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**Project Crystal:
Lithium 6 for thermonuclear
weapons**

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PROJECT CRYSTAL: LITHIUM 6 FOR THERMONUCLEAR WEAPONS

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1 Introduction

The first hydrogen bomb was exploded by the USA in October 1952. Code-named *Ivy Mike*, the thermonuclear fuel consisted of liquid deuterium, contained in a device the size of a house. Subsequent practical thermonuclear weapons used solid lithium deuteride as the thermonuclear component. Britain fired experimental devices that included lithium in the *Mosaic* series in the summer of 1956, followed by the *Grapple* series of megaton tests the following summer. Each of the three nuclear powers developed the concept of using lithium deuteride independently, assisted by whatever intelligence they could glean. Lithium deuteride is a non-radioactive solid. Natural lithium consists of a mixture of the isotopes Li6 and Li7 and it is necessary to use Li6 in a thermonuclear reaction. When irradiated by neutrons, the Li6 produces tritium, which under conditions of intense pressure combines with deuterium to produce a thermonuclear explosion. The design challenge was to use a fission warhead to act as a trigger that would produce a large thermonuclear explosion in lithium deuteride before the device blew itself apart. Britain's development of thermonuclear weapons required that the isotope lithium 6 be produced in sufficient quantities and at the required degree of separation.

This note concentrates on the separation of lithium 6 from the natural metal. Much of the early thinking behind Britain's hydrogen weapons remains classified, as does the design of the weapons themselves. However, recently released UKAEA Harwell files record the initial requirement for Li6 from AWRE Aldermaston.¹ In response, Harwell set up Project Crystal, which was targeted with the production of Li6 in sufficient quantities for Britain's thermonuclear programme. The task proved unexpectedly difficult and at one stage delays threatened the entire megaton project, but a successful process was developed at Capenhurst in time for the *Grapple* series of nuclear tests at Christmas Island in the summer of 1957.

2 First thoughts on lithium

Sir William Penney, Director of AWRE, and the Aldermaston weaponeers were considering the possible use of Li6 as a source of tritium in a thermonuclear weapon

¹ Most references come from original files held at The National Archives, Kew, abbreviated TNA.

by 1953. We do not have notes of Penney's thinking at this time, but it is clear that lithium was emerging as an important material. An early mention is dated June 1953, when Penney wrote to the Director of AERE, Harwell, Sir John Cockcroft: 'We badly need total cross section [for neutron capture]... of Li6 in range 0.1 to 2MeV. We are making big strides now. We haven't enough people'.² Presumably at Penney's instigation, in June 1953 Cockcroft gave instructions to aim at a target production of 2 kg of Li6 by early 1955.³

In her history of the development of Britain's H-Bomb, Lorna Arnold reproduces a document on the history of thermonuclear weapons written in September 1958. This states that AWRE began thinking of high yield weapons in 1953, including the possibility of using thermonuclear reactions and the production of tritium from Li6. Plans were started for the production of experimental quantities of Li6. The original request, in late 1953, was for 10 kg/year, to be increased to 100 kg/year.⁴ Arnold mentions a paper by Penney, written presumably towards the end of 1953, in which he introduces the concept of a hybrid weapon, using 'relatively cheap' thermonuclear material to enhance the yield of a fission bomb. He went on to say that hydrogen bombs employing liquid deuterium would be much more powerful. By early 1954, 'certain snippets' of information gleaned from the Americans while conducting cooperative analysis of the debris from Russia's first thermonuclear test, *Joe-4*, enabled the AWRE scientists to reach 'sensational and revolutionary' conclusions. We may speculate that these included thoughts on the use of Li6.

On 27 July 1954, the Cabinet authorised the Lord President 'to proceed with his plans for the production of thermonuclear bombs in this country'. Arnold comments that the main implications for the Atomic Energy Authority were 'certain requirements for materials – probably thorium, heavy water and tritium'.⁵ She does not mention lithium. There is no reference in the Project Crystal file at Harwell to the decision, though possibly the classification conventions excluded or discouraged mention of weapons in the file. Nor is there any mention of analysis of the fallout from *Joe4*. The American *Castle* series in early 1954 employed LiD fuelled hydrogen bombs. This fact became known to the British and in December Penney wrote a memo summarising what was known about the American employment of lithium.⁶ He did a detailed textual analysis of the evidence given in the Oppenheimer hearings, which took place in April 1954, and concluded from this that the US decision to go for LiD was made at a meeting of USAEC held at Princeton in June 1951. Penney also wrote that it was clear that the US had worked earlier on Li6D for boosting.

