History of the Harwell 136 MeV electron linear accelerator — a brief personal view

1. Context

Knowledge, skills and experience in neutron scattering in the meV – eV energy range gained on the Harwell 136 MeV electron linear accelerator contributed significantly to the success of condensed matter studies on the ISIS Spallation Neutron Source in the early years of ISIS operations. Consequently it may be relevant to summarise the history of this Harwell electron linac.

2. Harwell electron linacs

The Harwell 136 MeV electron linear accelerator was not the first electron linac at Harwell; in fact, it was the fourth. Eighty years ago, in 1944, Cockcroft[1], Chadwick[2], Oliphant[3] and other élites of the contemporary Scientific Establishment drew up a specification for what would become the Atomic Energy Research Establishment (AERE) at Harwell. In 1945, the Foreign Secretary, Bevin[4], persuaded the Prime Minister of the day, Attlee, to authorise the setting up of Harwell, and, if AERE Harwell had not been set up, the Rutherford Appleton Laboratory (RAL) and consequently ISIS would not be here today. First contracts to transform RAF Harwell to AERE Harwell were awarded in early 1946, and by August 1947 the first reactor in the world outside North America was up and running at Harwell — progress inconceivably rapid by today's standards.

From the outset, the potential of the electron linear accelerator for neutron production and for the application of the time-of-flight technique for neutron energy measurement was fully recognised, and Table 1 lists the four Harwell electron linac in time order.

Energy	Operated	Location	Comments
~3 MeV	1949[5] – 1952	Hangar 8	Used for nuclear data neutron cross-sections, time of flight.
~15 MeV	1952 – 1959	Hangar 8	Used for nuclear data neutron cross-sections, time of flight.
~50 MeV	1959 – ~1975	Building 418	Used for neut. x-sec's, some photonuclear, some condensed matter.
≤136 MeV	1979 – ~1986	Building 418	Used for neut. x-sec's, photonuclear, condensed matter studies.

Table 1. List of the four Harwell electron linacs.

[1] The first Director of Harwell, and co-inventor of the Cockcroft-Walton accelerator which was used to 'split the atom' for the first time by artificial means.
[2] The discoverer of the neutron.
[3] The inventor of the synchrotron, in 1943. He eventually became Governor of South Australia.
[4] A sort of 20th-century Lord Palmerston.
[5] Very much based on work carried out at TRE Malvern. See D W Fry *et al.*, Nature 160 (1947) 351.

3. The Harwell 136 MeV electron linear accelerator

A diagram of the layout of the Harwell 136 MeV electron linac is shown in Fig. 1, and a view in the linac hall is shown in Fig. 2. A list of machine parameters is given in Table 2. More detail is given in the Appendix.

