Decommissioning preparations for the accident-damaged Pile 1 reactor at Windscale, UK

Presented at the International Experts' Meeting on Decommissioning after a Nuclear Accident, IAEA, Vienna, 28 January – 1 February 2013

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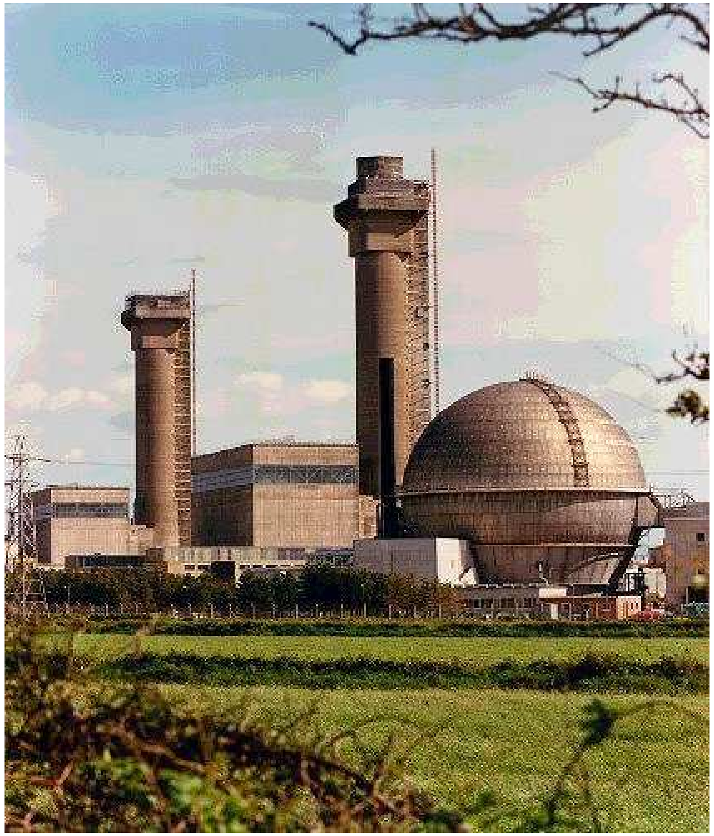
January 2013

Introduction

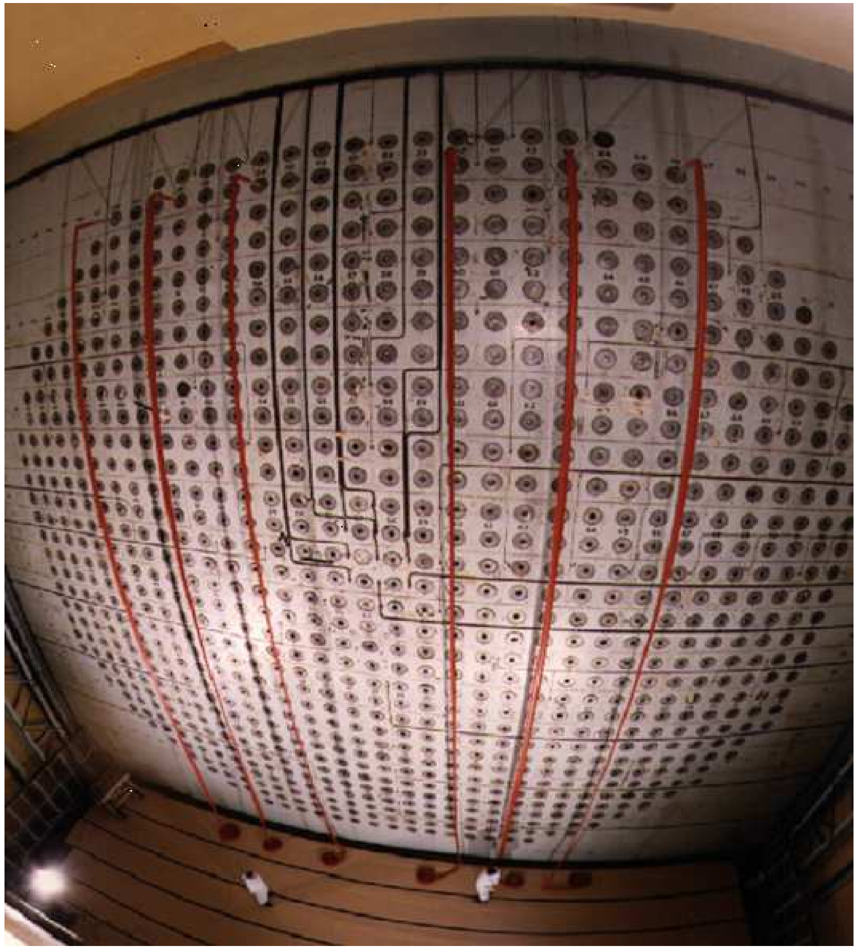


- **Non-conventional large decommissioning project (accident-damaged reactor with fire damaged core, not all fuel removed)**
- **2 reactors in safestore since core fire in Pile1, 1957**
- **Characterisation issues dominate**
  - some unique considerations
  - intrusive inspection of fire-damaged region now carried out

The decommissioning problem has been dominated by the lack of a detailed knowledge of the state of the core