Cockcroft informed the Board of the AEA in October 1953 that AWRE had requested Harwell to provide separated isotopes of 'a light element'. Target quantities were several kg by 1955 and then 50 to 100 kg per year. The experimental plant would be built at Harwell by the General Physics department and the second plant by Chemical Engineering.⁷ Eventually, the Industrial Division of the AEA, headed by Sir

² TNA AB 6/1085. Letter Penny to Cockcroft 8 June 1953.

³ TNA AB 6/1085 E7. Cockcroft to AS White.

⁴ L. Arnold, *Britain and the H-Bomb* (Basingstoke: Palgrave, 2001), Appendix 3. The document is anonymous, but Arnold credits it to John Corner, Head of the Theoretical Division, AWRE.

⁵ Arnold, p56.

⁶ TNA AB 6/1085. E77. Memo from Penney, 22 Dec 54.

⁷ TNA AB 6/1085 E25. Cockcroft to AE Board. 19 Oct 1953.

Christopher Hinton at Risley, would become very much involved. Lithium separation was given the name Project Crystal, though the use of this name was confined to Harwell.

3 Development of separation processes

3.1 Sourcing of lithium

Before work could start on the separation programme to produce Li6, a supply of natural lithium had to be secured. Lithium had been used during the war in the form of lithium hydride; this was employed as an emergency hydrogen gas generator for balloons, which were carried in RAF dinghies. However, there was little post war requirement and in October 1954, Plowden wrote to the Lord President that if Britain were seen to be buying up stocks of lithium, this would reveal that we were considering production of thermonuclear weapons. Early in 1954, lithium had been given Material X as a cover name. In March 1955, Penney was contemplating a requirement of 700 kg of Li6, implying 10 tons of natural lithium per annum, which would require the purchase of 1000 tons of ore per year. It was recommended that the purchase of lithium be carried out in relatively small quantities by agents. Their identity was to be kept secret from each other, even if this resulted in their bidding against each other, with consequent increase in price.⁸

3.2 Possible separation processes

The separation of lithium isotopes had been discussed in the UKAEA long before there was a commitment to a hydrogen bomb. Lithium isotope separation was discussed by Heinz London in a file opened in 1947, where he considered that molecular distillation would be a suitable method.⁹ In 1952, when Li7 was considered as a possible liquid coolant for a fast reactor, London reviewed separation methods again. A process involving adsorption in zeolite was considered promising: electrolytic methods (EM) were rejected on the grounds of high power consumption.¹⁰ In March that year, a technical steering committee decided that efforts directed at large scale separation were premature. However, by June 1953 planning had started for the eventual separation of lithium isotopes, but as yet there were not even experimental quantities available. WD Allen, of the Nuclear Physics section, AERE, complained of the difficulty of getting a pure specimen of lithium for the cross section measurements. 'We are asking the EM group to produce 0.25 gm'.¹¹ He added that this would require an eight-week run of the large EM machine. This employed the principle of the mass spectrograph on a scale large enough to separate isotopes in meaningful quantities. The same principle was used in the calutrons constructed at Berkeley by EO Lawrence for the separation of U-235.

By this time it was clear that there were two contenders for a practical separation process, molecular distillation and the amalgam process. In the distillation process,

⁸ TNA AB 16/1280. 'Policy on Production of Lithium'. Several items, dating from 1953 onwards.

⁹ TNA AB 6/289 Ionic migration and other methods for lithium separation: Dr. H. London's papers. AERE: 1947. tna.open. Heinz London was one of the refugees who contributed to the wartime atomic bomb project. Later he worked on isotope separation and superconductivity. See Schoenberg, D. 'Heinz London. 1907-1970'. *Biographical Memoirs of Fellows of the Royal Society* 17:441-461, 1971.

¹⁰ TNA AB 6/1085. H. London, Jan 1952.

¹¹ TNA AB 6/1085, E8. Allen to Director, July 1953.

lithium is heated to a temperature of about 550 C in a vacuum, well below its boiling point. Lithium atoms evaporate from the liquid surface. Those of the lighter isotope have a greater mean free path and are collected preferentially on a cold surface positioned a few cm above the liquid surface. The theoretical separation efficiency is about 8%, so that a multi stage process is required to produce a high degree of separation. The amalgam process is a type of chemical exchange. If an aqueous solution of lithium hydroxide is mixed with a lithium-mercury amalgam, the lighter Li6 isotope concentrates in the amalgam. As with the molecular distillation process, the separation is low and a cascade process is required to achieve high separation.¹²

Heinz London prepared a further review of potential separation methods in July 1953.¹³ He concluded that the separation of lithium isotopes by molecular distillation was a comparatively simple and economic process requiring little R&D. A plant producing 10 kg Li-6 per year or 30 kg Li-7 would consume 100 kW and cost £10,000 plus £5000 research. He was aware of the amalgam process, but while he considered this as having potential for a large-scale plant, believed it would require too much development. A covering letter by D Fry, the chief physicist, noted however that 'Chemical Engineering Division may not agree with this view'.