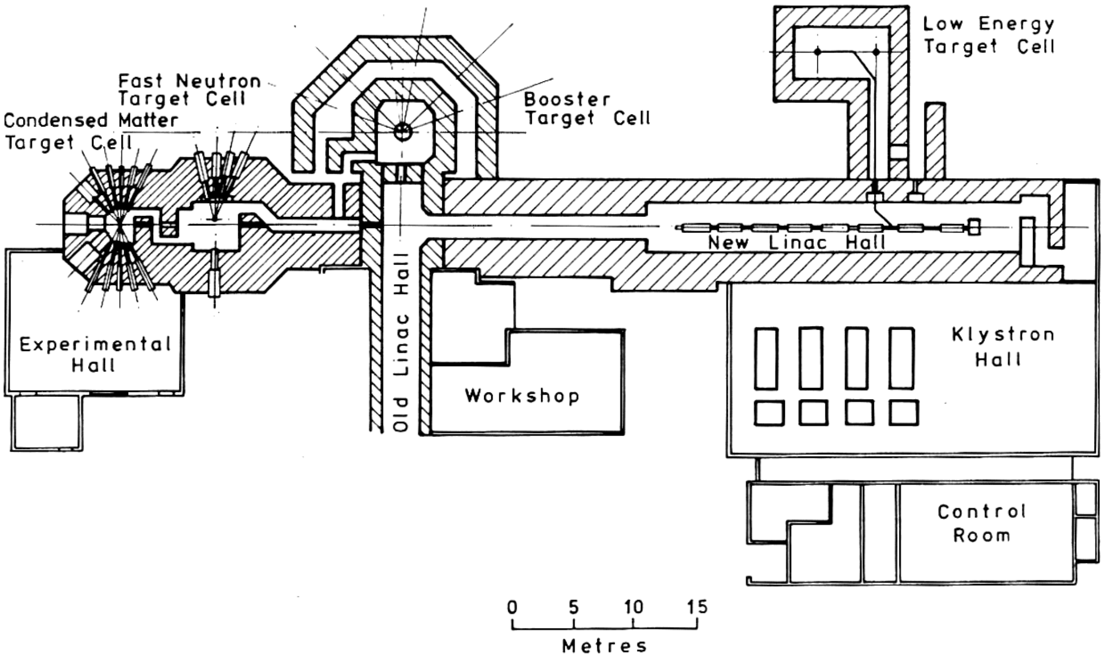

Fig. 1. Layout of the Harwell 136 MeV electron linac. The 'Old Linac Hall' housed the 1959 ~50 MeV electron linac which fired straight ahead into the Neutron Booster Target (NBT). Although only one experimental hall was originally built for condensed matter studies, another experimental hall was soon built on the other side of the Condensed Matter Target (CMT) Cell.

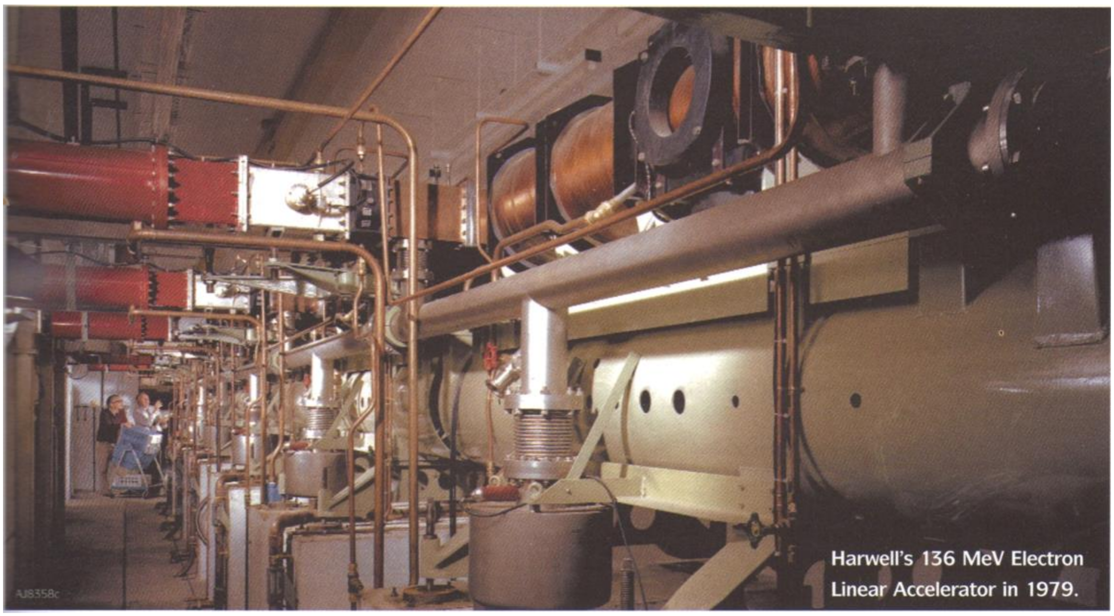

Fig. 2. The Harwell 136 MeV electron linac, inside the linac hall, looking upstream[6].