Pile parameters

- **Graphite moderated, 2000 te**
- **180 MW$_t$, air-cooled, once-thru, no PV, 200 ºC outlet temp**
- **3444 horizontal fuel channels**
- **977 horizontal isotope channels**
- **Fuel:**
  - natural uranium metal rods, 21 elements per channel
  - later used 0.92% U-235
  - clad in finned aluminium
  - 70, 000 elements, 180 te U full charge



The 1957 Accident in Pile 1

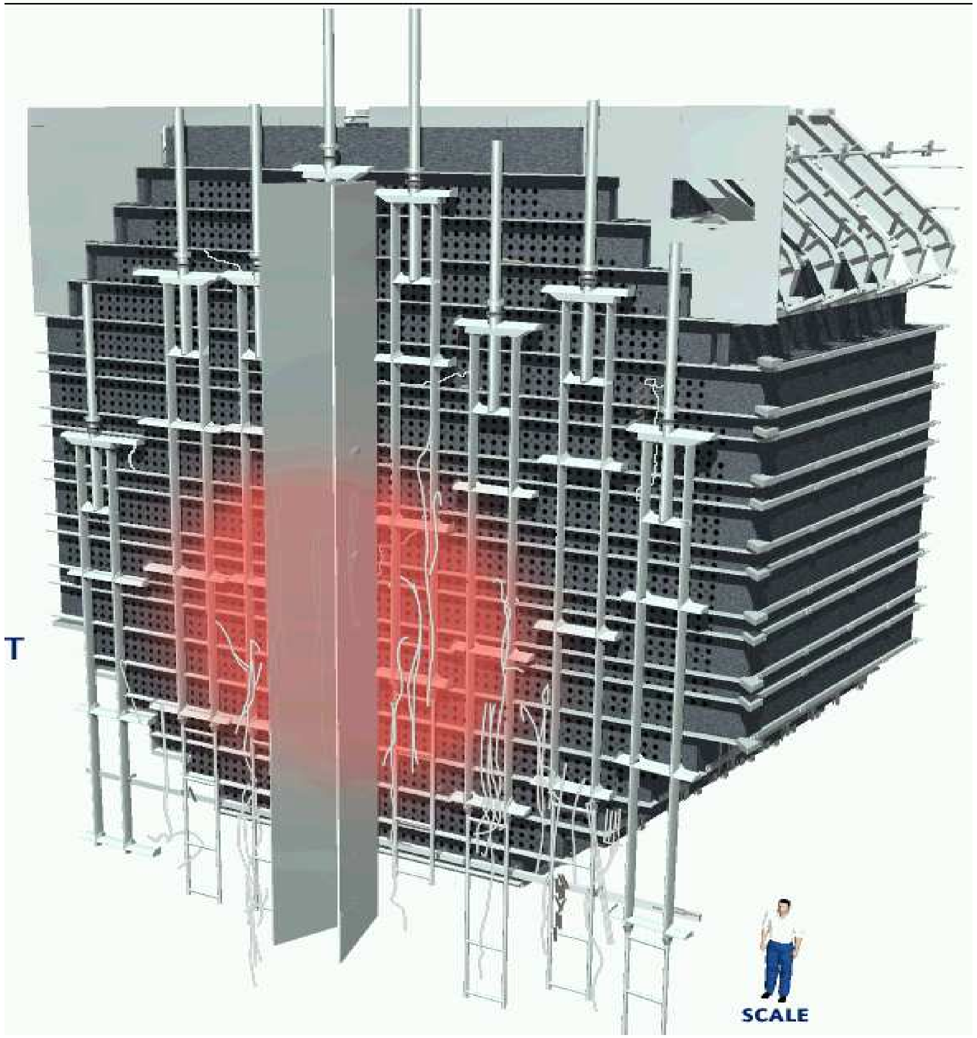
- **9th anneal started 7 October – abnormally high core temps by 10th Oct**
- **Increase in activity on stack monitors**
- **Selected channels at red heat, flames at discharge face**
- **‘Firebreak’ produced around affected zone**
- **Carbon dioxide injection – no effect**
- **Finally, water injection and cooling fans switched off**

Conjectured that inadequate instrumentation led to graphite over temperature and clad failure on isotope cartridges leading to runaway Wigner release and exothermic uranium, isotope and graphite oxidation.

