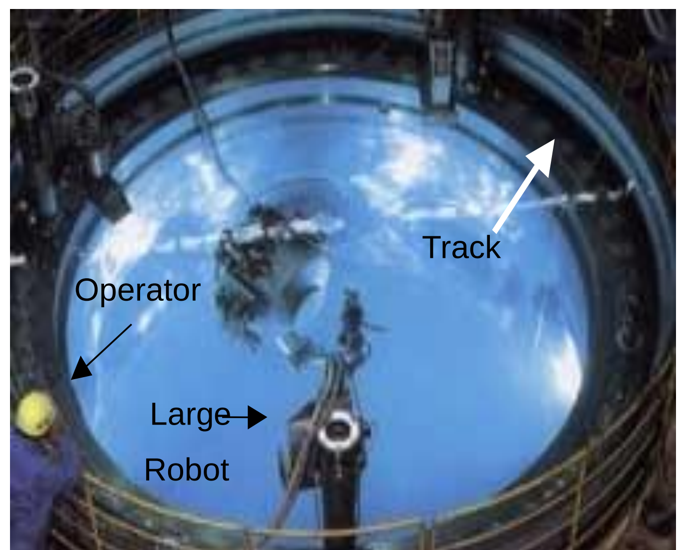
RPV Circumferential and Nozzle welds



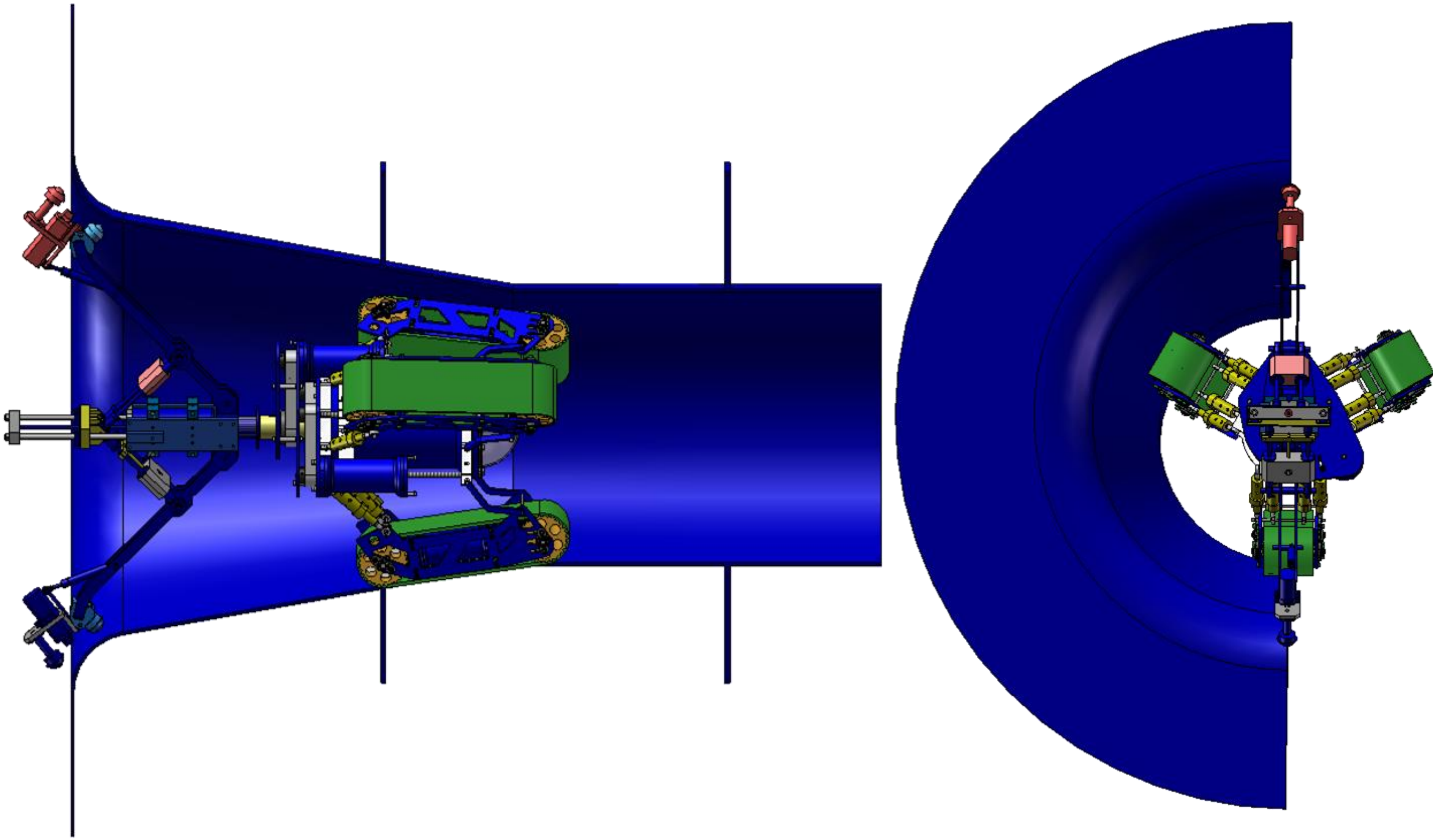
Current method of inspection uses large robots to do inspection – robot transported and assembled on site before immersion in RPV

• Require large and heavy robots with a central mast costing millions, manual set up time, tying up of polar crane needed for other tasks