[6] The two men in the photo (next to the electron gun platform) are Ron Dallimore and Pete Swinden.

Electron energy, open circuit	136 MeV
Electron energy, full beam current	~60 MeV
RF frequency	1300 MHz (L band)
Klystrons	Four Thomson-CSF TV2022 each giving 20 MW or 10 MW peak power or 40 kW mean power
Accelerating section (CWG[7]) lengths	8 × 2 metres
Maximum beam pulse length	5 µs at ≤300 pps
Maximum beam pulse repetition frequency	2000 pps for pulse widths ≤0.4 µs
Electron beam pulse duration	Variable, 5 ns – 5 µs
Maximum beam power	30 kW (short pulses), 90 kW (long pulses)
Maximum beam pulse current	6–10 A (short pulses), 0.6–1.0 A (long pulses)

Table 2. Machine parameters for the Harwell 136 MeV electron linac.

The machine was built by Radiation Dynamics Ltd. of Swindon, and the cost of the machine itself (in 1975 £'s) was £2.8M. Each of the four klystrons was powered by a 250-kV LC pulse-forming network contained within an oil tank 'modulator', and a thyratron was used to switch the voltage pulses from the network across the klystron. The LC networks could be switched to provide 7.6-, 3.8- or 2.0-µs-long high-voltage pulses, with the shorter pulse lengths being used at the higher beam pulse repetition rates. Nominal neutron outputs are listed in Table 3.

Target	Beam pulse length	Mean electron energy	Maximum rep. rate	Neutrons per sec.
Fast Neutron	5 ns	~90 MeV	2000 pps	2×10^{13}
Neutron Booster[8]	100 ns	~125 MeV	390 pps	3×10^{14}
Condensed Matter	5 µs	~60 MeV	300 pps	4×10^{14}

Table 3. Details of beam delivery to the Fast Neutron, Neutron Booster and Condensed Matter Targets, and corresponding neutron production rates. For a few years, the Harwell 136 MeV linac was the most powerful pulsed neutron source in the world.

[7] CWG = corrugated waveguide.
[8] The Neutron Booster Target incorporated a ×10 ^{235}U multiplier.

3. Operations

The Harwell 136 MeV electron linac[9] was formally switched on[10] by Walter Marshall, then the Deputy Chairman[11] of the UK Atomic Energy Authority, on 6 July 1979. Unfortunately, insufficient funding was available to provide the five Crew shift teams necessary to ensure continuous operation. Only four two-man shift teams were funded, with the result that continuous operation was not possible. Instead, machine operations were programmed as a series of 28-day sequences, each sequence consisting of three 6- or 7-day periods of continuous running interspersed by 2- or 4-day down times. Inevitably, because of the overheads of start-up and shut-down at the beginnings and ends of the 6- or 7-day beam-on periods, effective use of time was often a lot less than 100%. And, unfortunately, since the machine had been built essentially as a turn-key project, and was regarded as such, there was no dedicated accelerator physicist on the staff.

As is not surprising for such a high-power machine, teething troubles took two or three years to overcome, during which time rationing of beam time became inevitable. Equally inevitably, but of course to the chagrin of the nuclear physicists, priority in scheduling machine time was given to SRC-UKAEA Joint Research Programme[12] on condensed matter physics because that programme brought in funding from outside the UKAEA. A photograph of the experimental hall CA for condensed matter physics measurements by pulsed neutron scattering is shown as Fig. 3.

Around 1983, once the machine had begun to run more reliably, the restrictions on beam delivery to the Fast Neutron Target (FNT) for nuclear data measurements[13] and to the Low Energy (LE) Cell for photofission and photoneutron measurements[14] were relaxed[15], but, within a year or two thereafter, funding for the linac began to dry up, largely as a consequence of reduced Government support for the Fast Reactor Programme[16]. Also, at that time, a move within the UKAEA away from 'pure' science began to be strongly encouraged, and a range of more applied[17] and commercial work started to be carried out on the machine, mostly in the Low Energy (LE) Cell.

