V-89

8/134

UNITED STATES
ATOMIC ENERGY COMMISSION
CHICAGO OPERATIONS OFFICE
P. O. Box 59
LEMONT, ILLINOIS

April 8, 1959

Dr. Leo Szilard
Quadrangle Club
1155 East 57th Street
Chicago, Illinois

Subject: U. S. PATENT NO. 2,836,554, ISSUED: MAY 27, 1958; AEC CASE NO. S-506

Dear Dr. Szilard:

I am pleased to enclose for your files a corrected copy of the above patent.

I want to thank you for the courtesy and assistance which you extended to members of my staff in connection with the preparation and prosecution of the patent application.

Very truly yours,

George H. Lee

George H. Lee, Chief
Chicago Patent Group

Enclosure:
Patent No. 2,836,554

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 2,836,554 May 27, 1958

Enrico Fermi et al.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 12, line 61, for "the roof" read -- thereof --; column 13, line 58, for "unused channels" read -- unused air channels --; line 61, for "One the fifth side" read -- On the fifth side --; column 18, line 37, for "packets" read -- jackets --.

Signed and sealed this 13th day of January 1959.

(SEAL)
Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents

Aktenexemplar

DEUTSCHES REICH

AUSGEGEBEN AM
1. DEZEMBER 1933

REICHSPATENTAMT

PATENTSCHRIFT

№ 531 581

KLASSE 17a GRUPPE 3 04

S 92040 I/17a

Tag der Bekanntmachung über die Erteilung des Patents: 30. Juli 1931

Dr. Leo Szilard in Berlin-Wilmersdorf

Pumpe, insbesondere zur Verdichtung von Gasen und Dämpfen in Kältemaschinen

Lagerexemplar

Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949
(WiGBl. S. 175)

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM
13. JUNI 1957

DEUTSCHES PATENTAMT

PATENTSCHRIFT

№ 965 522

KLASSE 21g GRUPPE 37 01

INTERNAT. KLASSE H 05j

S 18863 VIIIc/21g

Dr. Leo Szilard, New York, N. Y. (V. St. A.)

Mikroskop

Patentiert im Gebiet der Bundesrepublik Deutschland vom 4. Juli 1931 an
Patentanmeldung bekanntgemacht am 20. Dezember 1956
Patenterteilung bekanntgemacht am 29. Mai 1957
Die Schutzdauer des Patents ist nach Gesetz Nr. 8 der Alliierten Hohen Kommission verlängert

(9)

45

DEUTSCHES REICH

AUSGEGEBEN AM
21. SEPTEMBER 1931

REICHSPATENTAMT

PATENTSCHRIFT

№ 533 945

KLASSE 17 a GRUPPE 3

S 91304 I/17 a

Tag der Bekanntmachung über die Erteilung des Patents: 3. September 1931

Dr. L. Szilard in Berlin-Wilmersdorf

Pumpe

Patentiert im Deutschen Reiche vom 25. April 1929 ab

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195 (10)

DEUTSCHES REICH

AUSGEGEBEN AM
3. FEBRUAR 1932

REICHSPATENTAMT

PATENTSCHRIFT

№ 543 214

KLASSE 17 a GRUPPE 3

S 92043 I/17 a

Tag der Bekanntmachung über die Erteilung des Patents: 14. Januar 1932

543 214

Dr. Leo Szilard in Berlin-Wilmersdorf

Vorrichtung zur Bewegung von flüssigen Metallen

Patentiert im Deutschen Reiche vom 4. Juni 1929 ab

DEUTSCHES REICH

AUSGEGEBEN AM
16. JULI 1934

REICHSPATENTAMT

PATENTSCHRIFT

№ 600 162

KLASSE 42g GRUPPE 11 01

S 98694 IX/42g

Tag der Bekanntmachung über die Erteilung des Patents: 28. Juni 1934

Dr. Leo Szillard in Berlin-Wilmersdorf

Verfahren zum elektrochemischen Aufzeichnen von Sprechströmen

Patentiert im Deutschen Reiche vom 17. Mai 1931 ab

Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949
(WiGBl. S. 175)

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM
13. JUNI 1957

DEUTSCHES PATENTAMT

PATENTSCHRIFT

№ 965 522

KLASSE 21g GRUPPE 37 01

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S 18863 VIII c/21g

Dr. Leo Szilard, New York, N. Y. (V. St. A.)

