WINDSCALE ACCIDENT

11/29/2017

INTRODUCTION

Air-cooled piles for the production of Pu were operated at the Windscale, now named Sellafield, site at the northwest coast of the UK. The UK was in a race to produce Pu for its weapons program in the nuclear arms race during the Cold War. It opted to build dual-use graphite moderated and air-cooled reactors for the production of electricity and weapons-grade Pu.

WIGNER ENERGY

One of the piles was shut-down on October 7, 1957 for the routine maintenance operation of releasing the stored Wigner energy typical in graphite moderated reactors. The neutrons irradiation would displace atoms from their positions, creating radiation damage in the form of vacancies and interstitials.

Nuclear heating was used to controllably anneal the graphite by raising its temperature where the interstitial atoms moved naturally back to their initial vacancy positions in the lattice. The initial nuclear heating releases the stored energy in the form of heat, at which point the nuclear heating is stopped with the Wigner energy release sufficient to complete the annealing process.

Should the release of the stored energy be allowed to occur uncontrollably, hot spots could be created in the graphite moderator.

Figure 1. Windscale graphite-moderated air-cooled piles with cooling towers (left) and ventilation stacks (center) with air filters on top,

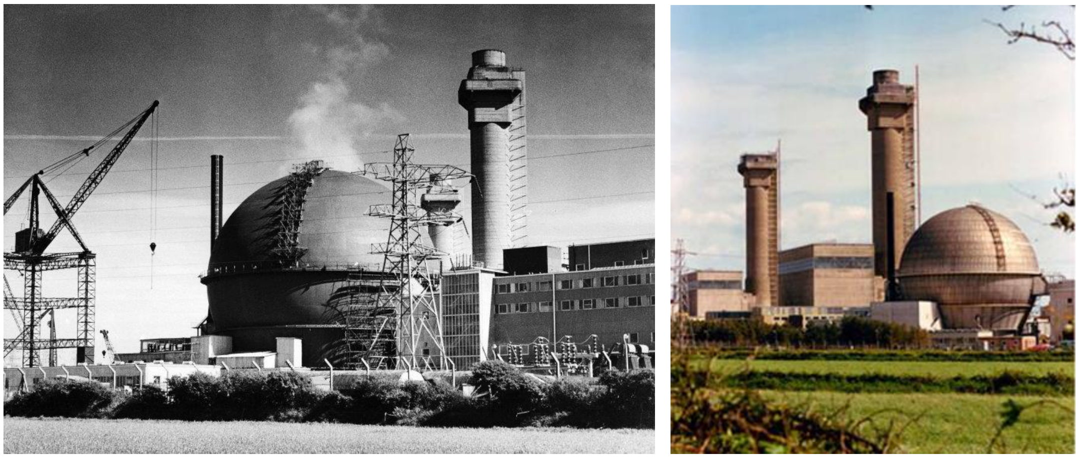

Figure 2. Windscale (Sellafield) piles facility with air-cooling discharge stacks and the Advanced Gas-cooled Reactor.

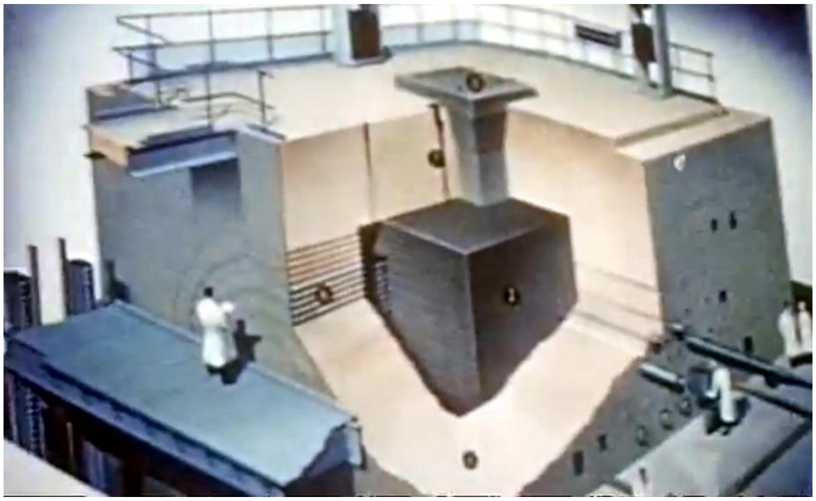

Figure 3. Windscale reactors cutout.