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[9] The Electron Linac Group Leader at the time was M (Mike) S Coates.

[10] Although the RF systems tripped just before Walter Marshall was about to push the 'beam on' button, the 'beam on' signs became illuminated as expected when he did push the button, thanks to some foresight in the wiring arrangements.

[11] He became the UKAEA Chairman in 1981.

[12] The SRC-UKAEA Joint Research Programme, which started around 1970 and ran until about 1985, had been devised as a means of enabling university scientists access to the neutron beam research facilities at Harwell and at Aldermaston. This entailed SRC paying in full for half the neutron beam time for their own use, and paying a further quarter for joint research programmes of university and UKAEA workers. The remaining quarter was used on UKAEA programmes. In addition, both parties collaborated on instrumental development. [These details are taken from https://neutronsources.org/media/anecdotal_autobiography_schofield_feb17.pdf]

[13] Work summarised in UK Nuclear Data Reports, https://www-nds.iaea.org/publications/group_list.php?group=INDC-UK.

[14] Photofission and photoneutron cross-sections, and the mean number of neutrons per fission $\bar{\nu}$, for ^{232}Th, ^{238}U and ^{241}Am were measured using a large high-efficiency oil-moderated 56-BF_3-counters neutron detector. Cross-sections were unfolded from bremsstrahlung-induced yields. The ^{241}Am measurements (in 1988 and 1990) were the last 'proper' nuclear measurements made on the linac.

[15] But there was little if any running to the Neutron Booster Target (NBT).

[16] Britain is the only country in the world to have achieved routine delivery of electricity to a national grid from a fast reactor (PFR, the Prototype Fast Reactor at Dounreay). *Sic transit gloria mundi!*

[17] For example, R&D on active interrogation of 500-litre drums of cemented radioactive waste was carried out, resulting in the ability to detect of the order of 1 gram of fissile material within such a

By ~1990 linac beam was rarely delivered to anywhere other than the LE Cell, and so sections 3–8 of the 8-section machine had effectively become redundant. At the same time, schemes were being developed to set up an electron beam irradiation plant for the sterilisation of disposable medical items, and, as a result, the linac hall was divided into two by pouring a 4-metre thick concrete wall[18] through a hole cut in the roof of the hall. Upstream of this wall remained the first two sections of the 136 MeV linac delivering ~5 – 30 MeV electron beams to the LE Cell. Downstream of this wall was set up the electron beam (EB) irradiation plant, based on a freshly built[19] ~10 MeV accelerating corrugated waveguide (CWG) powered by the original #2 modulator, an energy analysis and beam scanning system, a product conveyor system, and a large warehouse. The EB plant[20] was operated through the company EBIS Harwell Ltd.

By this time the original Electron Linac Group had been significantly reduced both in scope[21] and size and had been spun out into AEA Technology (AEAT) as the Electron Beams Department[22], and this Electron Beams Department ran satisfactorily for several years. However, in the longer term the department did not prosper[23], and around ~2005 it effectively shut down.

The buildings are all still there, just across the road from ISIS on the other side of the Harwell-RAL fence — a sad decaying monument to what might have been. Probably the Harwell 136 MeV electron linear accelerator will live longer as a decommissioning project than it did as a facility for potentially raising 'Harwell's facilities for doing [neutron physics] to the world front rank'[24].

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drum; formally, this work was carried out for Taylor Woodrow under a CEC contract. Another example was the invention and patenting of photonuclear transmutation doping of silicon.

[18] A choice had to be made between a 3-metre-thick heavy concrete wall or a 4-metre-thick ordinary concrete wall, but, in spite of the 1-metre reduction in thickness, the heavy concrete option turned out to be more expensive than the ordinary concrete option, not because of the cost of the heavy concrete itself but because of its higher density which makes transporting and pumping surprisingly more expensive.