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Patentiert im Gebiet der Bundesrepublik Deutschland vom 4. Juli 1931 an
Patentanmeldung bekanntgemacht am 20. Dezember 1956
Patenterteilung bekanntgemacht am 29. Mai 1957
Die Schutzdauer des Patents ist nach Gesetz Nr. 8 der Alliierten Hohen Kommission verlängert

X (30)

Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949
(WiGBl. S. 175)

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM
13. JUNI 1957

DEUTSCHES PATENTAMT

PATENTSCHRIFT

Nr. 965 522

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DEUTSCHES REICH

AUSGEGEBEN AM
16. JULI 1934

REICHSPATENTAMT

PATENTSCHRIFT

№ 600 162

KLASSE 42g GRUPPE 11 01

S 98694 IX/42 g

Tag der Bekanntmachung über die Erteilung des Patents: 28. Juni 1934

Dr. Leo Szillard in Berlin-Wilmersdorf

Verfahren zum elektrochemischen Aufzeichnen von Sprechströmen

Patentiert im Deutschen Reiche vom 17. Mai 1931 ab

Die vorliegende Erfindung bezieht sich auf ein Verfahren zum elektrochemischen Aufzeichnen von Sprechströmen mittels zweier beiderseits eines stromleitenden Bandes angelegter und längs einer endlichen Strecke sich gegenüberstehender Elektroden.

Es sind Anordnungen bekannt, bei denen in Abhängigkeit von den Sprechströmen die Stromstärke des durch den Film durchtretenden Stromes geändert wird und hierdurch Tonaufzeichnungen hervorgerufen werden. Dieses Verfahren hat den Nachteil, daß es verhältnismäßig unempfindlich ist, da große Stromänderungen zur Erzielung einer Aufzeichnung notwendig sind.

Diese Nachteile werden gemäß vorliegender Erfindung dadurch vermieden, daß einer der Elektroden ein Spannungsgefälle erteilt wird. Zweckmäßig ist es, hierbei in der Weise zu verfahren, daß als eine Elektrode ein entsprechend ausgebildeter Widerstand dient, durch den ein regelbarer konstanter Hilfsstrom durchgeschickt wird, so daß längs der Elektrode ein Spannungsabfall entsteht.

Hierbei können die Sprechströme den Stromkreis zwischen den beiden Elektroden oder den das Spannungsgefälle in einer Elektrode hervorrufenden Stromkreis beeinflussen.

Die Aufzeichnung erfolgt zweckmäßigerweise derart, daß das stromempfindliche Band normal zur Richtung der aufzeichnenden Elektrode bewegt wird, oder derart, daß eine der Elektroden quer zur Ablaufrichtung des stromempfindlichen Bandes umläuft, so daß auf diesem hintereinander quer zur Ablaufrichtung Aufzeichnungsreihen entstehen.

Die Zeichnung zeigt beispielsweise Anordnungen zur Ausführung des Verfahrens, und zwar zeigt:

Fig. 1 eine Anordnung der Elektroden,

Fig. 2 eine elektrische Schaltung zur Aufzeichnung,

Fig. 3, 4 und 5 eine Anordnung zur Verwendung des Verfahrens für Tonfilmaufzeichnungen.

In Fig. 1 bewegt sich der stromempfindliche Streifen 1 quer zur Richtung der Elektroden 2 und 3. Die Gegenelektrode 2 befindet sich hinter dem Streifen 1 und kann als breitere Fläche ausgebildet sein. Die als Schreiborgan dienende Elektrode 3 dagegen ist in diesem Fall schneidenförmig so ausgebildet, daß die Schneidenrichtung praktisch senkrecht zur Bewegung des Streifens 1 verläuft.

