Nuclear decommissioning challenges in the UK
– a rough guide for roboticists

Rustam Stolkin
University of Birmingham, UK

With some slides provided by Jeffrey A. Kuo
National Nuclear Lab, UK

Caveat: I am a robotics researcher and not a nuclear expert, however I have been collaborating with UK nuclear industry over past 5+ years, and have become familiar with some of the important challenges... I will try to present them in this talk.
Overview of UK nuclear cleanup

- Nuclear generates around 18% of UK electricity.
- 16 operational nuclear reactors at 9 sites.
- 17 sites undergoing decommissioning.
- Current cleanup estimates:
  - Between £90billion and £220billion
  - (i.e. US $135billion to $330billion)
  - Expected to take 120 years
- At least 20% must be done by remote handling methods...

The sites are hugely varied and include:
- facilities previously used to produce nuclear materials for weapons
- research sites used during the development of the nuclear industry
- nuclear fuel reprocessing facilities and fuel fabrication plants
- the UK’s first generation of nuclear power stations, the Magnox fleet
Former BNFL was removed and NDA, NNL and site companies were created during 2000s.

- **UK Government**: £3.2 billion per year

  - **Nuclear Decommissioning Authority (NDA)** (only 300 employees – issues contracts to: )
    - **Site companies, e.g. Sellafield Ltd**
      - Sellafield budget ~£1.6 billion per year
    - **Sellafield budget ~£1.6billion per year**

  - **National Nuclear Lab (NNL)** (run as commercial business)

  - **UKAEA** (mostly fusion research)

  - **UK AWE** (weapons)

  - **Active power plants** (mostly EDF Energy)

  - **Some PhD bursaries, sometimes consultancy etc.**

- **Universities and research labs**
History of UK nuclear

- Nuclear operations began at Sellafield in 1947 (formerly the Royal Ordnance Factory in WWII).
- Early reactors built very fast - first reactor online by 1950 (Windscale).
- Early reactors were designed to create materials for cold war arms race.
- World’s first civil nuclear power station online by 1956 (Calder Hall - four 60 MWe reactors).
- Nowadays, multiple sites from north coast of Scotland to south coast of England.

- 1950-2000, 21 serious incidents:
  - one at level 5
  - five at level 4
  - fifteen at level 3
Legacy waste sites

- **UK legacy waste** cleanup is the biggest environmental remediation project in the whole of Europe.
- Vast majority is at a single site – Sellafield.
- Six square km site in north-west England.
- Major plants include:
  - Legacy reactors
  - Reprocessing plants
  - Radioactive waste stores

Necessary operations:
- dismantling and demolishing the buildings
- managing and disposing of all waste
## Sellafield – One of The World’s Most Challenging Nuclear Sites

### THE CHALLENGE

- 1200 buildings in 6 sq km:
  - 200 hold nuclear inventory
  - 100 equivalent or greater than a nuclear reactor in terms of hazards and security
- Ageing infrastructure, 60+ years
- Poor historical record keeping

### LARGEST UK CONSTRUCTION SITE

- Multi-billion facilities being built for clean-up
- 450 engineering and construction projects
- 17 valued over £100 million

Source data: Nuclear Management Partners Performance and Progress at Sellafield (http://nuclearmanagementpartners.com)
To decommission Sellafield, it is estimated that:
- 3 million suit entries are required.
- There will be 111 radiological injuries.

Can we use robots to:
- Remove humans from harm?
- Increase clean-up rates?
- Reduce secondary waste (e.g. contaminated suits, gloves etc)?

So far, use of robotics in UK nuclear is very limited...
- Conservative industry
  - Lots of 60s style MSM devices
  - Robots for simple tasks
  - Very limited sensing
  - No autonomy
- Lots of R&D investment in 1980s – yielded low TRL robots which were abandoned
- Low confidence in robots in past.
- New interest emerging now...
Remote Intervention Challenges

- **Access**
  - Congested plants
  - Path planning

- **Obstacle avoidance**
  - Restricted access
Magnox Swarf Storage Silo

- Constructed 1960’s – 1980’s to hold irradiate wastes from Magnox fuel decanning
- Waste stored under water cover
- 22 compartments constructed in 4 phases
- Waste receipts continued until 2000
- Intolerable Risk
- Highest risk plant on the Sellafield Site and in the UK on NDA SED Score

Currently designing machinery to:

- Enter silos
- Excavate waste
- Place in skips ("dumpsters")
- Transport waste to Box Encapsulation Facility

- The MSSS Compartments contain Magnox swarf and solid ILW
- The Magnox swarf corrodes to magnesium hydroxide sludge
Storage ponds

- Became overwhelmed in 1970s during coal shortages from miners’ strikes
- Magnesium fuel rod casings react with water to make magnesium hydroxide sludge.
- Any entry stirs up sludge – reduced visibility and high dose levels on surface.
- Concrete bad condition – leak could cause fuel to ignite. Poor records/inventory.
- Some attempts to deploy ROVs. Sensing difficulties – possibly sonar can help?

Constructed 1950’s – 1960’s to store, cool and prepare Magnox fuel for reprocessing
Second highest risk plant on the Sellafield Site and in the UK on NDA SED Score
Glove box problem

- Large no. legacy labs ⇒ each with large no. glove-boxes
- Some are many decades old
- Contain fine plutonium powder/dust (alpha emitting)
- Age ⇒ decay to gamma emitters – dose hazard to workers
- Glove-boxes are decaying – plexi-glass becomes brittle with radiation
- Estimated at ~£1billion cleanup cost

Hundreds of glove-boxes
Plutonium dust & worse
50 yrs old and decaying

Chop up these
Put the bits in here

Glove-box decommissioning
4 year project
UoB + NNL +3i Technology Ltd.
Difficulties and research challenges

Impact / contact
- Destroys position-controlled arms
- Active compliance with force-feedback control? Not sufficient...
- Need end effector tools with passive/mechanical compliance also

Imaging & Virtual Reality
- 3D reconstruction of glove-box
- Planning and rehearsal of cuts in VR simulator

Human factors
- Tele-presence & human-robot interface
- Tele-autonomy
- Haptics, tactile and force feedback
- Data visualisation

Optimisation
- Quickest / safest cuts?
- Max. parts into min. storage bins?
Storage drums deformation

- Many drums contain grouted fuel-rod casing
- Contaminated with uranium
- Forms oxides over time
- Density changes
- Causes bulging/deformation in drums

- 140,000 ILW containers need to be evaluated to determine extent of deformations.
- University of Birmingham has carried out accurate 3D reconstruction using depth cams.
- Compare to CAD model to detect deformation zones and estimate strains.
Nuclear sort and segregation problem

- Cleanup of legacy nuclear waste in the UK alone is the largest environmental remediation project in the whole of Europe.
  - UK has 1.4 million cubic metres of intermediate level waste (ILW) alone.
  - At a single UK site (Sellafield), 69,600 cubic metres of ILW waste will have to be placed into 179,000 storage containers in near future.

- Much of this was stored decades ago, in containers with unknown (or partially known) contents and mixed contamination levels.
  - Old containers must be cut open.
  - Their contents must be examined, sorted and separated.
  - Highly contaminated waste must be extracted and placed into special new storage containers

Co-funded by the Horizon 2020 Framework Programme of the European Union

RoMaNS
ROBOTIC MANIPULATION FOR NUCLEAR SORT AND SEGREGATION
Current state of the art in UK nuclear manipulation

• New robotic waste processing testbed at NNL
• New robotic plant at Sellafield will take in legacy waste in skips, cut open containers, inspect/sort/segregate and re-package in newer, safer containers.
• 500 kg payload 6-axis KUKA robot arms
• Exciting – MAJOR investment by UK nuclear in advanced, modern robotics

But so far..

No autonomy.

No telepresence/haptics.

No compliance.

Limited visualisation.

Limited sit. awareness.

H2020 RoMaNS will address some of this...
Looking to the future...

• Recent re-awakening of interest in robots from UK nuclear managers.
• Efforts to form new national CoE for nuclear robotics.
• Many uses for robots have been identified:
  – Characterisation, monitoring, interventions, handling waste, cutting and resizing etc.
• Interest in many kinds of robotics emerging:
  – Arms/hands, vehicles, quadcopters, vision systems, sensor-fusion, augmented reality etc.
• New willingness to engage with university robotics teams to pursue major collaborative grants.
• A good time for robotics researchers to get involved in nuclear problems:
  – BIG problem (£90billion - £220billion)
  – Long future – 120 years of work needed
  – Huge societal impact (cleaning up the environment for future generations)
  – Most kinds of robotics research can find an application in this domain