In July 1953 there was a meeting chaired by Sir John Cockcroft to discuss the need for Li6 and how to prepare it. This meeting took place one month before the test of *Joe-4*, so the interest in lithium was independent of any clues from the analysis of the fallout from Russia's first thermonuclear weapon, which did indeed employ LiD. The meeting agreed that Harwell would arrange for the purchase of 1 to 2 tons of lithium and investigate production of 90% Li6. Molecular distillation was still the first choice, though there was a recommendation to investigate the mercury amalgam method.¹⁴ An advantage of the MD process was that it directly produced enriched metallic lithium, which was the form required by AWRE. A meeting between the Chief Physicist Fry and [presumably] Sir John Cockcroft agreed to proceed with the molecular distillation process, but observed that there were some difficulties, and that other methods of separation should be investigated. Dr Corner at AWRE had upped the purity requirement to 99%. It was expected that production would start in August 1954 and provide material for 1.5 weapons by August 1955, which translates from the rough figures given to about 3 kg Li6 per weapon. This is the first mention of a weapon on the Harwell file.¹⁵

3.3 Molecular distillation

Whatever separation process is used, each stage produces only a few percent enrichment. The achievement of the high separations required, up to 99%, requires a cascade of many units. The enriched output from one unit is fed into the next, and the impoverished remainder fed back upstream to the preceding unit. A production unit might require 100 stages. In early 1954 there must have been reasonable confidence in the viability of the molecular distillation method, as Cockcroft was making overtures to have the production plant built and operated elsewhere. He first tried to persuade

¹² Lewis, G.N. and Macdonald, R.N. 'The Separation of Lithium Isotopes'. *Journal of the American Chemical Society* 58(12):2519, 1936.

¹³ TNA AB 6/1085. 'Separation of Lithium Isotopes by Molecular Distillation', H. London, July 53.

¹⁴ TNA AB 6/1085, E17. Minutes of Interdepartmental Meeting, 30 Jul 53.

¹⁵ TNA AB 6/1085, Notes on visit to DW Fry (AERE) to discuss Li separation on 16 Sep 53.

Aldermaston to build the first small plant (4 kg/year), but Penney refused.¹⁶ Subsequent overtures to GEC and ICI were both turned down.¹⁷

In November 1954 Penney wrote to Cockcroft, expressing doubts that an operational distillation box could meet the theoretical efficiency of 8%, though he did enclose a calculation confirming the theoretical figure. Hinton replied that Kronberger thought that the process was sound, and that the pilot plant at Harwell was going well.¹⁸ By spring 1955 confidence was high. Plowden wrote to Helmore at the Ministry of Supply in May to discuss transfer of Li6 production from the AEA to the MoS: it was the policy at the time that the MoS should be responsible for the production of non-fissile, non-radioactive nuclear weapon components. He wrote that 'Harwell and Capenhurst have an acceptable process and Capenhurst will be in production this year'.¹⁹ A week later Cockcroft wrote to Sir Frederick Brundrett at the Ministry of Defence saying that '[we] are unlikely to require quantities of Li6 beyond what can be provided by the molecular distillation plant, which is to be erected at Stage II of the present programme'.²⁰ [NB Stage II of Crystal I was distillation]. Cockcroft went on to say that work on the second method of separation [the amalgam process or Crystal II] could be terminated, and that Penney agreed with this. The next day Cockcroft wrote to Owen at Risley saying that it was being proposed that Crystal II be wound up in view of the fact that it was unlikely that more Li6 would be needed than could be produced by a 600 kg/year plant. 'I ask the Design Committee if they are satisfied with the molecular distillation plant for us to abandon the chemical exchange [method] for the 600 kg/year plant'.²¹ Owen replied very positively 'As chairman of the Design Committee... the molecular distillation process is certain to separate the isotopes'.²² He went on that costs were still uncertain, but for the scale of 500 kg/year, any saving offered by another method was not worth the R&D costs involved. Brundrett replied to Cockcroft agreeing that work on alternative methods of Li6 production should stop.²³ It is not clear if work on Crystal II did actually stop, however, as a short time later the amalgam process became the favoured option.