Wird durch die Elektrode 2, die in der gezeigten Ausführungsform aus Material von hohem Widerstand ausgebildet ist, in Richtung des Pfeiles 4 ein elektrischer Gleichstrom hindurchgeschickt, so wird infolge des Ohmschen Spannungsabfalls in der Elektrode 2 die Spannung an verschiedenen Stellen verschieden sein, und zwar sinkt die Spannung der Elektrode stetig von links nach rechts, so daß zwischen den einzelnen Stellen der schneidenförmigen

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DEUTSCHES REICH

AUSGEGEBEN AM
3. FEBRUAR 1932

REICHSPATENTAMT

PATENTSCHRIFT

№ 543214

KLASSE 17a GRUPPE 3

S 92043 I/17a

Tag der Bekanntmachung über die Erteilung des Patents: 14. Januar 1932

Dr. Leo Szilard in Berlin-Wilmersdorf

Vorrichtung zur Bewegung von flüssigen Metallen

RESERVE COPY.

AMENDED SPECIFICATION.

Reprinted as amended under Section 8 of the Patents and Designs Acts, 1907 and 1919.

PATENT SPECIFICATION

Convention Date (Germany): Sept. 3, 1924. **239,518**

Application Date (in United Kingdom): Sept. 2, 1925. No. 21,972/25.

Complete Accepted: Aug. 26, 1926.

COMPLETE SPECIFICATION (AMENDED).

Improvements in or relating to Electron Discharge Tubes.

We, SIEMENS & SCHUCKERTWERKE GESELLSCHAFT MIT BESCHRÄNKTER HAFTUNG, of Berlin-Siemensstadt, Germany, a German company (part Assignees of Dr. LEO SZILARD, of 16, Faradayweg, Berlin-Dahlem, Germany, of Hungarian nationality), and Dr. LEO SZILARD, of 16, Faradayweg, Berlin-Dahlem, Germany, of Hungarian nationality, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

RESERVE COPY.

PATENT SPECIFICATION

Convention Date (Germany): Dec. 16, 1926. **282,428**

Application Date (in United Kingdom): Dec. 16, 1927. No. 34,096/27.

Complete Accepted: Nov. 15, 1928.

COMPLETE SPECIFICATION.

Improvements relating to Refrigerating Apparatus.

We, ALBERT EINSTEIN, of 5, Haberlandstrasse, Berlin, W. 30, Germany, a citizen of Switzerland, and LEO SZILARD, of 95, Prinzregentenstrasse, Berlin-Wilmersdorf, formerly of Faradayweg 16, Berlin-Dahlem, Germany, a Hungarian citizen, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

bodiment of the invention, 1 designates the evaporator containing a cooling agent 2, in this case methyl bromide. Through the pipe 3 gaseous ammonia enters the evaporator and flows from this pipe 3 into the cooling agent through a distributor 4. Divided into numerous small bubbles the gaseous ammonia then rises through the liquid cooling agent 2 and in this manner becomes saturated very completely with the vapour of the

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PATENT SPECIFICATION

Application Date: March 12, 1934. No. 7840/34.
" " July 4, 1934. No. 33540/35.
(No. 33540/35 being divided out of Application No. 19721/34.)
Application Date: Sept. 20, 1934. No. 27050/34.
One Complete Specification Left: April 9, 1935.
(Under Section 16 of the Patents and Designs Acts, 1907 to 1932.)
Specification Accepted: Dec. 12, 1935.

440,023

PROVISIONAL SPECIFICATION
No. 7840 A.D. 1934.

Improvements in or relating to the Transmutation of Chemical Elements

I, LEO SZILARD, a citizen of Germany and Hungary, c/o Claremont Haynes & Co., Vernon House, Bloomsbury, Square, London, W.C.1, do hereby declare the nature of this invention to be as follows:—

Ex letter copy

Patents Form—No. 1.

No Charge for the Form.

5730

PATENTS & DESIGNS ACTS, 1907 to 1932.

(To be accompanied by two copies of Patents Form No. 2 or of Patents Form No. 3.)

APPLICATION FOR PATENT.

(a) Here insert (*in full*) name, address, and nationality of applicant or applicants (including the actual inventor).

5730

21 FEB 1934

(a) I (or We) Leo Szilard, citizen of Germany and subject of Hungary, 6 Halliwick Rd Muswell Hill, London N.10. ~~2nd Stand Palace Hotel, Strand, London~~ do hereby declare that I am (or we are) in possession of an invention the title of which is (b) Asynchronous and Synchronous Transformers for Particles

(b) Here insert title of invention.