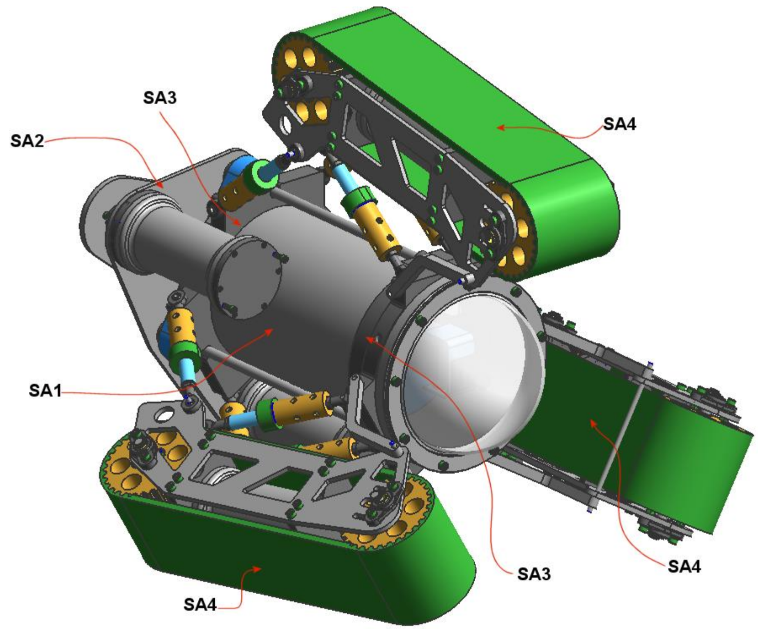


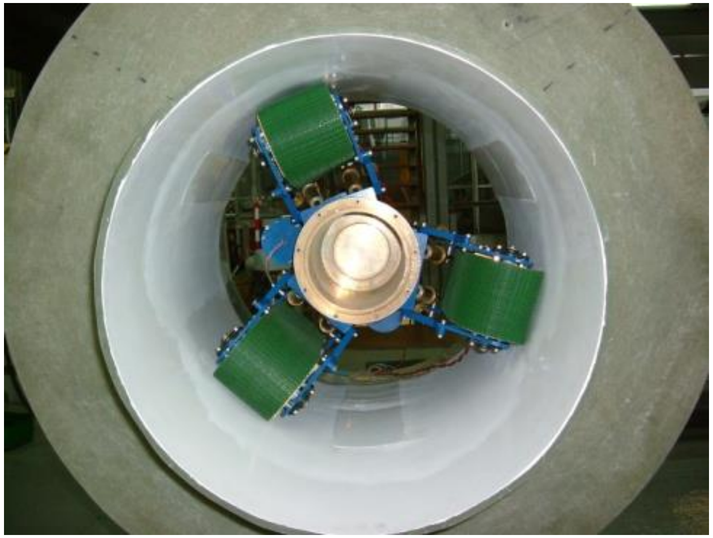
Drawing of the pipe crawling robot and scanning arm inside a nozzle



Nozzle inspection robot

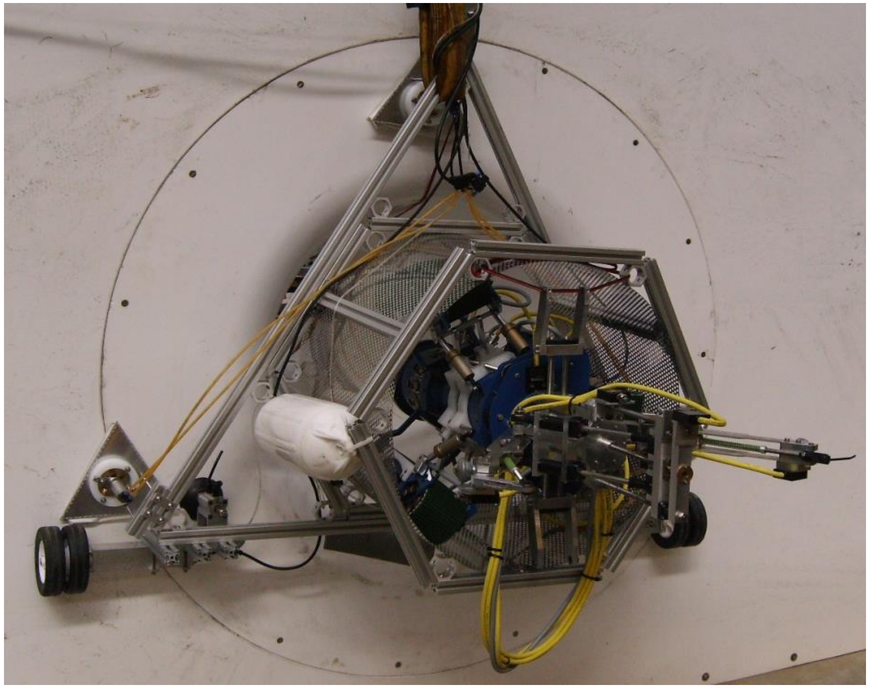
- SA1 - electronic compartment that actuates the ROV plus the pan/tilt camera for visual inspection inside the RPV nozzle.
- SA2 - structure holds 2 motors to actuate tracks (SA4) and provide rotation of nozzle inspection arm
- SA3 - actuation module forces simultaneously the tracks towards the nozzle. RPV nozzle is an axis symmetric shape with continuously variable diameter, the tractor support (SA3) provides suspension capabilities in order to cope with the nozzle diameter change.
- The tracks are 400mm in length, 100mm in width and height.





The final RIMINI Inspection robot

- Wall climber with nozzle crawler and scanning arm
- Neutrally buoyant climber+ nozzle crawler
- Positively buoyant climber, parked with suction cups