A report published in August 1955 indicated that the distillation method was producing disappointing results.²⁴ While experimental work showed that the theoretical separation should be achievable, in practice this was not being achieved. This was followed up by another paper that describes an experimental still built at Harwell to verify the separation achievable by the MD method.²⁵ The description was of a single still of simple construction. A separation factor of close to the theoretical value of 1.08 was achieved, using a lithium temperature of 550 C. However, considerable difficulties were reported with getting molten lithium to flow in the connecting pipes. A later report dated October 1956 describes the blockages, but

¹⁶ TNA AB6/1085 % March 1954.

¹⁷ TNA AB 6/1085. Correspondence March to June 1954.

¹⁸ TNA AB 6/1085. Penney to Cockcroft 8 Nov 54. Reply by Hinton to Penney 10 Nov 54.

¹⁹ TNA AB 6/2631. Letter from Plowden to Sir James Helmore, 2 May 1955.

²⁰ TNA AB 6/1085. Cockcroft to Brundrett 9 May 1955.

²¹ TNA AB 6/1085 Cockcroft to Owen at Risley 10 May 55.

²² TNA AB 6/1085 Owen to Cockcroft 12 May 1955.

²³ TNA AB 6/1085 Brundrett to Cockcroft 16 May 1955.

²⁴ Horsley, G.W. Some experiments on the deposition of the isotopes of lithium by molecular distillation. Harwell:AERE M/R1745, 1955. TNA AB 15/4579.

²⁵ Cole, H.C. An investigation of the performance of a single stage molecular distillation unit for the separation of the isotopes of lithium. AERE GP/R 1841, 1956. tna AB 15/4663.

probably refers to earlier work since these problems had been occurring throughout 1955.²⁶ The Culceth labs were asked to examine blocked stainless steel pipes from the isotope separation plant, almost certainly at Capenhurst. The pipes carried molten lithium at 300 C and were blocked by the growth of metallic crystals.

This takes the distillation method up to August 1955. In August, Hinton reported that the estimated cost for the XM plant at Capenhurst had increased from £660,000 to £1,060,000.²⁷ The file does not state which process is referred to, but is presumably molecular distillation.

3.4 Mercury amalgam processes

It is clear that there was still discussion between the rival methods of molecular distillation and the mercury amalgam process at the end of 1954. The two processes appeared to be championed by London and Lacey respectively. A letter from Schonland to Cockcroft said 'Lacey's method' could not produce 1 kg by the end of 1955. London thought he could get 'his molecular method' to work and produce 3 kg by the end of 1955.²⁸

At the start of 1955, Schonland wrote to Cockcroft summarising the position on Crystal.²⁹ For the first time the work was divided into three categories:

- Crystal I. Molecular Distillation.
The work at Harwell and Capenhurst is to continue.
- Crystal II. Amalgam Chemical Exchange.
Effort by Chemical Engineering at Harwell was satisfactory for the present. Capenhurst will provide 20 people to increase effort for Crystal II and III
- Crystal III. Electrolysis assisted chemical exchange.
Described by Lacey. Aldermaston was to put 8 to 10 people from Chemical Engineering immediately on to it under the direction of AS White.

The next enclosure in the file indicates that there was at this time some uncertainty over the time and effort required for Crystal to produce Li6 in time for the forthcoming tests. In a draft memo dated January 1955, Lacey examines the use of electrolysis as a way of producing a kilogram quantity of Li6 in a crash programme.³⁰ He concludes that, while such a method would be possible, it would require very high power input compared with chemical exchange and would be unacceptable for large-scale production. Lacey recommends 'electrolytic chemical exchange'.

Meanwhile, the supporters of the mercury amalgam process were working up their proposals. At Harwell, Lacey wrote a report in 1954 on isotope separation, favouring the amalgam method.³¹ The report closely followed the Lewis and Macdonald method, in which droplets of an amalgam of lithium in mercury fell down a vertical column 18m high and 4mm in diameter. A solution of lithium chloride in alcohol

²⁶ Davis, M. and Montgomery, K.M. A blockage in the lithium isotope separation plant caused by metal crystals. UKAEA. IGR-TM/C070, 1956. TNA open AB 7/5164.

²⁷ TNA AB 6/1085 E100. AER(55) meeting, 25 August, 1955

²⁸ TNA AB 6/1085 Letter Schonland to Cockcroft 9 Dec 54.

²⁹ TNA AB 6/1085, E79. Schonland to Cockcroft 13 Jan 1955 'Crystal Research Progress'.

³⁰ TNA AB 6/1085 PMC Lacey 'On the use of Electrolytic Separation in the Crystal Project', Jan 1955.