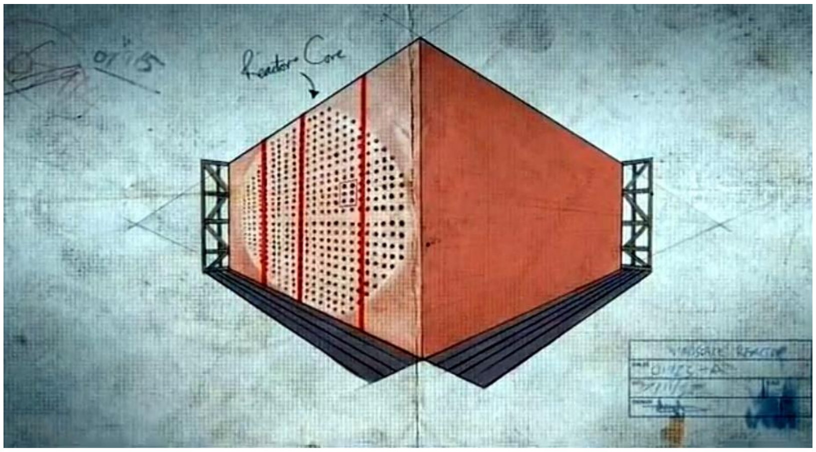

Figure 4. Windscale reactors core configuration.

Figure 5. Air circulators and ventilation stacks with filters atop them at the Windscale reactors.

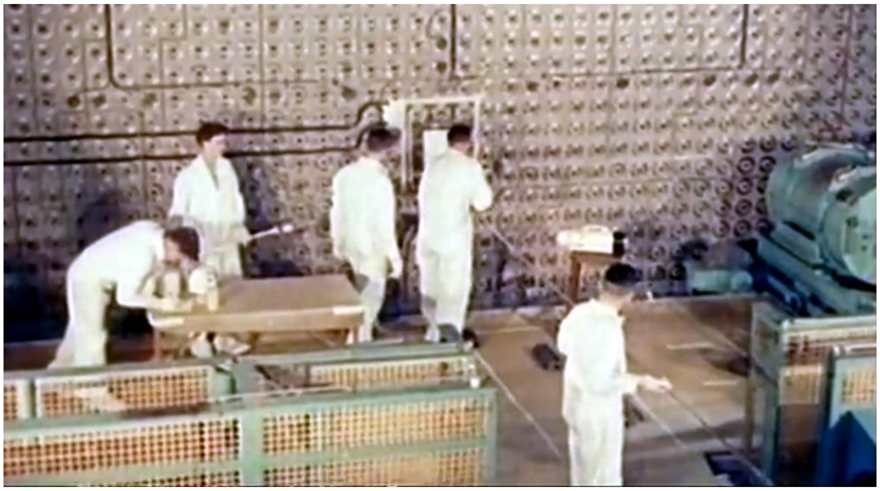

Figure 6. Loading face platform of the Windscale reactors.