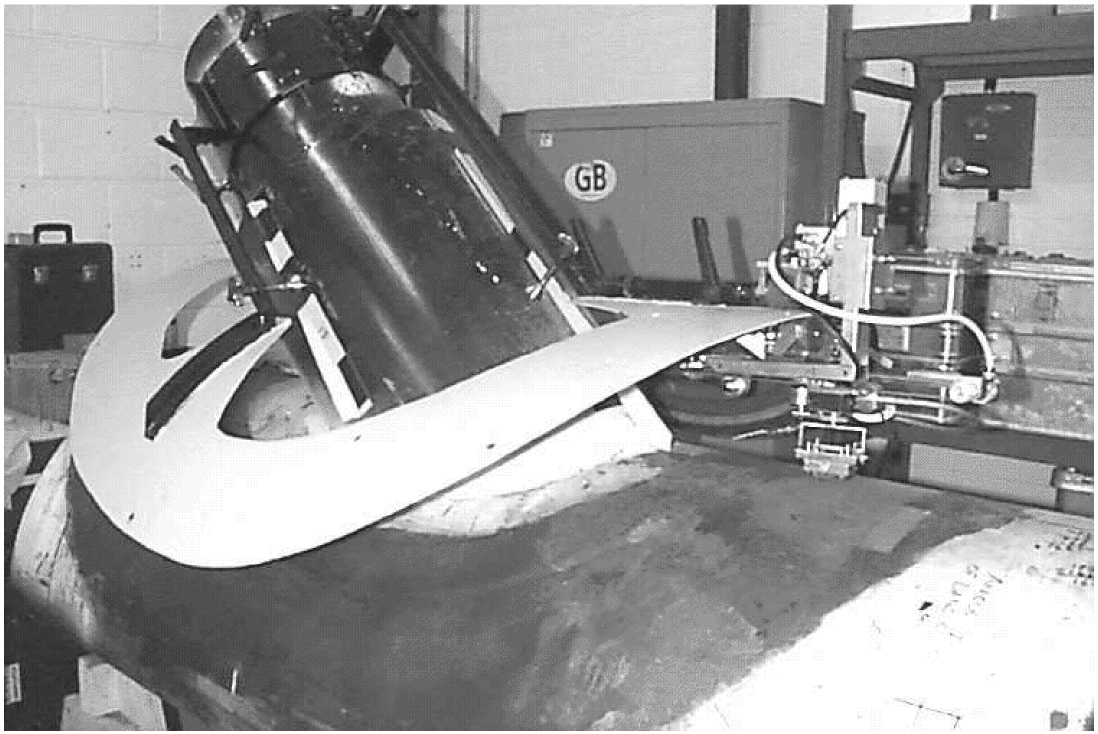


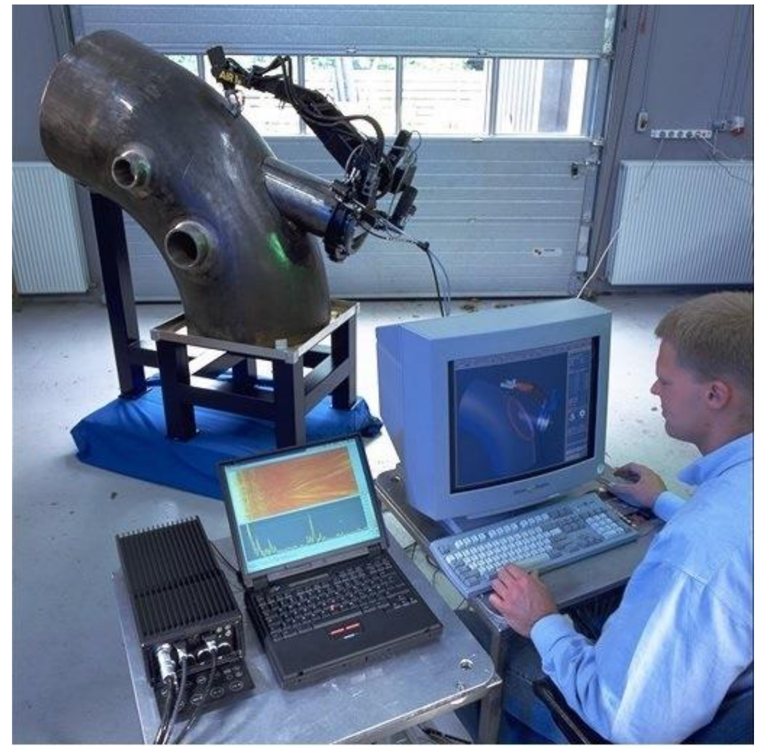
Design of a versatile robot for inspection of welds with complex contours in nuclear power plant

Nuclear Inspection Robot

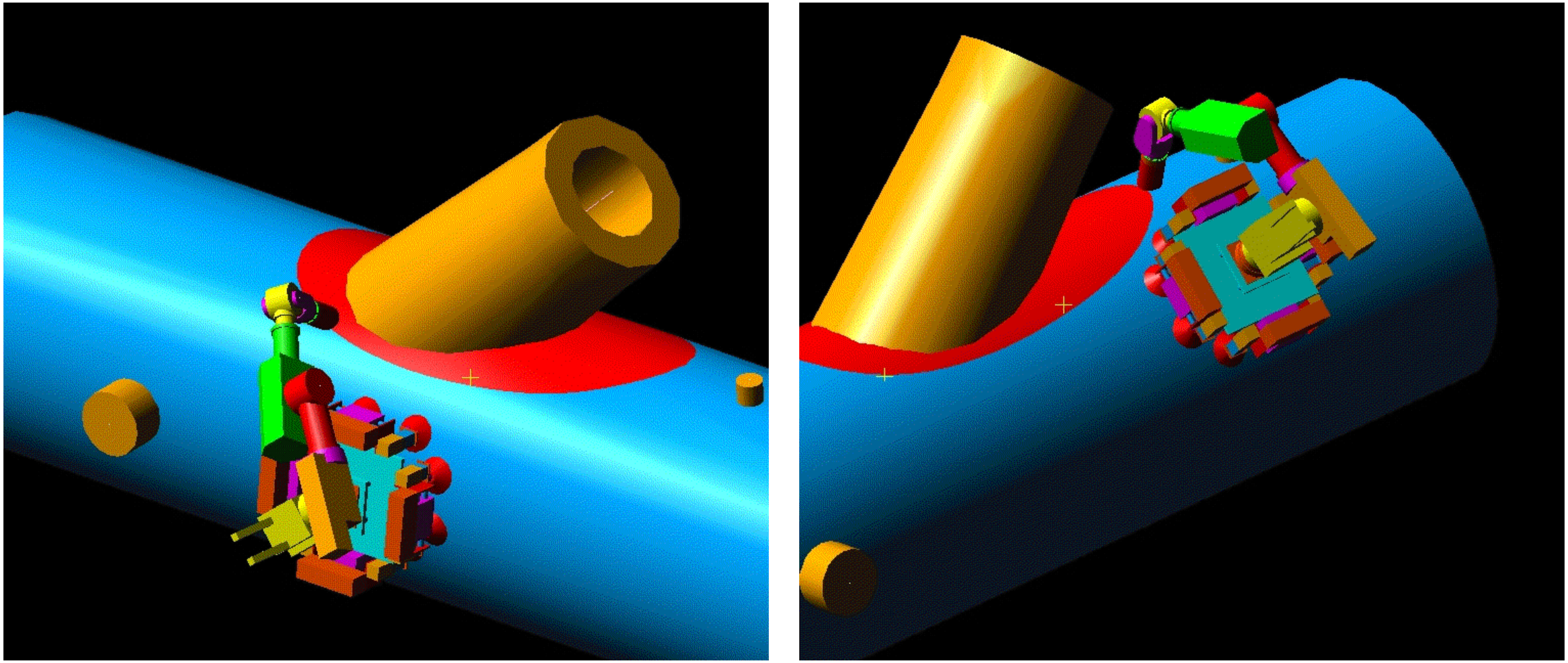
- Prototype generic, mobile inspection tool
- Compact robot + 7 axis robot arm + 5 kg payload of NDT sensors to test welds
- Climbing motion over highly curved surfaces of any material- 860 mm diameter pipes and 3 m pressure vessel
- Couplant retrieval system

NDT of nozzle weld on 45°, 860 mm diameter feeder pipe in the primary circuit





Requires operators to attach scanner arm in a radiation environment.