[19] P J Cracknell, Radiat. Phys. Chem. 46 (1995) 469–472.

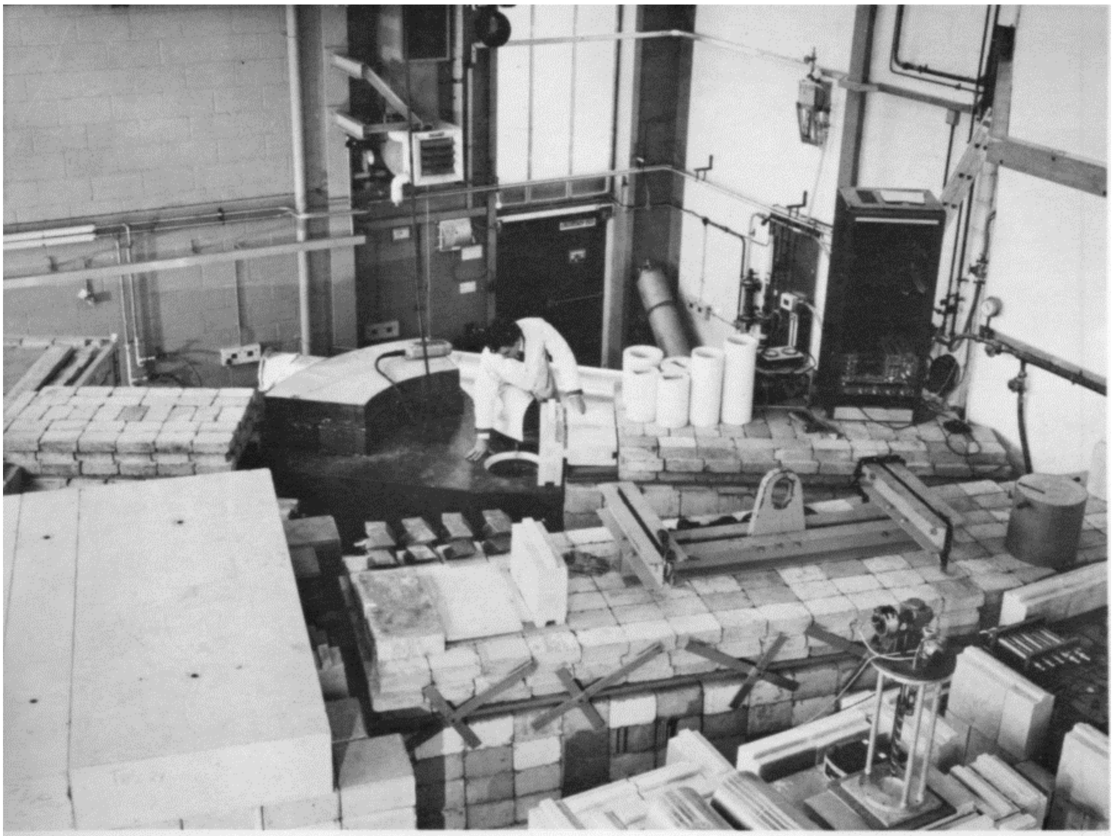
[20] M Bailey *et al.*, Radiat. Phys. Chem. 46 (1995) 465–468.

[21] The definitive debunking of neutron production from 'cold fusion' was carried out by the Harwell Electron Linac Group — see D E Williams *et al.*, Nature 342 (1989) 375–384.

[22] The Electron Beams Department was formally one of three departments within the Special Products Group (run unsympathetically by E deB Phelps — transgressors who did not meet their financial targets were periodically summoned to her office to be given 'a good Phelping'). Managers of the Electron Beams Department were D (David) J S Findlay (1994–1998),
M (Martyn) R Sené (1998–2001), and S (Steve) Sugden (2001–2005).