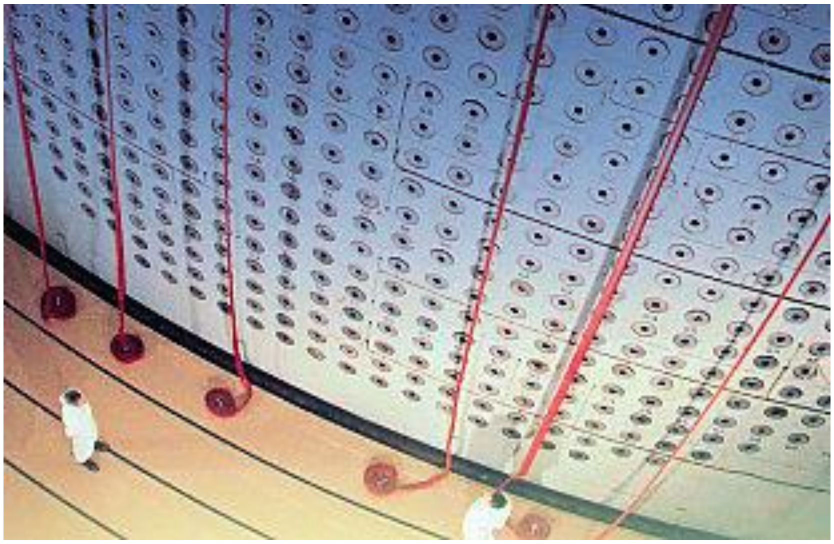

Figure 7. Windscale reactor fuel loading face.

Figure 8. Aluminum-clad uranium fuel elements used in the Windscale reactors. Notice the manufacturing nicks defects in the Aluminum fins which may have caused the frequent fuel channels obstructions.

Figure 9. Windscale fuel channels.

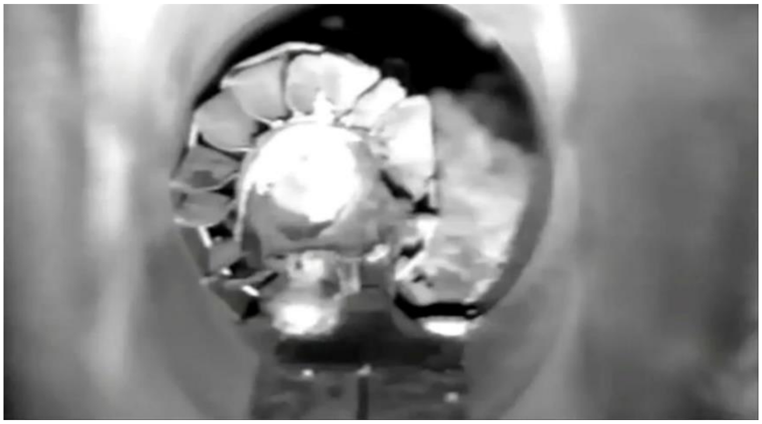

Figure 10. Fuel element stuck in a fuel channel at Windscale.

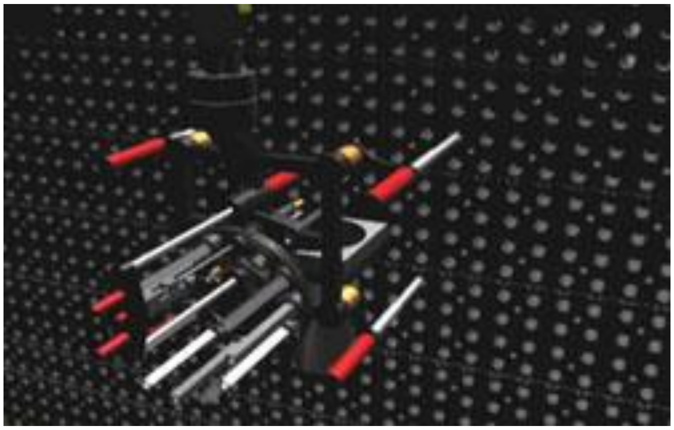

Figure 11. Windscale reactor's online fuel loading machine.

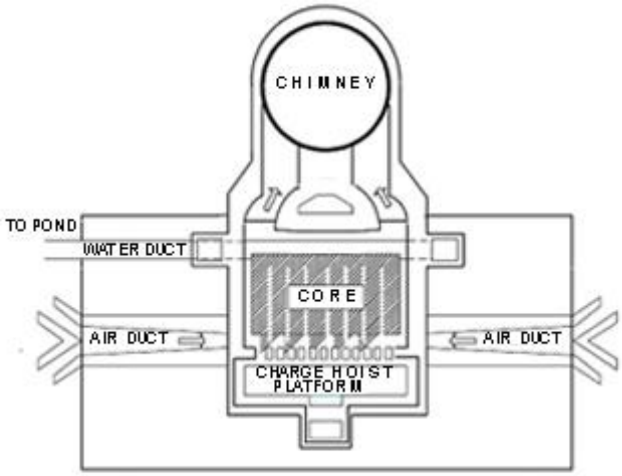

Figure 12. Fuel charge and discharge from the Windscale reactors.