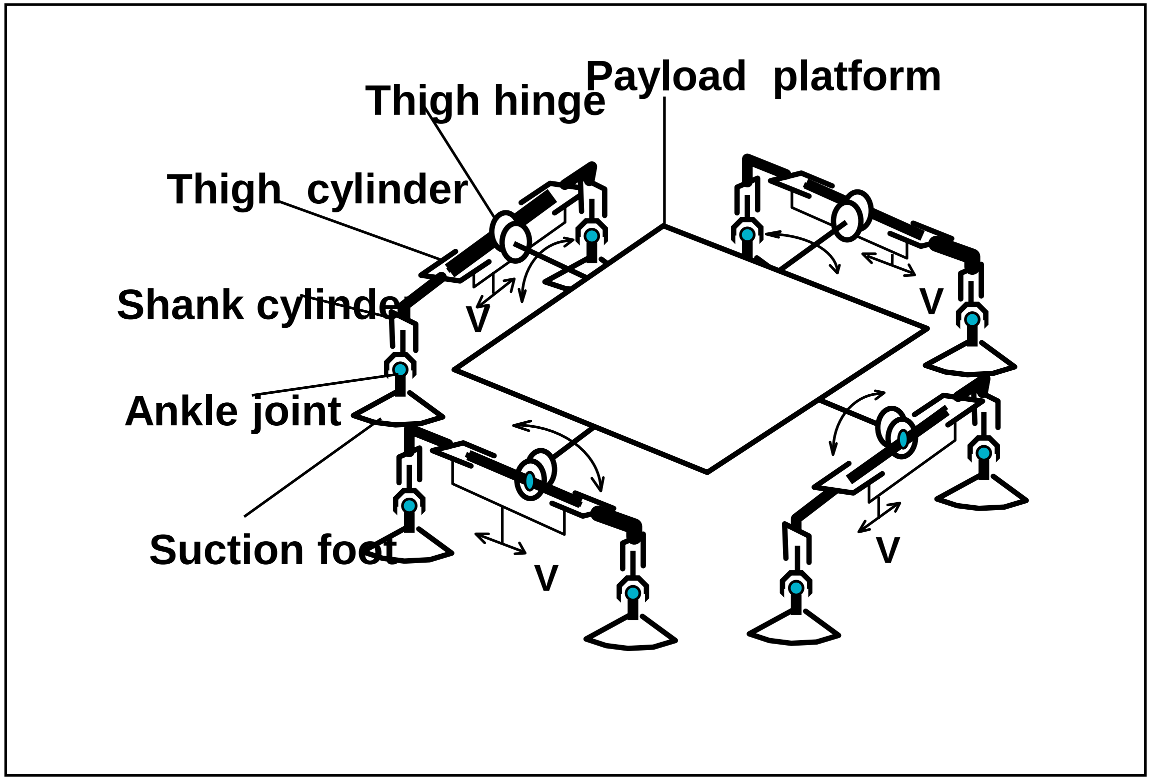
CAD schematic drawing - proposed mobile inspection robot deploying NDT sensors with 7-axis arm.

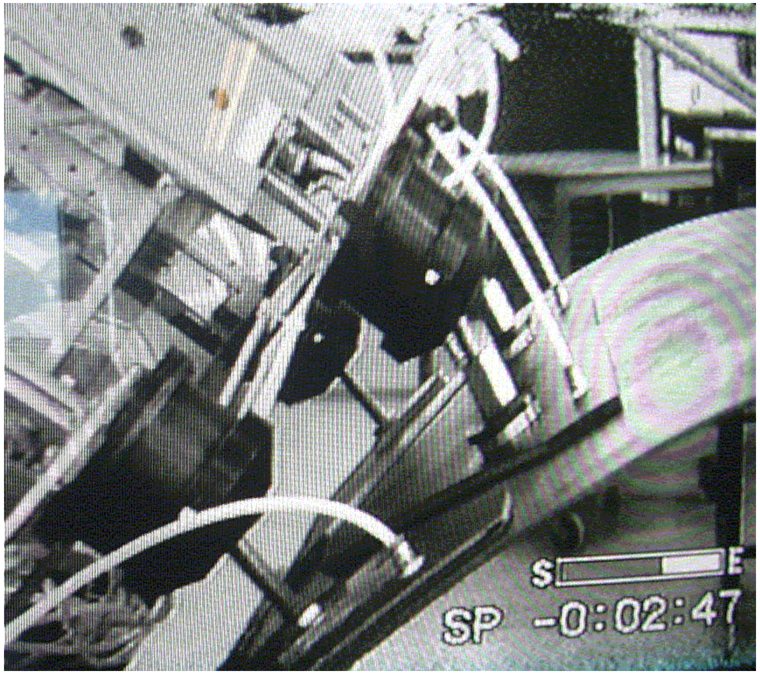
Mechanical Design: Key Concepts

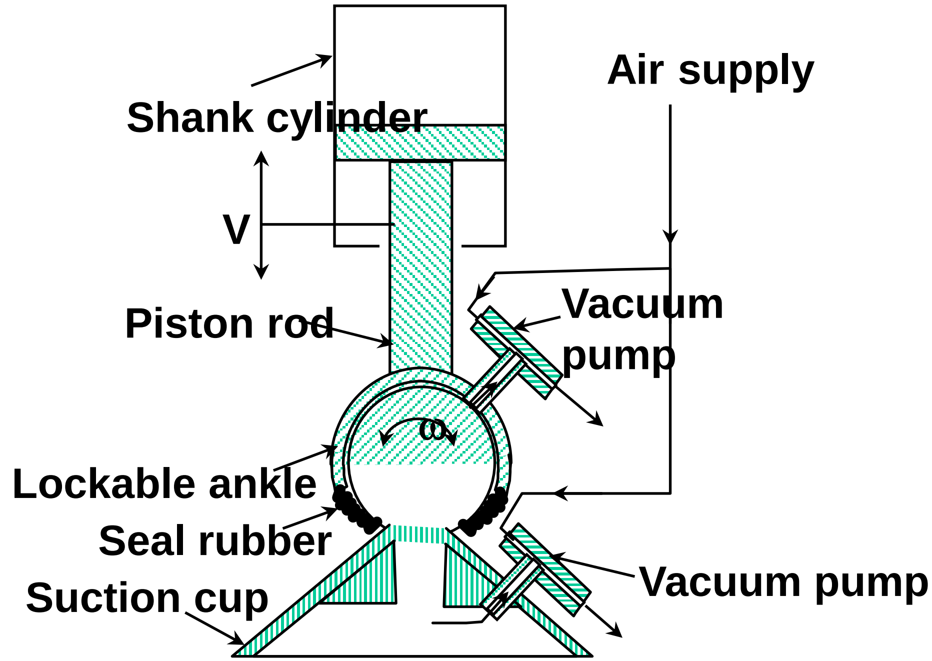
•Thigh Hinges tilt leg pairs relative to the vehicle chassis