[23] Although, in preparation for transfer to AEA Technology, some staff in UKAEA had been 're-educated' as business men and women, often 'real' business men and women ran rings round such 'pretend' business men and women. And, in any case, scientists and engineers who originally joined UKAEA for the science and engineering may not have been entirely happy in the particular world of commerce to which they were transferred.

[24] J E Lynn, ATOM (Monthly Information Bulletin of the UKAEA), no. 276, October 1979, page 263.



The experimental hall of the Harwell electron linac. The target is behind the shielding to the right, and the view shows the constant Q spectrometer, with the author, and the back-scattering spectrometer in the left foreground.

Fig. 3. This photo, taken from Colin Windsor's book *Pulsed Neutron Scattering*[25], is in experimental hall CA on the left-hand side of the target (as seen looking in the direction in which the electron beam is accelerated). As mentioned in the text, a similar experimental hall for condensed matter studies, CB, was subsequently built on the right-hand side of the target and similarly filled with instruments.

Further references

- D W Fry, Philips Technical Review 14 (1952) 1–32.
- C F Bareford and M G Kelliher, Philips Technical Review 15 (1953) 1–36.
- J E Lynn, Contemp. Physics 21 (1980) 483.
- The Harwell 136 MeV electron linear accelerator, P J Cracknell and C J Burt, https://accelconf.web.cern.ch/p81/PDF/PAC1981_3470.PDF.
- ‘Optimisation calculations for slow neutron production with the 136 MeV Harwell electron linac, J Needham and R N Sinclair, report AERE-R 9229, https://cds.cern.ch/record/120054/files/CM-P00068613.pdf.
- A Discussion Paper for the Exploitation of the New Harwell LINAC for Condensed Matter Studies, C G Windsor and R N Sinclair, HNBFC/75/P16 (1975), https://colin-windsor.github.io/HomePage/linac/linac.htm.

[25] Pulsed Neutron Scattering, C G Windsor, Taylor and Francis, London, 1981.