Figure 13. Feeding fuel elements into the Windscale reactors channels.

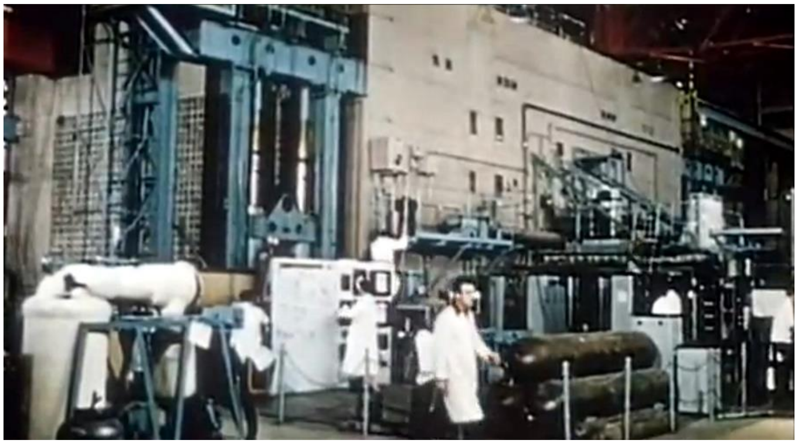

Figure 14. Side-view of the Windscale reactors.

ACCIDENT PROGRESSION

The first nuclear heating that was started on October 7, failed in fully releasing the Wigner energy. The structure of the Windscale pile was such that pockets of un-annealed graphite presented a problem.

A second nuclear heating was applied to treat those pockets.

On October 10, at 11 am, the operators noticed an alert originating from the radiation monitors. The radiation level increased 10 times the background level.

By 4:30 pm, a visual inspection of the fuel channels showed some cartridges were glowing red hot.

Attempts at discharging the hot cartridges failed as they had swelled and were jammed in the fuel channels.

During the night, failed attempts were made at cooling the pile with CO_2.

Initially, there was a fear of using water fearing the possible generation of CO and H_2; from the interaction of carbon with steam, possibly causing an explosion.

As attempts at cooling the reactor by other means failed, on October 11, at 8:55 am, water was used to cool the hot fuel and the core was brought to a cold state by the afternoon of the next day on October 12 at 3:20 pm.

ACCIDENT CAUSES

Detailed analysis revealed that the second nuclear heating was applied too rapidly, causing the burst of one of the cartridges.

The natural uranium metal which was used in this fuel cartridge oxidized causing a local fire that caused the combustion of the surrounding graphite moderator.

The burning of the graphite released more energy in the zone of the reactor core surrounding the failed cartridge. By the evening of October 10, 150 channels containing 8 metric tonnes of uranium fuel were on fire.

A fire break was attempted by removing the unaffected fuel cartridges around the zone involved in the fire.

RADIOACTIVE RELEASE

The fission products released from the burst cartridges was carried out and dispersed by the air cooling stream from the discharge stack.

The filter system in the stack removed only 50 percent of the particulates, and was not effective in capturing the fission noble gases xenon and krypton and the volatile I^{131}. About 20,000 Ci of I^{131} were released to the atmosphere.

This amount is considerably larger than was released from the Three-Mile Island accident.

The filters in the stack which held 50 percent of the particulate Sr^{90} and Cs^{137}, but not the volatile Kr, Xe and I^{131}, were useful in helping in reducing their release. Their installation was suggested by Sir (Dr.) John Cockroft but was objected to, being called: “Cockroft follies.”

Milk supplies were monitored for the presence of I^{131} which would seek the thyroid gland and possibly cause thyroid nodules. The sale of milk in the area surrounding Windscale was stopped for 6 weeks.

The National Radiological Board estimated that about 30 additional cancer deaths may have resulted in the general public, representing 0.0015 percent increase in the cancer deaths rate:

$$\frac{\Delta C}{C_0} = \frac{C - C_0}{C_0} = \frac{30}{C_0} = \frac{0.0015}{100} \tag{1}$$

where: C_0 is the population cancer deaths from all other causes.

