Nuclear Research in Germany 1938 to 1945

by J R THOMSON*

Introduction

Most readers will be aware that fission was discovered in Germany by Hahn and Strassman in 1938, and that there was a heavy water plant in Norway which was destroyed by a combination of sabotage and air-raid in 1943, as portrayed in the film 'The Heroes of Telemark'. This latter event begs many questions, however; for example, how far did the German programme get before the end of the war, and why were they using large quantities of heavy water?

These questions have been answered in previous accounts of German wartime research. Werner Heisenberg (of 'Uncertainty Principle' fame), who played a leading role in the German effort, published his account in *Nature* in 1947 (1). A fuller account has been written by the military historian David Irving based on information removed by Allied investigators and stored at Oak Ridge (2).

The object of this paper is to provide a brief summary of the major events, and to draw attention to some interesting anomalies between these two versions of events.

Early Developments

Frederic and Irene Joliot-Curie nearly discovered fission. They thought they had formed radium in a uranium sample which had been irradiated with neutrons, which they presumed was due to a double alpha decay. In fact their 'radium' was the chemically similar barium, as Hahn and Strassman discovered when they repeated the experiment. However, the Joliot-Curies shortly afterwards discovered that neutrons were released during fission. This discovery, together with the calculations of fission energy release by Meitner and Frisch, led to the first German War Office interest in April 1939 and a paper by Flugge in *Naturwissenschaften* in June 1939 entitled 'Can the energy contained in the nucleus be exploited on a commercial scale?'

Things proceeded at a rapid pace in the latter half of 1939. Enrichment and moderation (ie fast and thermal reactors) were proposed as alternative routes, some UF_6 was obtained to begin diffusion experiments, and heavy water and graphite were suggested by Heisenberg as possible moderators. Across the Atlantic, US military funding began in September 1939.

In early 1940, the Kaiser Wilhelm Institute (KWI) in Berlin was put in charge of the project under overall War Office Control. It is worth saying at this point that the project management was never as good, or the objectives as clear cut, as in the Manhattan project. There was considerable duplication of effort.

In February 1940, Germany attempted to buy heavy water from the Norwegians who had a plant at Vemork which produced heavy water using electrolysis*. (This process was a heavy consumer of electricity and relied on cheap hydro-power. Because of wartime restrictions on electricity the Germans were unable to undertake large-scale production of heavy water in Germany.)

The Norwegians turned the German offer down and instead gave, free of charge, 185kg of heavy water to the Joliot-Curies in Paris, who subsequently smuggled it across to Britain. In April, Norway was invaded by Germany.

Although the Second World War was now well and truly underway, much nuclear research was still being published openly. The last such article to be published before the restrictions of wartime secrecy were felt was Seaborg and McMillan's discovery of plutonium, which was published in *Physical Review* in June 1940. The significance of this discovery was not missed in Germany (since plutonium-239 was theoretically fissionable), and von Weizsacker shortly afterwards proposed a 'plutonium route'. To what, though, is not clear.

Autumn 1940 - June 1942

Sometime in late 1940, Hitler was reportedly informed about developments, but he was not interested since victory was in sight. By the end of the year, heavy water production had recommenced in Norway, uranium metal was being produced in Germany at the rate of 1 tonne per month (a rate of production not equalled in the US until 1942) and subcritical assemblies were being tested at KWI in Berlin.

In January 1941, the physicists Bothe and Jensen announced that graphite was unsuitable for use as a moderator because of its high absorption cross-section. This mistake — attributed by Heisenberg to impurities in the graphite — was to have far-reaching implications for the German programme. Graphite was not further considered (although it was later used as a neutron reflector) and this meant that the whole programme was bottlenecked by production of the only other suitable moderator for a natural uranium pile, heavy water. By the summer of 1941 150 litres were available, and production was still only at 200 litres per month by the summer of 1942.

The 150 litres of D_2O available by the summer of 1941 were used to construct a pile, called L-IV (Fig 1), at Leipzig under the direction of Döpel and Heisenberg. In March 1942, this pile showed definite evidence of multiplying the number of neutrons produced by a neutron source in the centre of the pile. Although still a

*Lecturer, Department of Mechanical Engineering, University of Edinburgh

*I have been unable to find out *why* the Norwegians had built a heavy water plant.