³¹ Lacey, P.M.C. The separation of lithium isotopes. Harwell:(AB 15/3519), 1954. TNA.AERE CE/M 107.Oct 54.

passed up the tube. An isotope exchange took place between the two lithium media and the amalgam reaching the bottom of the column is enriched in Li6. Lacey proposed setting up an experimental plant.

By June 1955, Lacey had firmed up the proposals and published an agreed programme of work on Project Crystal, which is described as 'a simple chemical exchange process'.³² The report does not mention lithium by name, but as material XM. Project Crystal was the name used in Harwell, while the Industrial Group at Risley and Capenhurst referred to XM. There is also mention of RM, which is probably either natural lithium or residual Li7. Lacey states that the chemical exchange process compares favourably with molecular distillation and that there should be a small pilot plant operating by December 1955. Capenhurst would start design of a larger scale plant in November 1955. In August 1955, Lacey followed up with a cascade design for the chemical exchange method.³³ Thus, even though in May 1955 it had been agreed that Crystal II be stopped, design and possibly experimental work had clearly continued on the amalgam process.

Things began to move rapidly to establish the alternative mercury amalgam process. Lacey had already done a substantial amount of design work on the process at Harwell; it is not clear how much experimental work had been done. It was decided in October that Aldermaston should set up an amalgam plant with Lacey providing design input to this. However, Hinton's letter made it clear that Capenhurst would immediately start work on an amalgam plant; it is not clear what Lacey's input to this would be. Lacey provided a statement of position just two weeks later.³⁴ He stated that the work had three objectives:

- (a) The provision of short term data for Aldermaston
- (b) Erection and operation of Phase III cascade in S.40
- (c) Experimental work yielding long-term data.

He enclosed a 'highly simplified' block flow sheet of the Phase III plant as planned. It may be noted that the contactor column is 14 ft high, compared with the 18 m of the original Clark and Macdonald. By this time Lacey had settled on using an aqueous solution of lithium hydroxide, instead of the lithium chloride dissolved in alcohol described in the original Lewis and Macdonald paper. He hoped to have the plant ready for trial runs at the end of November. He suggested where improvement might be expected to some of the components and said 'it is this work which will yield the design data for large scale plant, and it will be augmented by operational and design experience gained at Aldermaston and Capenhurst in the meantime'. This may imply that it was already being envisaged that the eventual large-scale plant would not be built and operated within the AEA, but at a Royal Ordnance Factory.

³² Johnson, K.D.B. and Lacey, P.M.C. Harwell-Capenhurst development programme for crystal project by chemical exchange method. Harwell:UKAEA. AERE CE/M 138, 1955. TNA AB 15/4323.

³³ Lacey, P.M.C. Cascade designs for lithium isotope separation by chemical exchange. AERE CE/M 147, 1955. TNA AB 15/4331.

³⁴ TNA AB 6/1085 E108. Crytal II – Statement of Present Position of work 20 Oct 1955.

4 Production

4.1 Problems

A letter from Penny to Hinton in March 1955 discussed the planned use of Li6 in the planned trials and revealed some of his thinking about weapons design.³⁵ In reply to Hinton's worries that the Li6 target of 90% separation might not be met, Penney said that Li6 would first be used in 1956 trials in small quantities, to get information on how Li6 burns and how it affects core fission; he would use Li as it comes (even 70%). The 1957 trials were a different matter, implying that larger quantities at high separation would be required for *Grapple*. Penney then mentioned the intention to use a shell of a 50/50 mixture of LiD and uranium [238]. This presumably refers to the design of the Type A, tamper boosted, weapon.

On 3 October 1955, Hinton wrote to Penney with bad news.³⁶

Things are going badly on the first line of our Lithium six plant at Capenhurst. In brief, the troubles are:

- (a) Presumably owing to a meniscus effect, the back flow of heavy fraction down the plant is intermittent
- (b) There is a thermosyphon in the interconnecting piping which is difficult to eliminate.
- (c) Presumably because of the difficulties (a) and (b) the boxes are able to run dry with consequent severe overheating and buckling of the base.
- (d) Brittle fractures of the interconnecting stainless steel piping which appears to arise from stressing at temperatures rather above normal operating temperatures have occurred.

I cannot hold out any hope to you that there is a better than a 50/50 chance of providing you with 2/3 kg of 70% material by March 1956.

I have little confidence that the molecular distillation plant can ever be made entirely satisfactory and in view of this we are immediately starting to construct a few...prototype stages for a mercury amalgam plant.

The letter goes on to refer to the proposed move of lithium 6 production to the Ministry of Supply and say that the DGOF should be told to postpone any work. The file then contains a handwritten note to Shonland, probably from Cockcroft, saying that in view of 'the flap on Crystal in the North, Penney and I' saw Lacey.