(c) State here who is or are the inventor or inventors.

that (c) I (Leo Szilard) claim~~e~~ to be the true and first inventor~~s~~ thereof, and that the same is not in use by any other person or persons to the best of my (or our) knowledge and belief; and I (~~or we~~) humbly pray that a Patent may be granted to me (~~or us~~) for the said invention.

Dated the 20 day of February, 193 34

(d) To be signed by applicant or applicants and, in the case of a Firm, by each partner.

(d) Leo Szilard

NOTE.—One of the two forms on the back hereof, or a separate authorisation of agent, should be signed by the applicant or applicants.

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AMENDED SPECIFICATION.

Reprinted as amended under Section 8 of the Patents and Designs Acts, 1907 and 1919.

PATENT SPECIFICATION

Convention Date (Germany): Sept. 3, 1924. 239,518

Application Date (in United Kingdom): Sept. 2, 1925. No. 21,972/25.

Complete Accepted: Aug. 26, 1926.

COMPLETE SPECIFICATION (AMENDED).

Improvements in or relating to Electron Discharge Tubes.

We, SIEMENS - SCHUCKERTWERKE GESELLSCHAFT MIT BESCHRÄNKTER HAFTUNG, of Berlin-Siemensstadt, Germany, a German company (part Assignees of Dr. LEO SZILARD, of 16, Faradayweg, Berlin-Dahlem, Germany, of Hungarian nationality), and Dr. LEO SZILARD, of 16, Faradayweg, Berlin-Dahlem, Germany, of Hungarian nationality, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

As is well known, hot cathode tubes are used for the control of electric currents. In such tubes, the current is conducted by the electrons which escape from the incandescent filament owing to the high temperature of the same. For the control of the current, between the incandescent filament and the anode of the tube, could be provided a grid influenced by a control voltage. It is difficult to obtain in this way high anode current intensities, and the life of the incandescent filaments is a limited one. At the same time it is necessary to use a considerable energy, the so-called heating energy, which restricts the efficiency of the tube to a low figure. In order to increase the current intensity in such a discharge vessel with control action, it has been already proposed to use for the discharge vessel the well known mercury vapour rectifiers, and to arrange control grids in front of the anodes. Although a sufficiently high anode current strength can be obtained in this way, it is on the other hand impossible to exercise an effective control of the anode current by the grid, as the vacuum in the space between the anode and the cathode is not sufficient for the control.

There are also known already electric discharge vessels in the form of mercury vapour rectifiers in which the vacuum in the space in which the anodes are contained, is higher than in the cathode space. This higher vacuum is obtained owing to the mercury vapour generated at the cathode, passing first through a tube narrowing at the mouth, and then, in the form of a jet, into the condensation chamber. This mercury vapour jet escaping from the mouth of the tube exercises a suction on the adjoining anode chambers, like in the case of a mercury vapour jet pump. These well known discharge vessels do not possess however any means for the control of the current between the anode and the cathode. The high pressure maintained in the neighbourhood of the cathode is rather intended to avoid the formation of an electric arc or a passage of current between the anodes themselves.

The invention has reference to a discharge tube with means for controlling the current between anode and cathode by electrostatic or electro-magnetic means, in which the admission from the cathode chamber to the chamber in which the control takes place is effected through a contracted passage. Now experience has shown that, in spite of the presence

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PATENT SPECIFICATION

Convention Date (Germany): Dec. 16, 1926.

282,428

Application Date (in United Kingdom): Dec. 16, 1927. No. 34,096/27.

Complete Accepted: Nov. 15, 1928.

COMPLETE SPECIFICATION.

Improvements relating to Refrigerating Apparatus.

We, ALBERT EINSTEIN, of 5, Haberlandstrasse, Berlin, W. 30, Germany, a citizen of Switzerland, and LEO SZILARD, of 95, Prinzregentenstrasse, Berlin-Wilmersdorf, formerly of Faradayweg 16, Berlin-Dahlem, Germany, a Hungarian citizen, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to refrigerating apparatus having a refrigerant evaporated in the evaporator by the introduction of a pressure equalising auxiliary medium thereinto and separated from said medium by the absorption of the latter and condensation of the refrigerant as described in British Patent Specification No. 250,983.