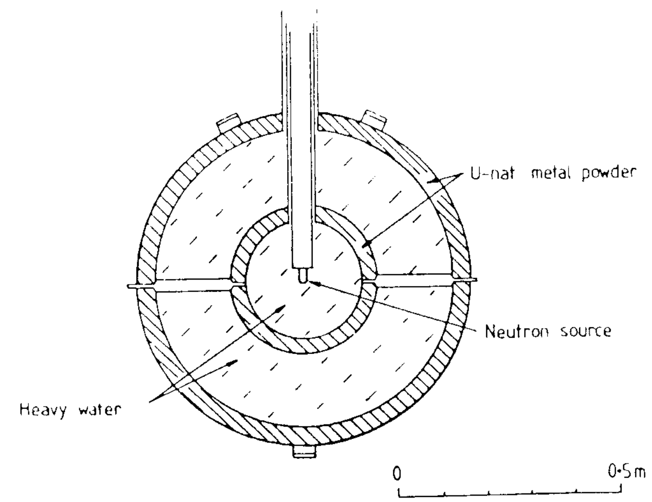

FIGURE 1 The L-IV pile, Leipzig, 1941-42 (2)

subcritical assembly, this result was a considerable achievement by the German team. (The Chicago pile did not go critical until December 1942.)

In October 1941, project control was transferred to the Reich Research Office from the War Office. This was a significant downgrading in the priority accorded to the project. In the same month a variety of methods for enrichment were proposed. Only one route — a gas centrifuge — led to any significant results before the end of the war. No attempts were made to employ either 'straightforward' gaseous diffusion or mass spectrography.

Also in October 1941, Heisenberg paid his infamous visit to Niels Bohr in Copenhagen. Bohr later claimed that Heisenberg told him that Germany was developing a bomb**. Heisenberg claimed he told Bohr that German scientists were incapable of producing a bomb and that he hoped the message would be passed by Bohr to the Allies, thereby discouraging them from producing a bomb and sparing Germany the consequences.

Whichever version is true, this episode at least makes Heisenberg's credibility questionable. It is possible, of course, that there may have been a genuine misunderstanding. It seems highly unlikely that Bohr would have lied, however, since he (apparently) lacked any motive for so doing.

What is definitely known is that Heisenberg told Speer, the Reich's armaments minister, in June 1942 that 'a bomb the size of a pineapple' would destroy a city. This remark seems at odds with Heisenberg's statement about this meeting, made in his 1947 paper, that 'the only goal attainable was the development of a uranium pile producing energy as a prime mover — in fact, future work was directed entirely towards this one aim'.

Despite talking of 'bombs the size of pineapples', the meeting with Speer led to a further downgrading of the priority given to the project. According to Irving, Heisenberg had 'insufficient moral courage to recommend a project requiring 120,000 people' — perhaps understandably, given the likely reward for failure.

The programme received a second setback in the same month, June 1942. In what could conceivably be called 'the world's first nuclear accident', the subcritical L-IV pile was destroyed in a hydrogen explosion. The hydrogen was generated when water leaked into one of the two concentric shells containing uranium metal powder.

**Otto Frisch reportedly believed that Heisenberg tried to recruit Bohr to the German team (3).

Hydrogen bubbles were observed escaping from the apparatus and the heavy water was drained. Shortly afterwards, the hydrogen exploded, assisted by the combustion of the pyrophoric uranium metal powder. According to Irving's account, Heisenberg was fortunate to escape the blast.

June 1942 - 1945

The programme apparently lost a lot of its momentum following the L-IV explosion, and no new major advances occurred until 1944. However, a number of interesting experiments were performed in this time interval. Fusion experiments were carried out by imploding heavy paraffin with TNT. (It was thought that this was a possible explanation for the severity of the Allied bombing on German cities.) Numerous subcritical experiments were carried out, some using arrays of uranium metal cubes in heavy paraffin wax or heavy water ice. (Ice was used so that the effects of parasitic neutron capture by structural materials could be eliminated.)

Two attacks on the Vemork heavy water plant in 1943 put the plant out of action for the duration of the war. (It is interesting to speculate upon whether this action risked attracting the attention of the German High Command to the nuclear research effort, by highlighting the importance accorded to it by the Allies). In total, the plant produced about 2.6 tonnes of heavy water for Germany.