The note recommends that Lacey step up his efforts and AWRE should establish a pilot plant.³⁷ Within a few days of Hinton's bad news, the chairman of the AEA, Sir Edwin Plowden, had written to Hinton, Cockcroft and Penney, respectively the directors of Risley, Harwell and Aldermaston.³⁸ Headed 'Manufacture of XM', the letter stated that 'the political and military implications of delay are so great that this project has absolute and overriding priority'.

4.2 Success at Capenhurst

Hans Kronberger left Harwell for Capenhurst in 1951, becoming Head of Laboratories. Later, in 1958, he became Director of R&D in the Industrial Group of the AEA. He supervised the programme on the use of centrifuges for the separation of U-235. Rotherham's memoirs state: 'Kronberger's name does not appear on the publications but from personal knowledge I can say that he was the inspiration of the group which included many others whose names are not declared...However, perhaps

³⁵ TNA AB 6/1085. E83, Penney to Hinton 7 Mar 55.

³⁶ TNA AB 6/1085. Hinton to Penney 3 October 1955

³⁷ TNA AB 6/1085 Undated note. About E104.

³⁸ TNA AB 6/1085 E105. Letter from, Plowden 7 October 1955.

the separation of lithium-6 and lithium-7 fascinated him most. Part of this enthusiasm arose from the feeling which metallurgists sometimes feel of satisfaction with a metallurgical process. Hans needed to produce fairly large specimens of high purity lithium and successfully carried out the purification and casting of suitable ingots in equipment built in the laboratory'.³⁹

Kronberger took over direction of lithium separation at Capenhurst; this included both distillation and amalgam methods. It is clear that a major source of difficulty with the distillation method was the plumbing. The stainless steel pipes used to transport the liquid lithium suffered frequent blockages and other flow problems. There were also problems with the amalgam method, again associated with the peripheral plumbing. The amalgam process for Crystal II, Phase III, sketched out by Lacey at Harwell, used a vertical amalgam exchange column 14 feet high. To achieve the necessary separation, many columns would have to be operated in cascade. The height of the column implies that pumps would be required to handle mercury at a pressure of some 6 atmospheres and it is understood that this presented practical difficulties. At Capenhurst, Clark and Whitehead experimented with a mixer-settler system and so avoided the problems produced by the large head of mercury in the column exchange method.⁴⁰ In this system the amalgam and aqueous solution are agitated together. The mixture is then passed to a settler tank, where the amalgam, now enriched in the lighter lithium isotope, settles to the bottom. No description has been located in the archives, but an eyewitness recalls a five-stage cascade constructed out of Perspex, which was used to demonstrate the process.

By February 1956, successful separation was under way. A progress meeting reported:⁴¹

1. The Capenhurst molecular distillation plant is limping along with frequent failures of welded joints. It will be closed down soon.
2. Chemical exchange plant has been running well for 8 days. It is hoped to get 90% separation soon (after 21 days). Then it should produce 0.5 kg of 905 separation every 21 days.
3. Matthew Hall is getting on well with the Aldermaston version of the Harwell plant. [Matthew Hall & Co built GLEEP and other Harwell plants]
4. The Ministry of Supply will put up a larger plant but has not decided on a mixer-settler (Capenhurst) or columns (Harwell). Lacey says Hinton has pressed them to adopt the Capenhurst design.
5. The Crystal committee needs to be wound up

By March the Ministry of Supply was accepting responsibility for future production. Sir John Eldridge wrote to Shonland in March, saying the future production of lithium 6 would be in the hand of the Royal Ordnance Factories (ROF). It would be known as Project M and would use the Capenhurst method.⁴² The work was to be undertaken at ROF Chorley. By July 1956, the Harwell contribution was over. Shonland wrote to Cockcroft on the conclusion of Crystal, pointing out that while the industrial workers

³⁹ Rotherham, L. 'Hans Kronberger, 1920-1970'. *Biographical Memoirs of Fellows of the Royal Society* 18:412-426, 1972.

⁴⁰ Private communication. Owen Pugh worked at Capenhurst during the late 1950s. Subsequently became CEO at UKAEA Dounreay.

⁴¹ TNA AB 6/1085 Notes on Crystal Meeting 23 Feb 1956.

⁴² TNA AB 6/1085 Eldridge to Shonland 12 Mar 1956.

had been congratulated the scientific staff had not.⁴³ ‘Could they not do the same to the combined AERE-R&D-AWRE team which solved the very many difficult R&D problems involved in the chemical exchange method. Lacey and his boys, and Johnson of R&D and many others worked extremely hard indeed.’