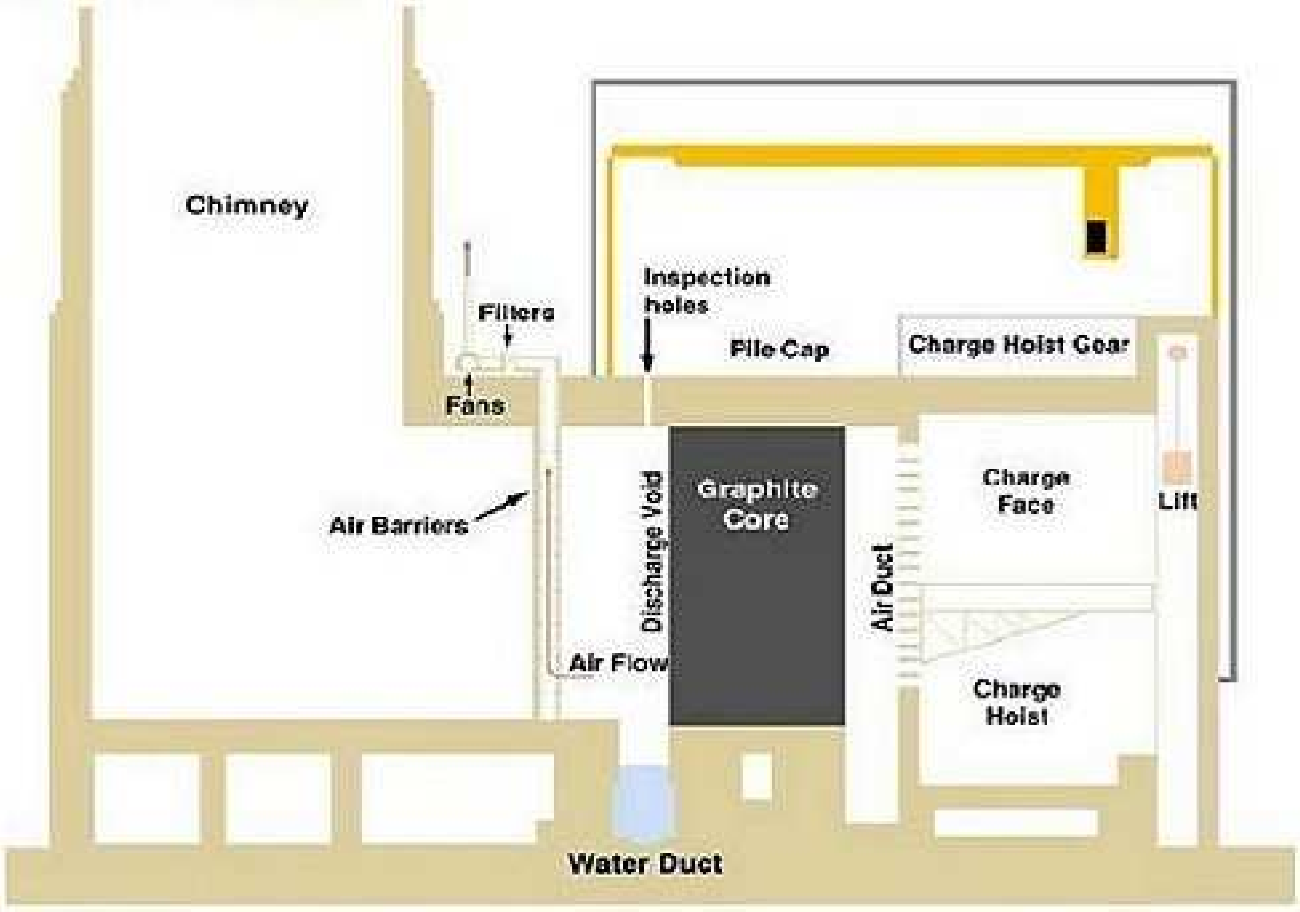
Environmental Effects

- **Filters on stack retained most Sr-90 and prevented a major disaster**
- **Most release, I-131 (740-1100 TBq)**
- **Fallout deposition on local farmland, milk discarded for several months to prevent human consumption**
- **Excess cancers re-estimated at 240 in 2007**