The majority of this quantity of D_2O was to be used in a new pile, called B-VII, construction of which began in Berlin in late 1943. The B-VII pile was the first attempt at a critical array, containing 1.25 tonnes of uranium and 1.5 tonnes of heavy water. However, following an air-raid in February 1944, work was suspended pending transfer of the experiment to a new facility to be constructed in Southern Germany. Uranium billet production was also temporarily halted following air raids on Frankfurt in early 1944.

Work had been continuing, meanwhile, on the development of gas centrifuges for uranium enrichment. This is an area which seems to be very poorly documented, but a group under Harteck, Groth and Beyerle did build a prototype centrifuge which by June 1944 — when work at KWI in Berlin was finally stopped due to air-raids — had produced 2.5 gms of 'highly-enriched' (Irving) uranium. Whether this 'highly-enriched' uranium was weapons grade is unclear, but again it is interesting to speculate about the outcome if this technology had been more vigorously pursued.

In late 1944, a new experimental facility in a cave at Haigerloch in Southern Germany was made ready, and the B-VII pile — now rechristened the B-VIII — was reassembled. By this time, of course, the net was tightening around Nazi Germany, so much so that in December Heisenberg was drafted into the Volkssturm (Home Guard). Nevertheless, by February 1945, the pile was ready (Fig 2). A critical approach was attempted by adding quantities of D_2O, but criticality was not achieved although the number of neutrons released by the neutron source was multiplied by 6.7. The pile was about 50% too small to achieve criticality (Irving).

The descriptions of this pile given by Irving and Heisenberg differ significantly. Irving states explicitly that the pile was not fitted with any form of control rods since Heisenberg believed that thermal feedback effects would make them unnecessary. (It also appears that the German team were unaware of the existence of delayed neutrons, which implies that reactor kinetics had not received very much consideration.) However,

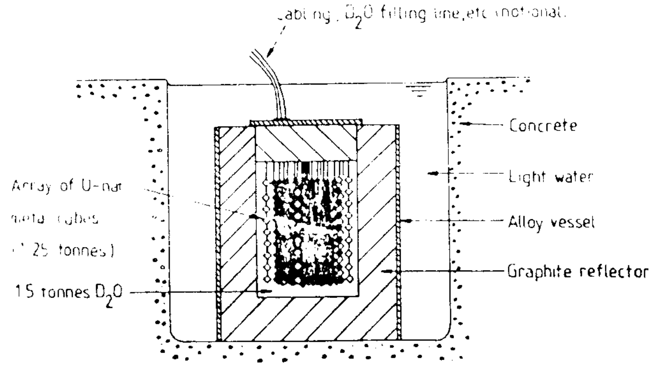

FIGURE 2 The B-VIII pile, Haigerloch, 1945 (after (2))

Heisenberg, in his 1947 paper, states that the B-VIII pile was fitted with cadmium control rods. Is it possible that Heisenberg was being wise after the event? If Irving is correct — and Heisenberg's credibility has already been seen to be questionable — then it is perhaps just as well that the B-VIII pile was too small for criticality§.

The Haigerloch facility was captured by US troops in late April 1945. The B-VIII pile was dismantled and the cave was blown up. The German team were interned. They were reportedly amazed to hear of the Hiroshima bomb three months later.

Conclusion

Although the German research effort failed to produce a critical reactor, their achievements should be viewed in the light of the conditions under which they worked, and their financial restrictions. The German programme budget was about 3 million RM per year compared to about $100 million for the Manhattan project.

Heisenberg claimed that the object of the programme was the development of a prime mover and not a weapon. However, it is unlikely that any attempt would have been made to produce a bomb when a sustainable chain-reaction had not already been demonstrated. Would the Allied effort have been maintained if the Chicago pile had failed to go critical?

Heisenberg's explanation for the non-development of a German weapon is that, in any case, it could not have succeeded in Germany under wartime conditions. After all, even the Manhattan project with its much greater resources did not produce a bomb until after the conclusion of the war with Germany.

References

1. W Heisenberg. Nature, *160*, no 4059, 16th Aug 1947, pp211-215.
2. D Irving, 'The Virus House', William Kimber, 1967.
3. J Gribben, New Scientist, no 1479, 24th Oct 1985, p56.