A Capenhurst half-year report of September 1956 indicates that the distillation method had not been abandoned, but had been developed into a production method. The report states that the ‘upper section’ of the XM [distillation] plant consisting of 108 stages had been operated throughout the period at 66% availability. The product concentration had risen to 45% by mid-August. Product removal commenced to provide an enriched feed to the CXM [amalgam] process. Operational difficulties however continued due to plugging of process lines and failure of stressed stages. The CXM [amalgam] process was operating satisfactorily and the initial AWRE requirement [presumably delivery of Li6] had been met by mid-May. The plant was modified to give larger output and restored to operation in July.⁴⁴ In November, Cockcroft wrote ‘I was interested to see that the distillation process for XM was working well at Capenhurst and that in Kronberger’s view there was little difference in cost between this and the chemical exchange process’.⁴⁵

5 Handover to Ministry of Supply

By May 1955, Harwell was confident that its molecular distillation process would be capable of meeting the production targets for Li6, once the larger scale plant was in operation at Capenhurst. The general policy was that the Ministry of Supply should produce non-fissile and non-radioactive components of nuclear weapons and that this should include Li6 separation and fabrication of LiD. In May 1955, Sir James Plowden wrote to Sir James Helmore at the Ministry of Supply asking that the Ministry should be prepared to undertake the production of 500 kg of Li-6 per annum from 1959 onwards. He went on to say ‘Harwell and Capenhurst have acceptable processes and Capenhurst will be in production this year for 100 kg/year.’ The Ministry should also procure the lithium ore. Helmore was not happy with this request, stating that the required techniques were well outside the experience of the Ministry’s factories. In July, Plowden tried again with a revised request. The bomb requirement was reduced to 300 kg/year; with the planned production of 100 kg/year from Capenhurst, the Ministry of Supply would only have to provide 200 kg/year. However, weapon tests were now planned for 1957, and the Li6 had to be ready in time. Plowden requested that the Ministry of Supply should provide these requirements.⁴⁶

Helmore then got Kenneth Gordon, Director General Ordnance Factories, to visit Capenhurst. Gordon preferred the mercury exchange process, but accepted that molecular distillation would have to be used to reduce delays. Helmore then accepted the job on behalf of the Ministry of Supply⁴⁷, but was informed with a few weeks that the molecular distillation process was not working and a mercury exchange plant

⁴³ TNA AB 6/1085 E143. Schonland to Cockcroft July 1956.

⁴⁴ TNA AB 7/4880. Capenhurst Works Report for half year ending 30 Sep 1956. UKAEA Industrial Group IGO PR/CA09.

⁴⁵ TNA AB 6/1085 E145 Memo from Cockcroft to Fry 19 Nov 56.

⁴⁶ TNA AB 16/2631. Plowden to Helmore, 2 May 1955; Helmore to Plowden, 12 May 1955; Plowden to Helmore, 19 July; Plowden to Helmore, 26 August 1955.

⁴⁷ TNA AB 16/2631 2 Sep 55, Helmore to Plowden.

would have to be set up. Plowden reported that laboratory scale work was being carried out as a matter of urgency at both Capenhurst and Aldermaston; he then reiterated his desire that the Ministry of Supply should take over the job. Helmore agreed to take responsibility, but pointed out that this would create a six-month delay compared with the work being carried out at Aldermaston. The Ministry would erect the plant by mid April 1958 and supply 300 kg/year Li6 for conversion to LiD. Helmore expected that the plant would be situated at the Royal Ordnance Factory, Chorley, Lancashire.⁴⁸

The Royal Ordnance Factory at Chorley, Lancashire was the site used to produce lithium components for the weapons programme. There were two production processes involved here. One was a mechanical area for the hot pressing of lithium hydride and lithium deuteride crystals into weapon component blanks. Another was a "chemical" phase to produce lithium hydride and lithium deuteride crystals from lithium 6 metal and for recovery of ex-weapon components and scrap, which were then returned to their crystalline form. By 1979, however, the Chorley plant was becoming old and in need of replacement; in addition it was too expensive to put on a care and maintenance basis (the costs of doing this, for example, included keeping suitably security vetted staff available on site). As a consequence, MOD decided that these production processes should move to ROF Burghfield where most other nuclear warhead assembly and disassembly activities were taking place.⁴⁹