According to the present invention the refrigerating process in such apparatus is carried out by utilising ammonia as the auxiliary medium, water as the absorption medium and butane or methyl-bromide as the refrigerant.

When utilising the above substances in the refrigeration process the condensation of the refrigerant and the absorption of the auxiliary medium is preferably effected in known manner in the same vessel which is hereinafter called a condenser-absorber.

As no condensation of the auxiliary gas is required, the apparatus is further worked with ammonia as the auxiliary gas at any desired small total pressure. The total pressure is practically the same in all parts of the apparatus except the pressure differences counterbalanced by the hydrostatic pressure of liquid columns.

The invention will be hereinafter more particularly described with reference to the accompanying drawings in which:—

Fig. 1 shows diagrammatically one embodiment of the invention.

Fig. 2 is a modification of the invention.

Fig. 2a is a section on the line A—A of Fig. 2.

Figs. 3 and 4 are further modified arrangements of the invention.

Referring to Fig. 1 showing one embodiment of the invention, 1 designates the evaporator containing a cooling agent 2, in this case methyl bromide. Through the pipe 3 gaseous ammonia enters the evaporator and flows from this pipe 3 into the cooling agent through a distributor 4. Divided into numerous small bubbles the gaseous ammonia then rises through the liquid cooling agent 2 and in this manner becomes saturated very completely with the vapour of the methyl bromide. The mixture of the two gases then flows through the conduit 5 into the condenser-absorber 6 into which water is dropping continuously through the conduit 7. Preferably the water flows along the wall 8 of the condenser which wall is cooled by external cooling water.

The saturation pressure of the ammonia being strongly reduced in the presence of water the gaseous ammonia will be absorbed by the water, the gas content of the condenser 6 being thus deprived of said gaseous ammonia. As the total pressure remains constant in this process, the partial pressure of the methyl bromide will be correspondingly increased on account of the removal of the gaseous ammonia, especially adjacent the walls, so that the vapour of methyl bromide will become super-saturated and will be condensed on the walls of the condenser simultaneously with the absorption of ammonia. Gaseous ammonia and vapour of methyl bromide tend simultaneously to approach the walls of the condenser and the condensation proceeds very rapidly; the velocity of condensation depending in the first place on the speed with which the heat is removed from the walls of the condenser. The condensed methyl bromide has a higher specific weight than the ammonia solution and collects in the condenser as at 9, whereas the ammonia mixture 10 floats above.

The methyl bromide in the condenser communicates with that in the evaporator by means of the conduit 11. 12 designates a cooling jacket for cooling the condenser 6. The ammonia solution is transferred into the vessel 15 through the pipe 13 by means of gas bubbles ris-

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NOTE.—*The application for a Patent has become void.*

This print shows the Specification as it became open to public inspection.

PATENT SPECIFICATION

Convention Date (Germany): Dec. 29, 1926. 282,808

Application Date (In United Kingdom): Dec. 29, 1927. No. 35,201/27.

Complete not Accepted.

COMPLETE SPECIFICATION.

Refrigerating Machines in which the Pumping of Liquid is Effected by Intermittently Increasing the Vapour Pressure.

We, Dr. LEO SZILARD, of 95, Prinzregentenstrasse, Berlin-Wilmersdorf, Germany, and Professor Dr. ALBERT EINSTEIN, of Haberlandstrasse 5, Berlin, Germany, both German citizens, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The construction of continuous refrigerating machines of the absorption type has hitherto been impeded by the necessity for special feed pumps to convey the liquid from the absorber to the heater or still, because of the considerable positive pressure usually prevailing in the still. The employment of a special feed pump is too expensive and cumbrous. Various proposals have been advanced for dispensing with a special feed pump, for example by conveying the liquid from the absorber to the still by means of ascending bubbles of gas (after the manner of the mammut pump); but this, and various other suggestions, proved unsuccessful in cases where the positive pressure in the still is considerable. In order to get round the difficulty in question, it has even been proposed to abandon the principle of operating purely by absorption, and to construct refrigerating machines in which the pressure between the absorber and still is balanced by means of a permanent gas.