•Universal ankle joints made alternately free during walking step, otherwise locked rigid for vehicle stability during the data acquisition stages

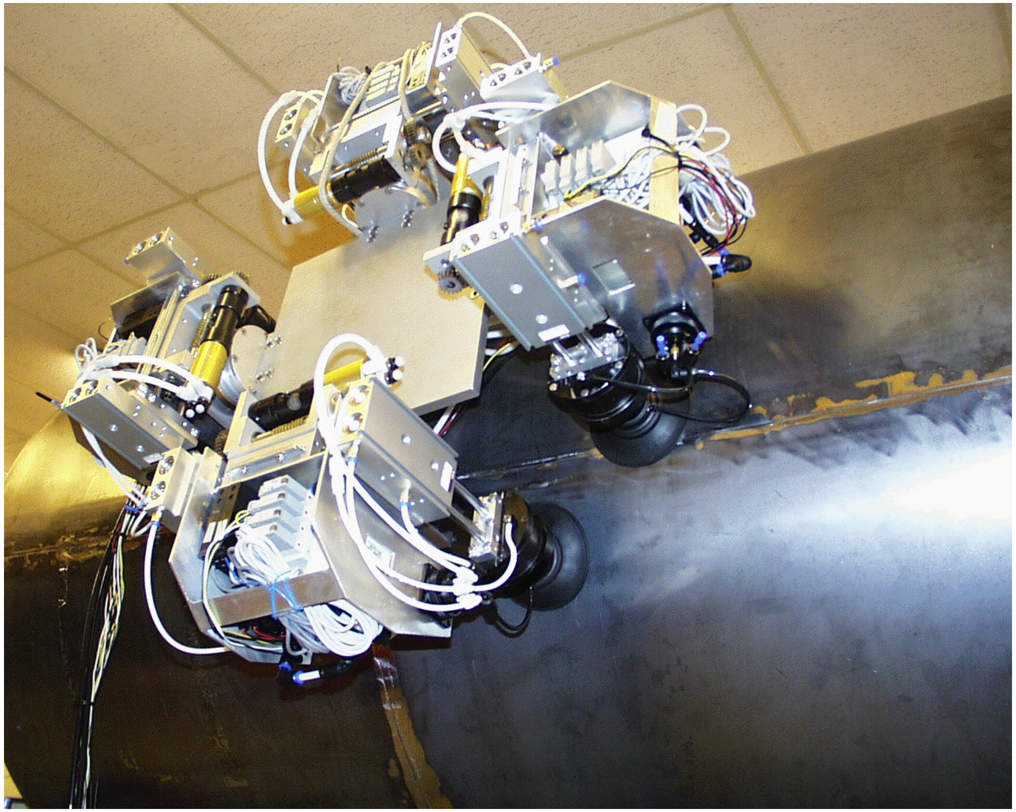
•Suction feet adapt and adhere to curved surfaces whilst remaining sufficiently rigid for vehicle stability



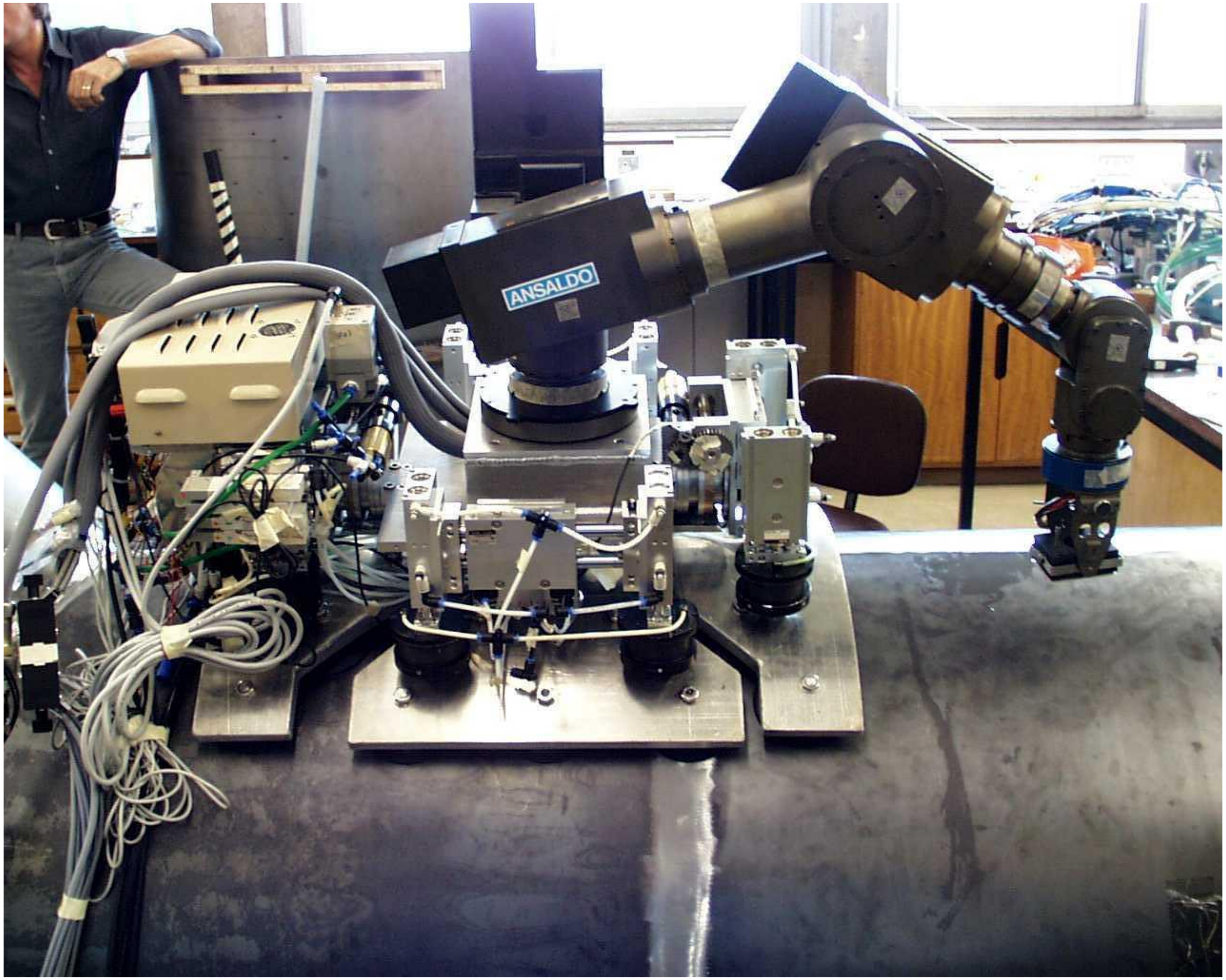




Novel Universal Ankle Joint - alternately flexible or rigid by means of a double vacuum system.