6 In the USA

In America, the Oak Ridge Y-12 Plant began the initial effort to develop lithium isotope separation processes in 1950. Three processes were explored: COLEX, ELEX, and OREX.⁵⁰ The first successful laboratory separation was achieved with the ELEX process, an electrically driven chemical exchange process. The ELEX pilot plant was built at Y-12 in 1951. Y-12 operated a production scale ELEX plant in building 9204-4 (Beta 4) from 1953 until 1956. This plant was cleaned out and dismantled by 1959. The OREX process, in which an organic solution of lithium was exchanged with a solution of lithium in mercury, termed an amalgam, never advanced further than the pilot plant stage. The COLEX process (the name is a contraction of column exchange) supplied most of the enriched lithium needed for the weapons complex. AEC built two large COLEX facilities, called Alpha 4 and Alpha 5. Alpha 4 operated from January 1955 until 1963. The unit was placed on standby until it was dismantled in the late 1980s. Alpha 5 began operating in 1955. It was shut down in 1959 and restarted in 1963 for a six-month campaign. Y-12 Plant engineers dismantled and disposed of the Alpha 5 COLEX process equipment in 1965 and 1966

The COLEX process employed approximately 24 million pounds of mercury. Most of the mercury used in the COLEX and ELEX processes was returned to the General Services Administration (GSA) once it was no longer needed. However, a great deal of mercury was lost in wastes, spills, and through evaporation. Approximately two million pounds of mercury, i.e. 1000 tons, used in the lithium enrichment processes have still not been accounted for.

⁴⁸ Helmore 'Production of Lithium Six Deuteride' Detailed undertaking to Plowden, 29 Mar 1956. TNA AB 16/2631.

⁴⁹ TNA DEFE 72/167 Transfer Salts facility from Chorley to Burghfield 1977-1979.L.Bone, PAFO DAWP&F to Mr J.Elliott, Head of DS2 S Group transfer 13 June 1979 folio E45

⁵⁰ DOE The Legacy Story: A history of the US nuclear weapons complex. Washington:Department of Energy Office of Environmental Management. , 1997. <http://legacystory.apps.em.doe.gov/index.asp>.Mar 2007.

7 A note on sources

The major source was the Harwell file on Project Crystal, held as AB 6/1085 at TNA. It was opened to public view in 2006. File AB 6/1086, apparently covering the same topic, is listed as missing. Relevant AWRE files are listed in the TNA catalogue, but have not yet been released. No relevant source material originating at Capenhurst or the Industrial Group at Risley has been located.

8 Appendix. Nuclear reactions of lithium

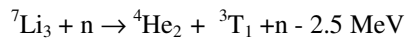
Nuclear fission releases energy by the splitting of a heavy nucleus such as uranium. At the other end of the periodic table, energy is released if hydrogen nuclei can be persuaded to fuse together and create a heavier nucleus of helium. However, it is not possible to transmute hydrogen nuclei directly into helium. There are a few possible fusion reactions involving isotopes of hydrogen that can be considered for fusion weapons.



For these reactions to take place, it is necessary to create conditions of extremely high temperature and pressure. The reaction in Equation 1 is relatively easy to ignite and can be initiated using high explosive alone. While this method cannot produce a large thermonuclear explosion, it can be used to boost a fission reaction. Incorporating a few grams of deuterium and tritium at the centre of a fissile core will produce a substantial neutron flux, which will increase the burn up of the fissile material. The emitted neutron has energy of 14 MeV, which is sufficient to cause fast fission in U238, allowing the possibility of the fission-fusion-fission bomb. The other reactions require a nuclear fission primary to produce the necessary temperature and compression.

Deuterium occurs naturally and is a stable isotope with an indefinite life. Natural hydrogen contains 0.015% deuterium. Deuterium may be produced by electrolysis of water in a process that concentrates the heavier atoms. Tritium, however, is radioactive and decays with a half-life of 12 years. It is not found in nature and must be manufactured using a nuclear reactor. The process is expensive and long-term storage of tritium is limited by its natural decay. Several types of nuclear weapon utilise the D-T reaction of equation 1. Where a small amount of deuterium and tritium is used to boost a fission bomb, they can be admitted in gaseous form to the centre of the core at the last moment. Where larger quantities of tritium are needed, it is more practical to generate it on the spot. In a “dry” thermonuclear weapon, neutrons produced by a fission explosion are used to generate tritium by bombarding lithium nuclei:





Equation 6

Thus a fuel containing lithium deuteride can provide a supply of both tritium and deuterium and so produce the components for the reaction in Equation 1. The reaction in Equation 5 is used in most thermonuclear weapons and demands use of the isotope Li6. The reaction in Equation 6 requires an incident neutron with energy greater than 4 MeV. Neutrons from nuclear fission are not sufficiently energetic to produce this reaction. However, it can be significant in the later stages of an explosion where high-energy neutrons are available from a thermonuclear reaction of the type in equation 1. The presence of Li-7 caused an unexpected increase in yield in the *Castle Bravo* test.