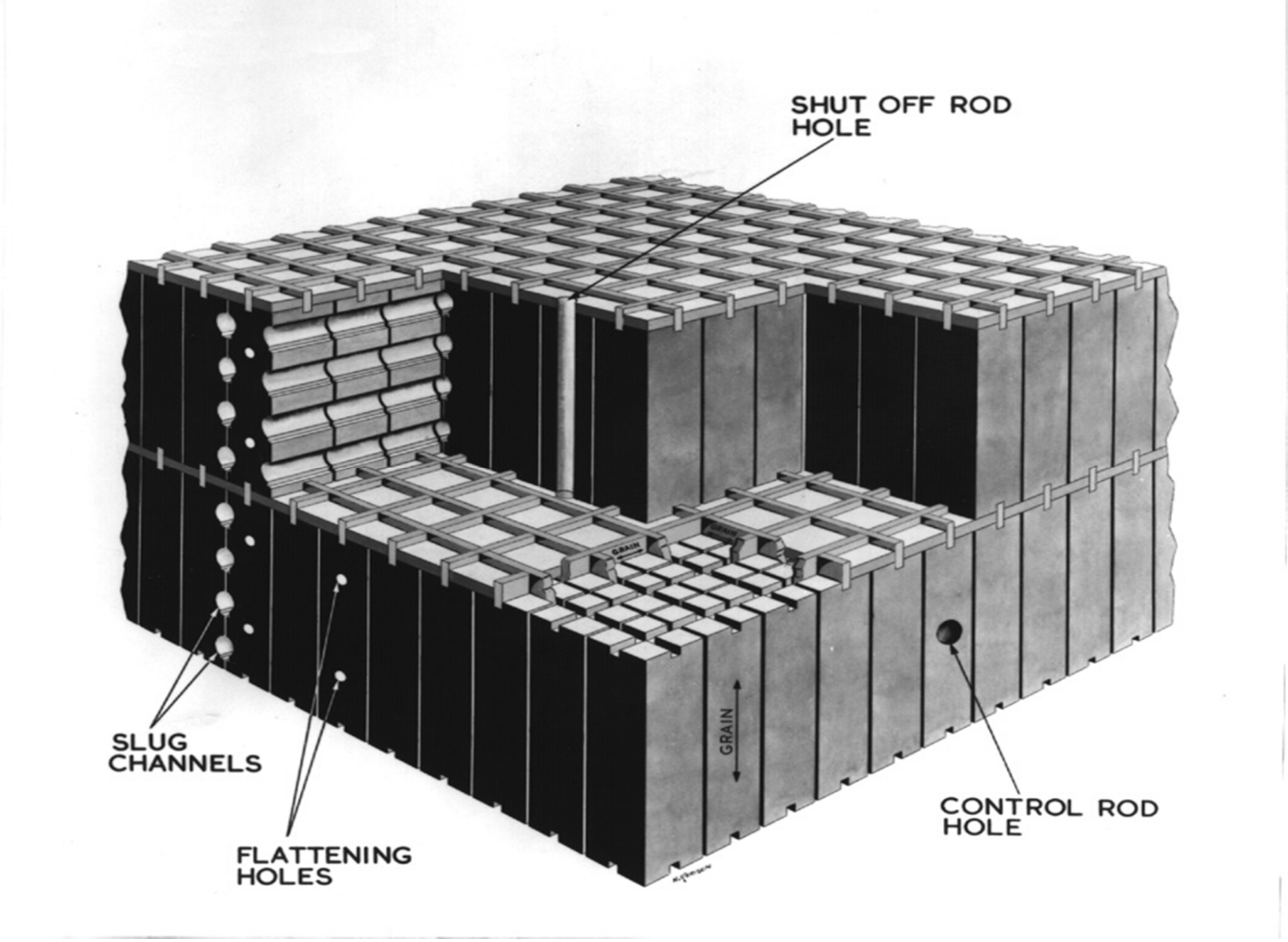
Fire-Affected Zone (FAZ) in Pile 1



Lateral cross-section



Piles' graphite core structure



Early Decommissioning, Phase I - securing the safety of the facility

- **Commenced early 1980’s**
  - Sealing of bioshield
  - Installation of ventilation and monitoring
  - Loose fuel removal from outside core
  - Drain-down of water duct
  - Core removal option studies
  - Completed June 1999