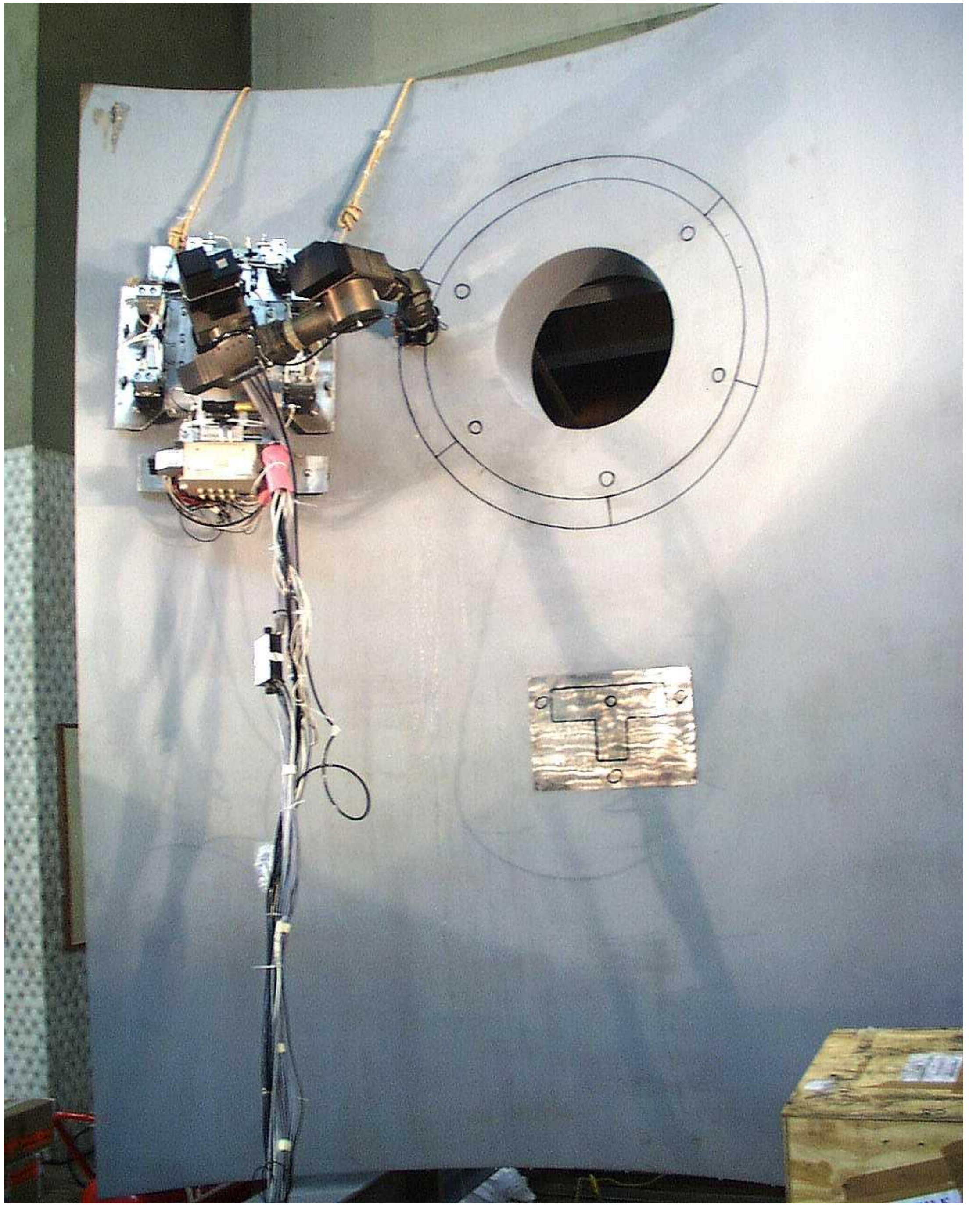
Prototype generic vehicle - 4 thigh joints for motion on spheres -conventional suction cups -payload 6 kg with a safety factor of 3



Vehicle mass = 30kg, 500x500 mm, max P= 37 kg, Arm mass = 22 kg, 7 DOF, Arm payload = 5 kg, repeatability ±1 mm

The Climbing Robot

Nuclear Inspection Robot at the SOGIN nuclear power plant in Torino, Italy. Shown scanning nozzle welds on a 6 ton mock-up of a stainless steel pressure vessel.



Sellafield Site

Inspection (1) – Large Structures and Buildings

- Rebar at 50mm depth
- Faces/surfaces have safety implications for scaffold/rope access, remote measurements advantageous.
- Simple structural geometries suitable for ROV.

Inspection (2) – Aerial Stacks

- Concrete re-enforced curved stacks over 100ft high, diameters 2 -8 m at the base.
- Associated with ventilation systems for nuclear safety purposes. ROV minimises downtime if the internals are to be inspected by avoiding man access near to the outlet that fundamentally makes a task safer.
- ROV required to inspect the internals of an operational stack, with the associated air flows and velocities.
- External examination of stack expected.