From Eqn. 1:

$$C_0 = \frac{30 \times 100}{0.0015} = 2 \times 10^6 \tag{2}$$

This implies that over the period when these 30 deaths occurred, the general population suffered 2 million cancer deaths from all other causes.

DISCUSSION

The British hurried in building the two dual purpose plants for electrical power and weapons-grade plutonium production after World War II by the Irish Sea at Windscale, now renamed Sellafield. The air-cooled reactors were followed by the Advanced Gas Cooled (AGR) CO_2-cooled Magnox (Magnesium Oxide) reactors.

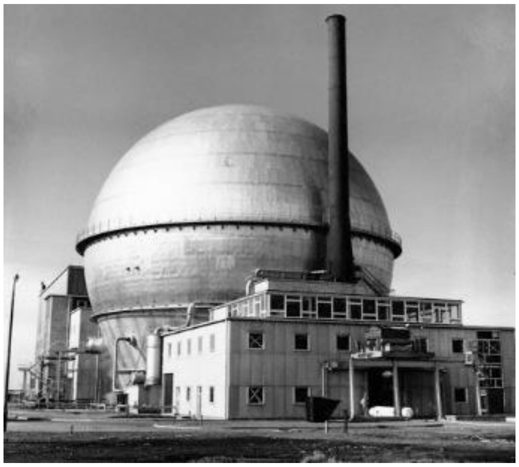

Figure 15. Advanced Gas Cooled (AGR) CO_2-cooled reactor at Sellafield.

Figure 16. Magnox fuel elements used in the AGR reactor. Source: Westinghouse.

The hurried-out design and construction, to join the nuclear arms race, resulted in that in 1955, 251 workers were exposed to radiation during repair work. This was followed on October 10, 1957, by a reactor core becoming subject to a fire. A radioactive plume was released, followed by a second one the next day. The radiation reached as far as Switzerland.

The fires were brought under control after two days. The authorities kept the situation under a tight lid, initially suggesting that there had been an incident in which the workers involved had been able to be decontaminated with soap and water.

The seriousness of the situation was divulged when the authorities later required that cow's milk within a radius of 200 miles from the reactor should not be consumed because of the inclusion of the thyroid gland seeker I^{131} isotope in the milk.

The population surrounding the reactor received radiation doses 10 times higher than that seen as permissible for a lifetime. Official figures suggest that 33 people were killed by the after-effects of the accident, with about 200 diagnosed with thyroid nodules.

Fifteen tons of damaged fuel rods remain stored on site as is radioactive ash and mud remnants from the fire.

Figure 17. First UK plutonium implosion device pit being inserted into the explosive lenses assembly.

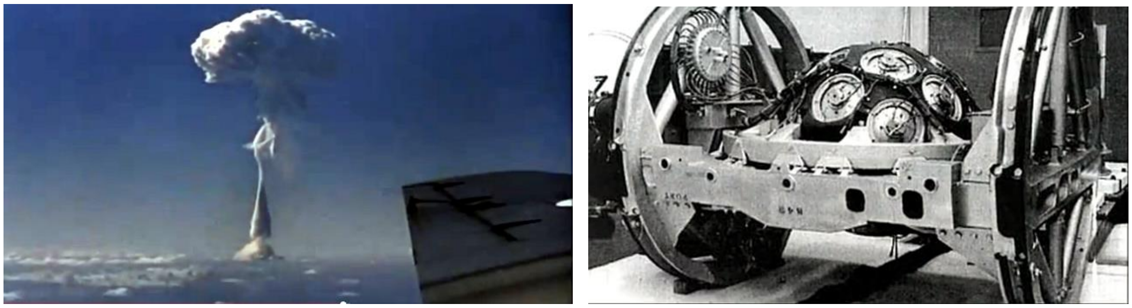

Figure 18. UK’s 800 kT of TNT-equivalent tritium-boosted Harold Orange device.

The reactor was decommissioned using a robot built exclusively for the project at a cost of 500 million pounds. The UK continued producing plutonium as well as tritium and participated in the nuclear arms race of the Cold War period.