§Heisenberg's version seems to be seeking to give him the kudos for what the German team achieved, but also seeks to give him the kudos for what they failed to achieve — a German weapon. This may have left him in a dilemma over the presentation of some details.

Chronology of Major Events

I Early Developments

Dec '38	Fission discovered by Hahn and Strassman
Feb '39	Joliot (in Paris) discovered that neutrons are released during fission
Apr '39	German War Office expressed interest
Sept '39	(a) Two routes proposed: (i) U-235 separation (ii) Neutron moderation (b) I G Farben supply UF_6 for diffusion experiments
Dec '39	Heisenberg proposed heavy water or graphite as suitable moderators
Jan '40	(a) Reich War Office takes delivery of one tonne of uranium oxide (b) Kaiser Wilhelm Institute (KWI) (Berlin) put in charge of programme
Feb '40	German order for heavy water is turned down by Norwegians, who instead give 185kg of D_2O to Joliot
Apr '40	Norway invaded by Germany
June '40	Seaborg and McMillan (US) discover plutonium. Their discovery is published in *Physical Review*. In Germany, von Weizsacker proposes a 'plutonium route'

II Autumn 1940 - June 1942

Autumn '40	(a) Hitler informed about possibility of nuclear energy (b) Uranium metal being produced at 1 tonne per month (c) D_2O production recommenced (d) First subcritical array built at KWI
Jan '41	Bothe mistakenly concludes that graphite is not suitable as a moderator
Summer '41	Construction of L-IV pile begun at Leipzig
Oct '41	(a) Project control transferred from War Office to Reich Research Council (b) Various routes proposed for enrichment (c) Heisenberg visits Bohr in Copenhagen
Mar '42	L-IV pile shows neutron multiplication

June '42	(a) Heisenberg tells Speer (Reich armaments minister) that a 'bomb the size of a pineapple' could destroy a city (b) L-IV pile destroyed in hydrogen explosion

III Summer 1942 - 1945

Summer '42	Experiments performed to investigate the possibility of inducing fusion in heavy paraffin by imploding with TNT
1942 -'43	Numerous subcritical experiments performed
Feb '43	Norwegian D_2O plant attacked by saboteurs and air-raid
Nov '43	D_2O production did not recommence for the duration of the war
Winter '43-'44	Construction of B-VII pile - a would-be reactor — commenced at KWI. Work suspended following air-raid in February 1944, pending transfer to southern Germany
June '44	Gas centrifuge produced 2.5gms of 'highly-enriched' UF_6 before work suspended for transfer to southern Germany
July '44	Construction of new lab in cave at Haigerloch commenced
Feb/Mar '45	B-VIII pile assembled at Haigerloch. Pile is about 50% too small for criticality
Apr '45	Haigerloch captured by US troops

CALL FOR PAPERS

Nuclear Power Plant Aging and Life Extension

7th-12th June 1987

Lincolnshire Resort, Lincolnshire, Ohio

Sponsored by
American Society for Metals
Energy Division
Co-sponsored by INucE

Technical Programme

The goal of this conference if to provide a continuing forum to promote research, development, and understanding of materials degradation phenomenon, plant aging assessment, reliability and maintain ability improvements, and life extension techniques for nuclear power plants. It is the intent of this conference to provide the first of a series of biennial follow-on programmes to the International Conference on Nuclear Power Plant Aging, Availability Factor, and Reliability Analysis that was held in San Diego, July 1985.

Sessions are planned to cover the following topics:

Ageing and Availability
- Pressure Vessels/Reactor Internals
- Steam Generators
- Piping and Valves
- Steam Turbines
- Electrical Equipment and Controls
- Balance of Plan Equipment

Aging Phenomenon
- Corrosion/Stress Corrosion Cracking
- Fatigue
- Creep
- Erosion/Wear
- Radiation Effects
- Thermal Effects

Aging Assessment Techniques
- Nondestructive Testing and Evaluation
- Metallurgical Examination
- Statistical Methods
- Transient Data Logging

Life Extension and Reliability Improvement
- Predictive Models
- Operational Strategies
- Planned Maintenance
- Statistical Methods
- Water Chemistry Control/Chemical Cleaning
- Reliability and Maintainability Programmes

Preliminary abstracts of 300 words should be submitted by 1st November 1986 to Donald V Varanese, American Society for Metals, Metals Park, Ohio 44073.