Inspection (3) – Internal Radiation Contaminated Cells

- Store plant, vessels, pipework and other devices
- Concrete and rebar construction and clad with stainless steel 2-3mm thick with a transition part way up the wall (if not fully clad)
- Floors of these cells are also clad with stainless steel, demanding a high friction medium for traction. Accumulations of dusts/loose debris are possible
- ROV introduced via man-access door or cell wall penetration
- Walls range from 200 to 1800mm thick
- The cell wall penetrations are as small as 150 to 200mm in diameter

Inspection of Nuclear infrastructure with mobile ROV

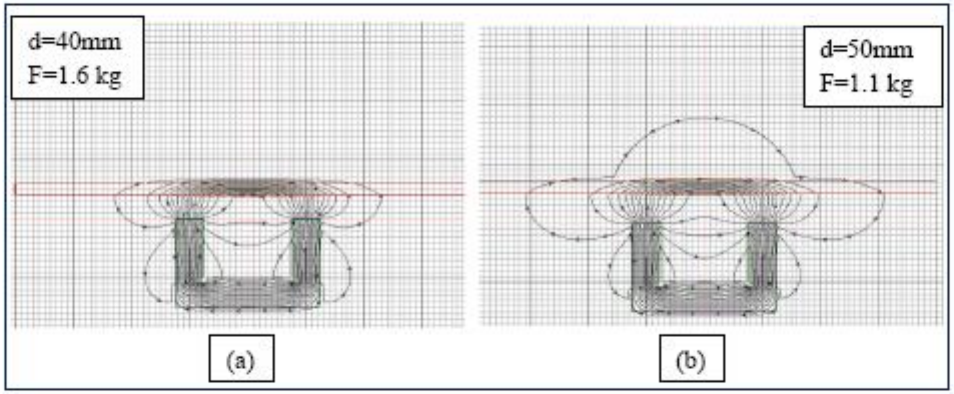


Figure 7-9 Magnetic field lines inside steel reinforced concrete when concrete cover (d) is (a) 40mm (b) 50mm

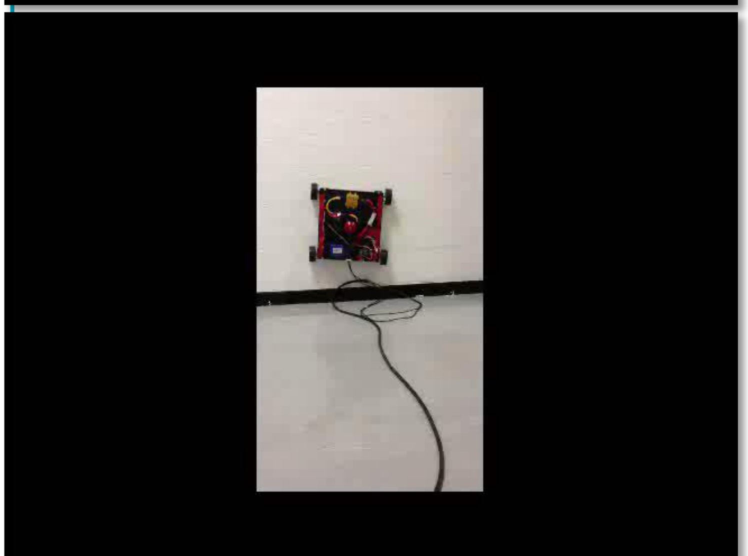
Permanent Magnet Adhesion Climbing Robot for inspection of large concrete structures e.g.

- Stacks
- Radiation Cells
- Buildings
- Civil engineering structures

Features

- Uses magnetic flux focussing techniques to adhere to steel rebars
- Zero energy adhesion with permanent magnets
- Longer operating time with battery powered robots
- Robot remains safely attached during power failure

VORTEX MACHINES: Wall climbing robots for NDT, inspection and surveillance on non-ferrous surfaces



DEPLOYMENT OF LASER CUTTING HEAD WITH WALL CLIMBING ROBOT FOR NUCLEAR DECOMMISSIONING

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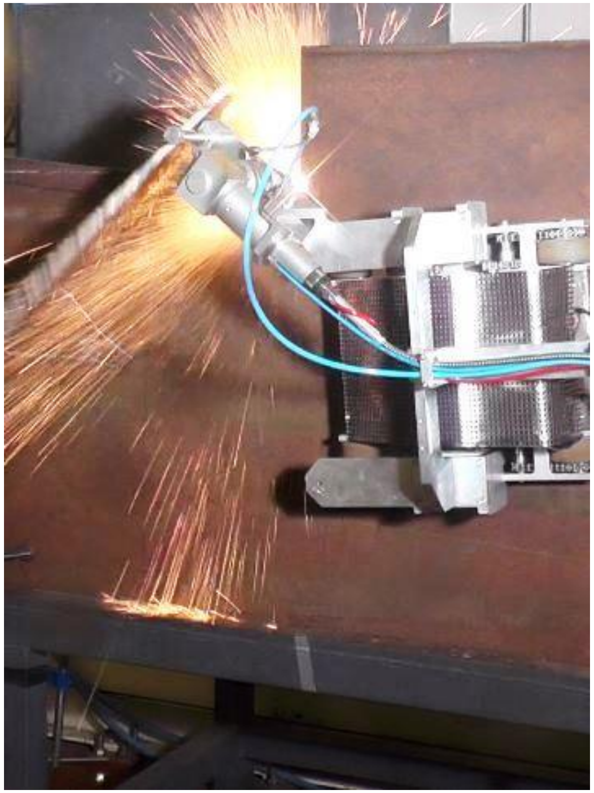
Paul Hilton
Md Omar Faruq Howlader

Demonstration of STRONGMAN carrying TWI laser cutting tool for nuclear decommissioning – 21 September 2016



The Lasersnake2 R&D project funded by the UK Technology Strategy Board, the Department for Energy and Climate Change, and the Nuclear Decommissioning Authority is using snake arms to deploy laser cutting heads