Appendix

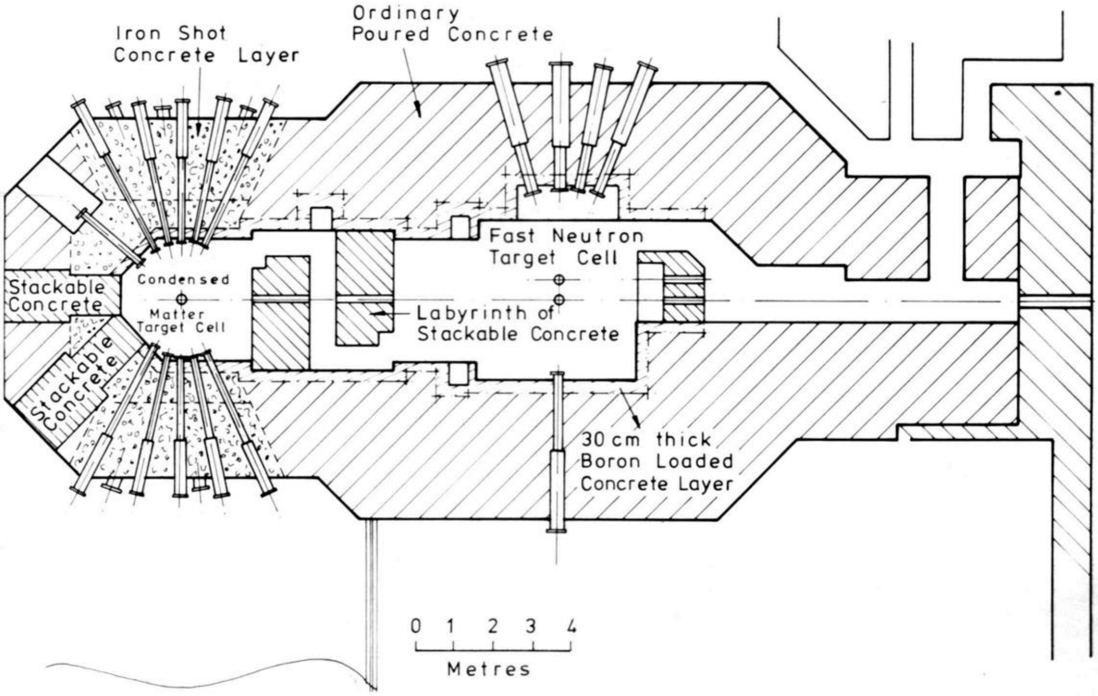


Fig. A1. More detailed drawing of the Fast Neutron Target (FNT) Cell and the Condensed Matter Target (CMT) Cell and their respective neutron flight paths. The axis of the 136 MeV linac was located above the axis of the older 1959 ~50 MeV linac so that flight paths from the FNT and CMT would not foul the flight paths from the Neutron Booster Target (NBT).

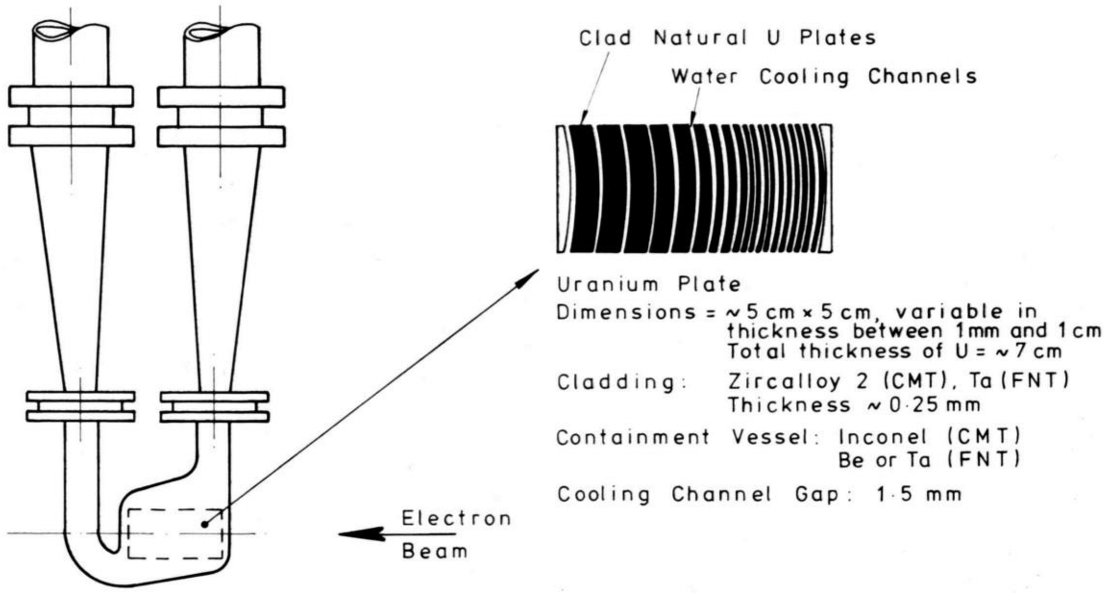


Fig. A2. Details of the Condensed Matter and Fast Neutron Targets. Calculations and measurements made in connection with the design of these targets benefited the designs of the ISIS targets. The targets could be raised remotely into a heavily shielded 'attic' to allow personnel access to the target cells.

Fig. A3. Walter Marshall formally opening the 136 MeV Harwell electron linear accelerator on 6 July 1979. Seated at table beside Marshall: J E (Eric) Lynn, Head of the Harwell Nuclear Physics Division. Behind control desk: P (Pete) P Thomas, Harwell manager for the new linac project; R A J (Jim) Riddle, Radiation Dynamics, subsequently employed by Harwell as the 'machine expert'.
[From https://www.chilton-computing.org.uk/harwell/reactors/electron.linac.htm.]