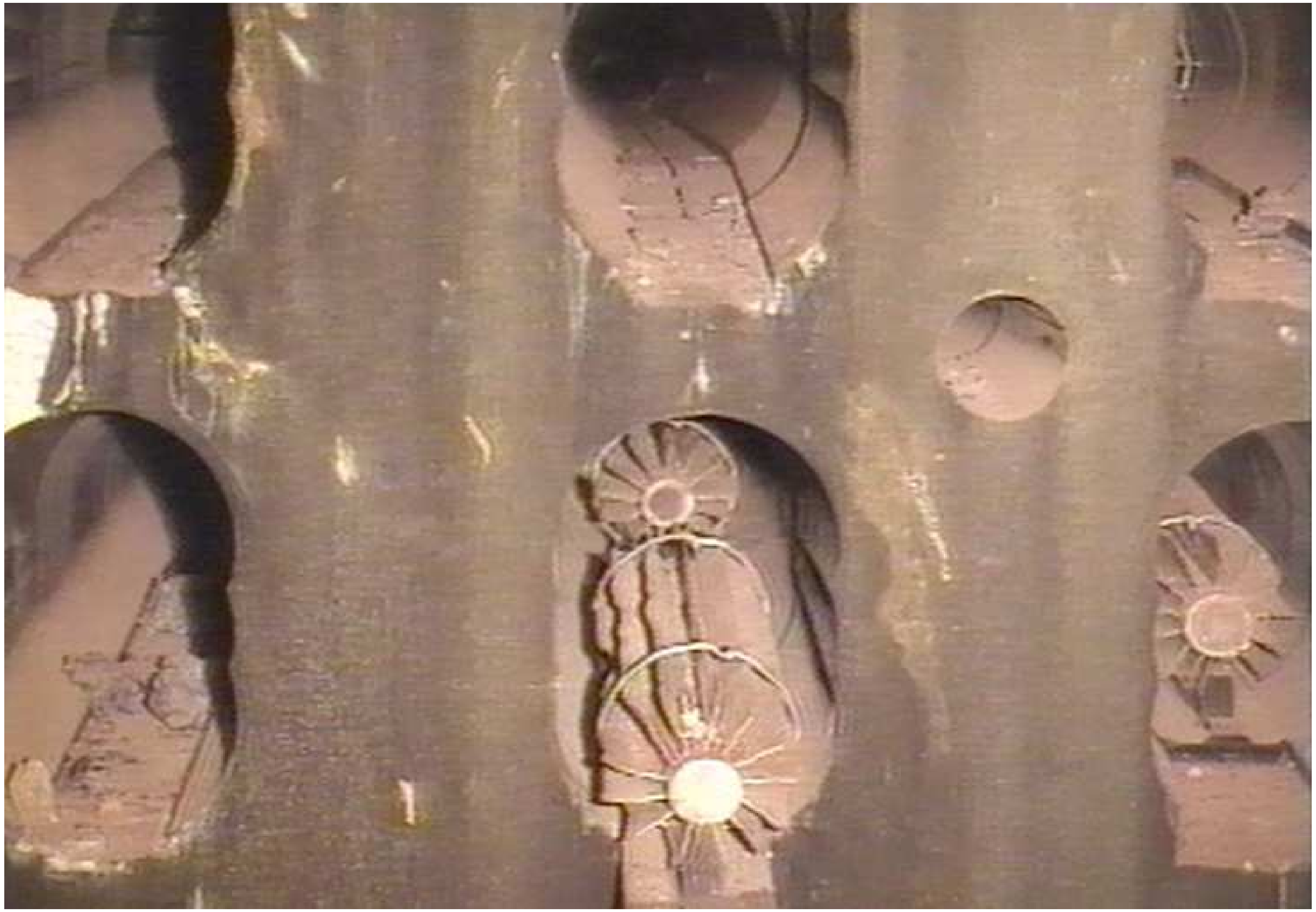
Air Duct Clearance

Water Duct Clearance - Before

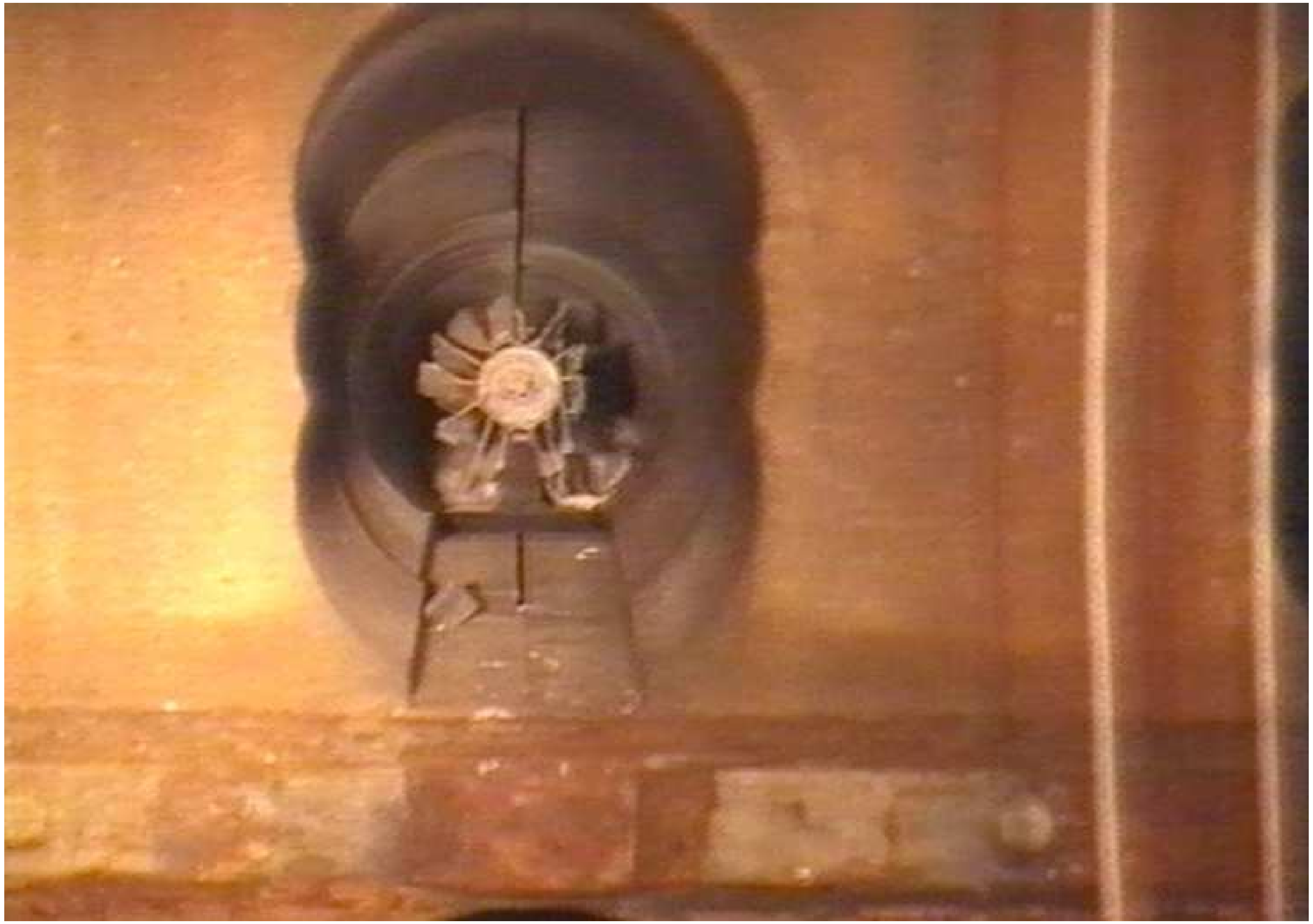
Water Duct Clearance - After

Present condition of Pile 1

Apparently Pristine Fuel



Slightly Damaged Fuel

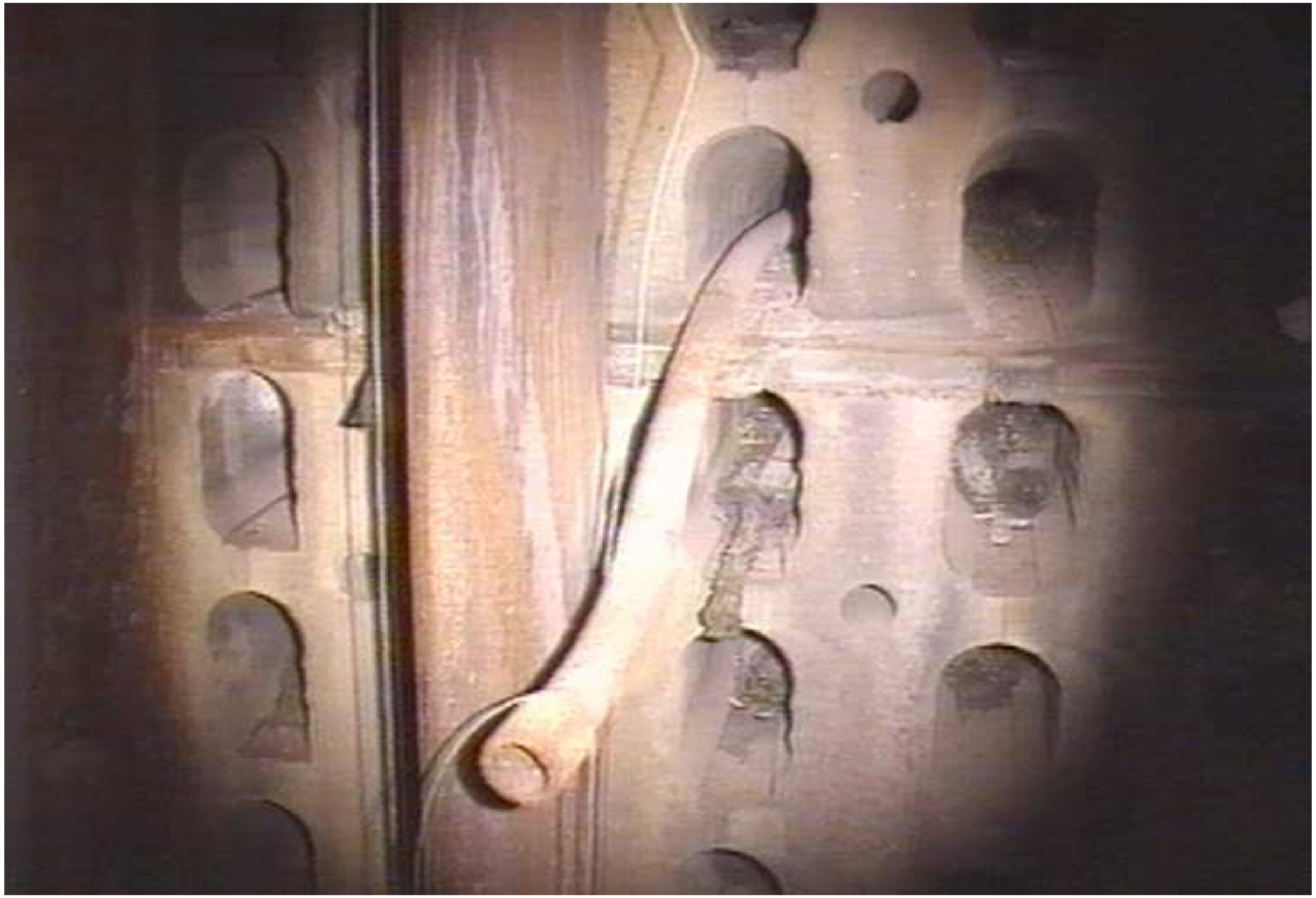


Destroyed Fuel - 23.54

Intact Isotope Cartridge

Damaged Isotope Cartridge

Metal Pipe - channel 21.55



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Hazards and decommissioning issues

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January 2013

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Pile 1 safety issues for decommissioning

- **~15 te fuel still present**
- **Possible core voidage post ‘57 fire - seismic collapse is Design Basis Accident under C&M**
- **Characterisation issues:**
  - Wigner energy in graphite
  - ‘hydride event’ (pyrophoric material present?)
  - graphite dust explosion?
  - Criticality?

Physical characterisation dominates.

Hazards - Wigner energy

- **Pile was left partially unannealed in ‘57**
- **Extent of anneal is unknown**
- **WE will be greatest nearer cooler charge face and core edges in high flux regions**
- **WE is principally issue for waste disposal**
- **Pile 1 accumulated ~3 times more neutron dose than Pile 2 (4.1 x 10^4MWd cf Pile 2, 1.5 x 10^4MWd)**

Only route forward for Wigner energy determination is physical sampling!