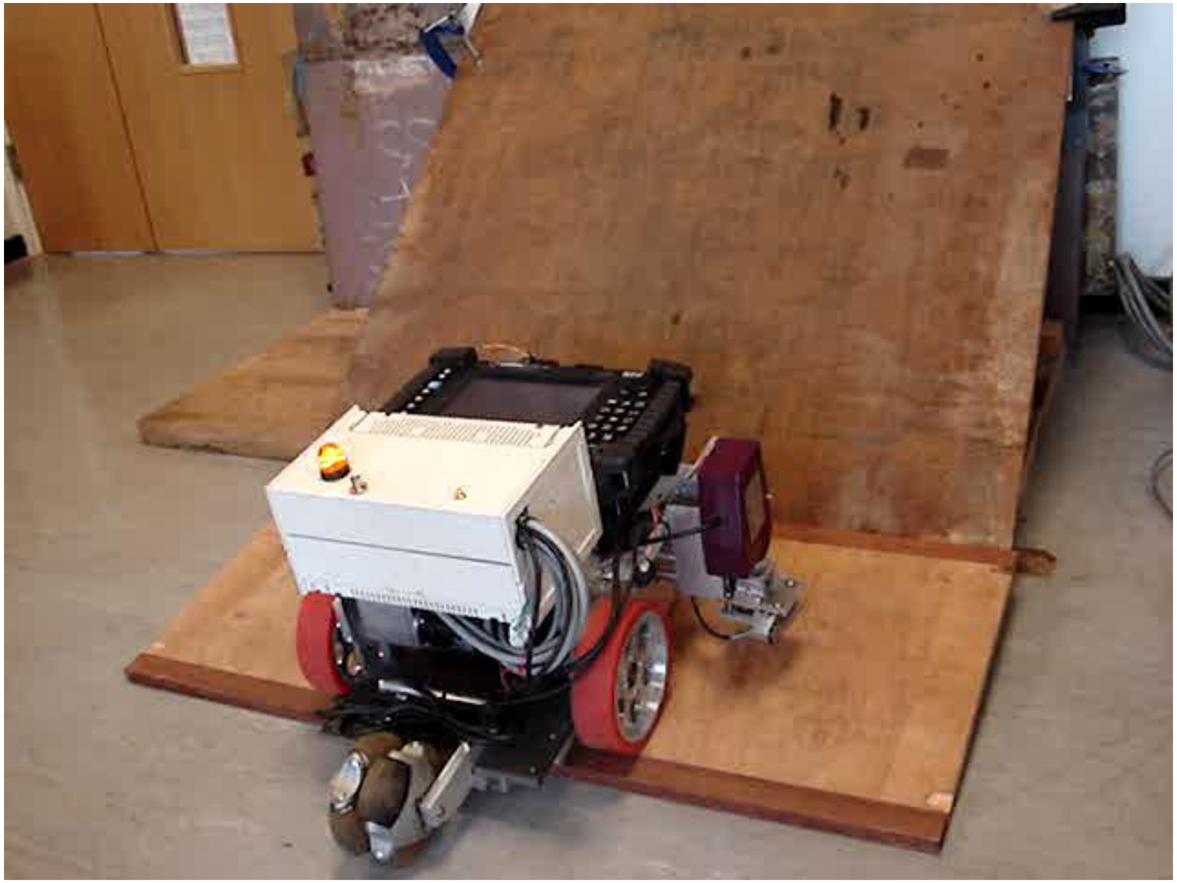
Advanced Wall climbing robot for the inspection of welds on cargo containers ships

Permanent magnets

Wireless control and data acquisition

Ultrasonic phased array NDT

Mass 35Kg



Climbing Robot Cell for welding and NDT - CROCELLS

- Team of climbing robots
- One performs Electric arc welding by profiling seam with a laser system
- A utility robot follows the welder and carries the wire drum and feeder
- A tug robot aides the welding robot
- An NDT robot tracks the welding hot spot and performs weld inspection with phased array ultrasonics

The nuclear decommissioning task

Operators require technology to cut steel structures that:

- Is highly automated and remotely operated
- Delivers noncontact dismantling & cut most materials
- Produces minimum secondary waste
- Works at a high speed
- Is reusable in many decommissioning processes

Laser cutting technology meets requirements

- Solid-state lasers, with optical fibre delivery of laser power, reduce complexity and risks, providing laser power in the multi-kilowatt regime with good focus ability of the delivered beam

- High value asset, which is the laser itself, situated and maintained in a safe clean area, remote from the cutting

- Commercially available laser technology, at powers of the order 5kW, is well capable of cutting material up to 50mm in thickness

The Laser cutting system

- 5kW fibre laser, manufactured by IPG Photonics,

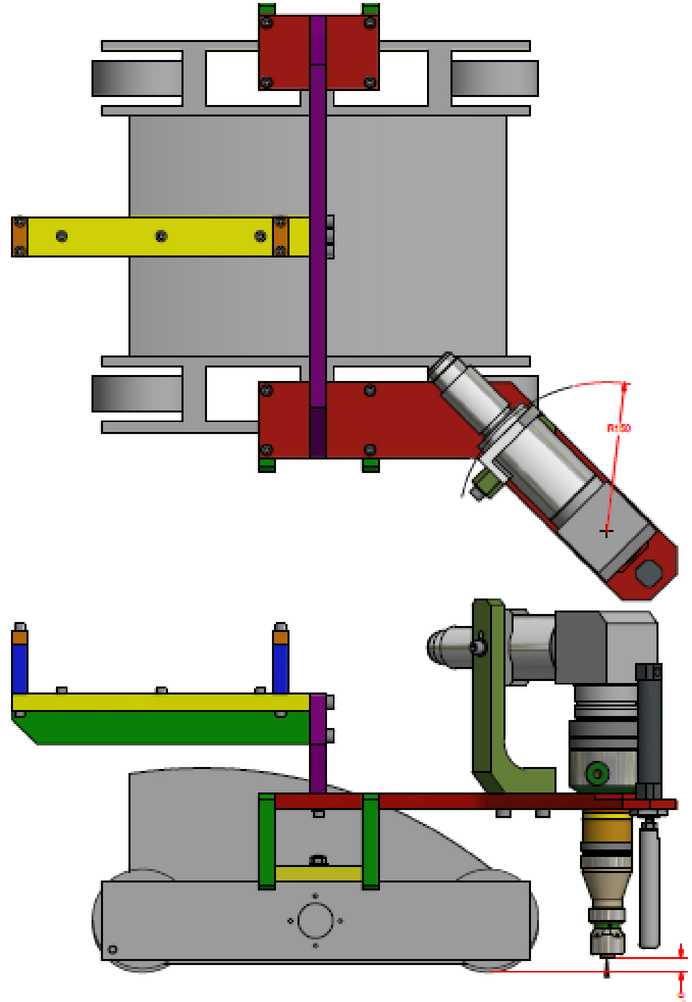
- 30m long, 150 micron core diameter optical fibre delivers power to a cutting head.

- Cutting head uses 120mm focal length collimating lens makes the diverging beam emerging from the end of the fibre, parallel.

- This beam is then diverted through 90 degrees to a focusing lens of length 250mm, to form a focused spot of about 0.4mm in diameter.

- A cut kerf is formed by blowing away the molten material with a jet of compressed gas. For decommissioning applications, cut quality is not really an issue so compressed air (for cheapness) is used as the assist gas.

- The maximum cutting speed, for a given thickness, depends primarily on the applied laser power, the position of the laser beam focus with respect to the surface of the material and the pressure and composition of the cutting assist gas.



Climbing robot carrying laser cutter head to cut on the right side

Cutting head positioned 15mm above plate, 45° w.r.t. robot

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