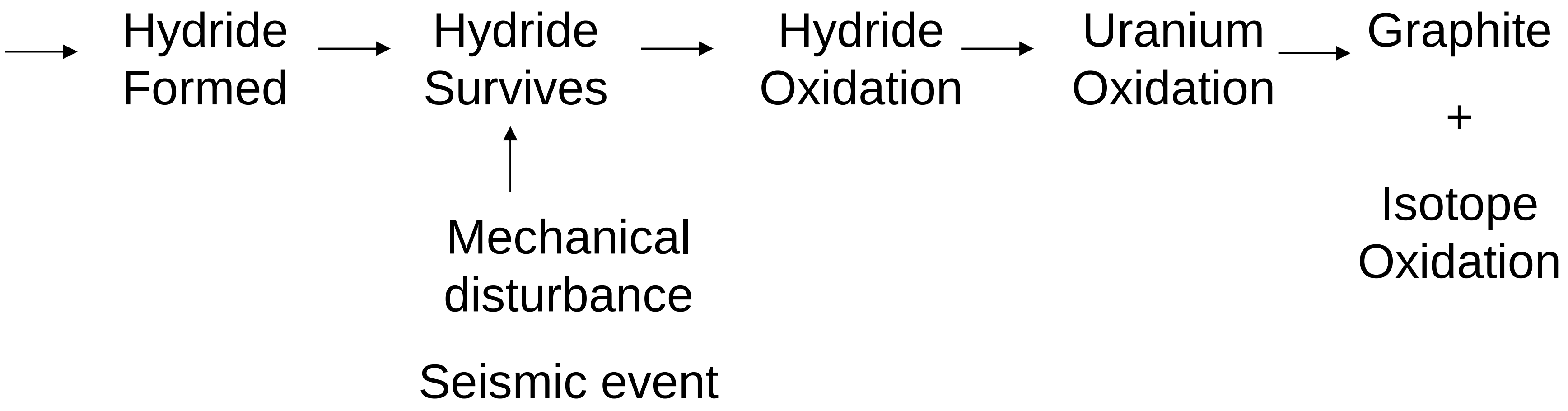
Hazards - pyrophoric materials

- **U metal reacts with oxygen in air → UO_{2+x}**
- **U metal reacts with water vapour → UH_3**
- **In Pile 1 conditions UH_3 would not form (air)**
- **In Pile 1 conditions UH_3 would not survive unless in microclimate situation – unlikely, but cannot ‘prove a negative’**

Hence we have pessimistically assumed that the presence of some UH_3 cannot be ruled out for safety case purposes!

Uranium Hydride Event Sequence

Conjectured event sequence:



Hydride Formed

Hydride Survives

Hydride Oxidation

Uranium Oxidation

Graphite + Isotope Oxidation

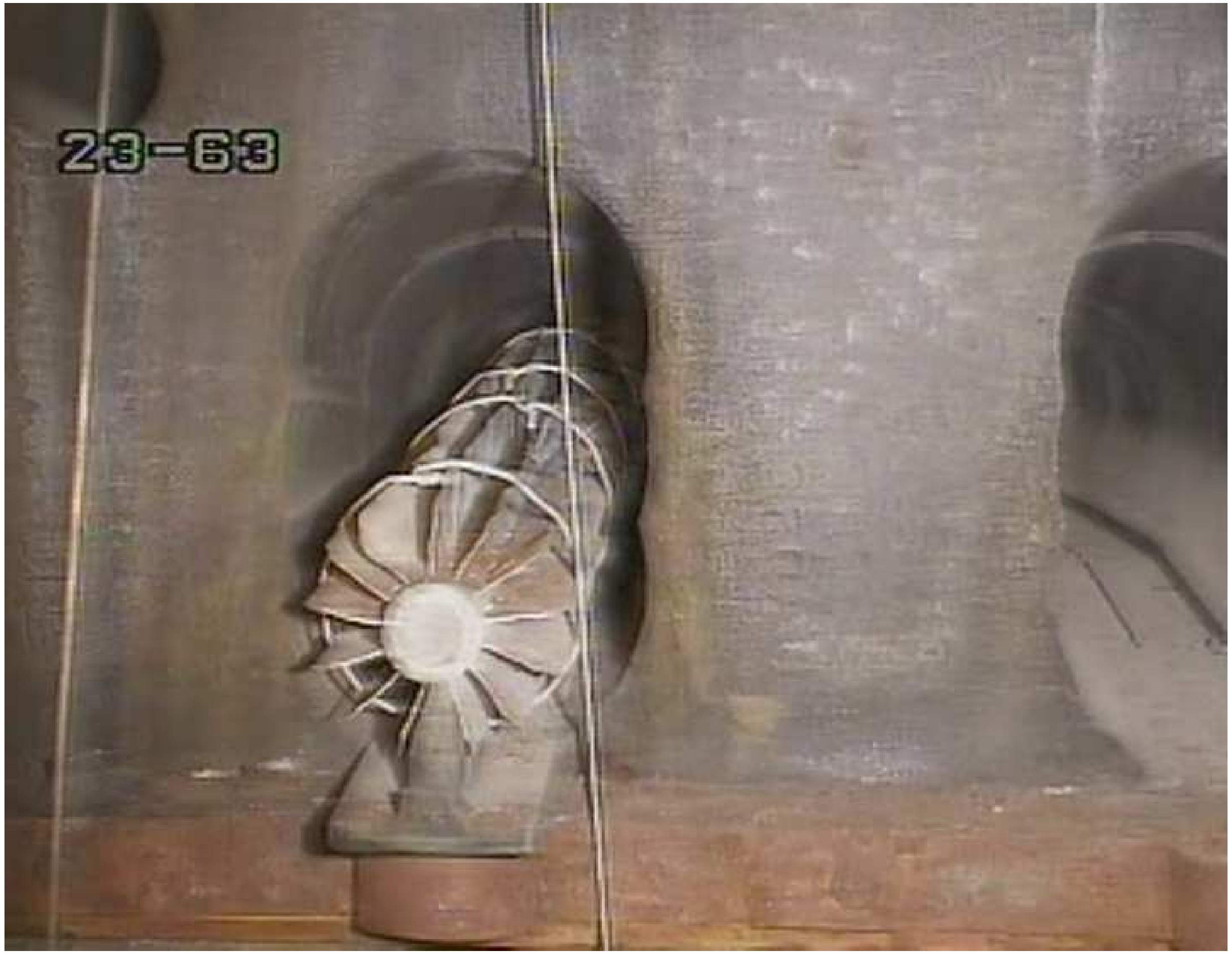
Mechanical disturbance

Seismic event

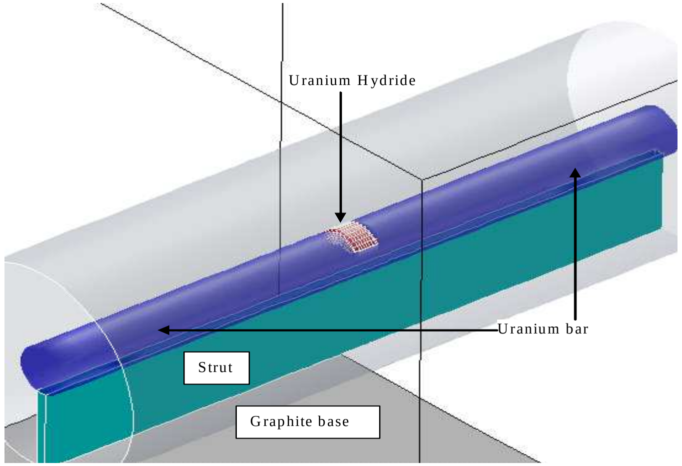
Fuel element condition - gross corrosion, Channel 21, 58, hydride ruled out

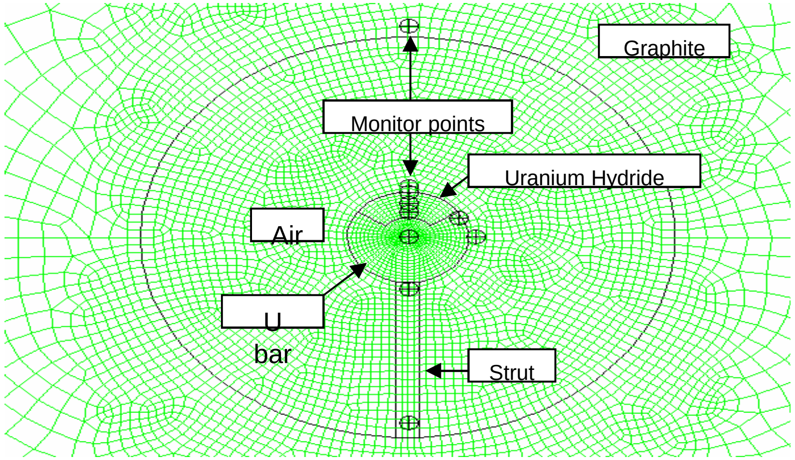
Fuel element condition - severe fuel damage, Channel 24, 61, unlikely hydride survived

Fuel element condition - minor fuel damage, Channel 23, 63, hydride possibility?



3D-geometry model of a Pile 1 channel with a hydride patch located in the centre of the uranium bar





- Microclimate hypothesis - small-scale localised corrosion
- Not pure hydride - hydride surface-oxidised
- Assume mechanical disturbance removes clad closure

Assume air now has unrestricted access to corrosion product

Hydride oxidises with heat generation

Self-heating depends on heat transfer

Lessons learned for Pile 1

Conjectured surviving hydride will not self-heat to give a propagating thermal excursion if exposed to air:

- Bulk U metal will not be heated enough to oxidise significantly
- Temp. rise so small - no WE release in neighbouring graphite
- Isotope cartridges remain unaffected; no cross-channel effects
- Effects of hydrogen liberation are insignificant

Argon cover will not be required during dismantling

Hazards - graphite dust explosibility

- **Controversy has existed over the potential for a graphite dust explosion during decommissioning (UK, France, Italy, Japan)**

- **Graphite dust when levitated in sufficient concentration, with appropriate particle size and high energy input is weakly explosible**

- **Lead (Pb) is known to enhance graphite oxidation markedly – lead cartridges in Piles**

- **For safety case purposes some quantitative data was required – research programmes have now been conducted**
    -

Conclusions

Studies for Pile 1 have shown graphite to be weakly explosible – but:

- it is unlikely that there will be sufficient graphite dust present or that it will be rendered airborne;
- it is likely that a significant fraction of the inventory of graphite particles will be in the explosible size range;
- the graphite dusts are likely to be mixed with a substantial amount of inert material;
- a sufficiently powerful and energetic ignition source is not available (2000 J required); and
- it can be eliminated completely by careful attention to operation practice *i.e.* by removing at least one of the necessary conditions for a deflagration.

Hazards – criticality

- ~15 te U still present
- Direct neutron measurements showed improved criticality margin (k_{eff}) over value estimated by MONK code (6% less)
- Indication that less fuel present than previously thought
- Safety report demonstrated that criticality margin is preserved during DBA (seismic core collapse)
- Li cartridges supress reactivity!

Conclusions on decommissioning issues

- **Pile 1 presents some particularly difficult decommissioning problems with unique issues**
- **Situation will be improved by ability to remove samples from fire-damaged area**
- **Progress has been made on several fronts:**
  - Visual inspection via CCTV
  - Better understanding of the Wigner energy levels in graphite
  - Uranium Hydride
    - pessimistic analysis shows oxidation transient will not propagate
    - can dismantle in air
  - Graphite dust explosions can be dismissed
  - Criticality - no problems during a seismic event providing neutron absorbing material remains
    - no additional N absorber needed
    - sequenced removal of material during dismantling

Lessons learned

- **During operations**
  - UKAEA ‘overstretched’ at time of accident
  - Insufficient technical support to what became ‘routine’ operations
- **Decommissioning**
  - Emphasises the need for priorities put on characterisation
  - Decommissioning problems initially overestimated
  - Lack of continuity - many hiatus’, plans and organisation changes
  - Loss of expertise due to lack of continuity