A similar difficulty to that encountered in the absorption refrigerating machines is also met with in machines of the injection type, since these machines would need a special feed pump to pump the condensate back from the condenser into the boiler.

The present invention enables special feed pumps to be dispensed with in refrigerating machines, even when considerable degrees of positive pressure have to be overcome. It provides a refrigerating machine in which a liquid is forced into a chamber wherein a positive pressure exists, characterised in that the vapour pressure is intermittently increased between two closure members, by warming. As closure member there may be employed a valve or a porous substance from the capillaries of which the liquid is not displaced by the positive pressure.

But in order that the invention may be clearly understood, reference will now be made to the accompanying drawings.

Fig. 1 of the drawings represents, diagrammatically, a typical embodiment of the invention, in which 1 is an intermediate receiver communicating through a stop valve 4 with the pipe 2 leading from the absorber of an absorption refrigerating machine, and also communicating, through a second stop valve 5, with the pipe 3 leading to the still of the machine. The valve 4, in this case, is arranged to close when the pressure in the receiver 1 exceeds that in the pipe 2. Conversely, the valve 5 is arranged to open when the pressure in the receiver 1 exceeds that in the pipe 3, the pressure in which latter is the same as that prevailing in the still, with which it may be in direct communication. The arrangement operates in the following manner:—

Liquid coming from the absorber flows, by way of the pipe 2, through the opened valve 4 into the receiver 1, in which it collects above the closed valve 5. During this period the walls of the receiver may be cooled by means of cooling water. Thereafter the receiver 1 is warmed, and the vapour pressure of the liquid contained therein rises. As a result, the valve 4 closes, and when the vapour pressure has risen to such an extent as to exceed that in the still, the valve 5 opens to permit the liquid to flow from the receiver 1 through the pipe 3 to the still.

It will be evident that, in this case, the liquid is confined between two stop valves, and the arrangement necessarily operates intermittently, inasmuch as an increase in the vapour pressure is produced, from time to time, in the receiver

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This print shows the Specification as it became open to public inspection under Section 91 (3) (a) of the Acts.

PATENT SPECIFICATION

Convention Date (Germany): Jan. 24, 1927. 284,222

Application Date (in United Kingdom): Jan. 24, 1928. No. 2268/28.

Complete not Accepted.

COMPLETE SPECIFICATION.

Refrigerating Machine with Organic Solvent.

We, Professor Dr. ALBERT EINSTEIN, of 5, Haberlandstrasse, Berlin, Germany, and Dr. LEO SZILARD, of 95, Prinzregentenstrasse, Berlin - Wilmersdorf, Germany, both German citizens, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

Among refrigerating machines of the class in which cold is generated direct with the aid of applied heat, the absorption machines occupy the premier position at the present time. In these absorption machines, ammonia and water have hitherto been almost exclusively employed, the water forming the absorbent, and the ammonia the refrigerating medium; but it has also been proposed to employ sulphuric acid as the absorbent and water as the refrigerating medium. In all the known or proposed refrigerating machines wherein the vapour of the refrigerating medium is taken up by a second liquid absorbent medium, a special chemical affinity has existed between the refrigerating medium and the absorbent. The chemical combination between these two is responsible for the fact that the partial pressure of the refrigerating medium situated above the dilute solution in the absorbent medium is considerably reduced, on which account the phenomenon may also be regarded as one of absorption, and not merely solution, of the refrigerating medium in the absorbent.

In fig. 1 of the accompanying drawing, the concentration of the ammonia in the aqueous solution is plotted as abscissas, in terms of Mol. %. The ordinates of the plotted curve denote the partial pressure of the ammonia above the aqueous solutions, at 20° C. The straight, broken line indicates what the partial pressure of the ammonia would be if the same were approximately proportional to the Mol. % concentration. As can be seen, so long as dilute solutions are in question, the partial pressure of the ammonia is enormously reduced by the water; and this is the reason why pure water so avidly absorbs ammonia under these conditions.

The cause of the enormous lowering of the vapour pressure in the ammonia-water system is the chemical fixation of the ammonia in the dilute aqueous solution. Similarly, the chemical fixation of the water by the concentrated sulphuric acid is the cause of the avid absorption of the water by such concentrated acid. Evidence of the occurrent chemical reaction is also afforded by the heat disengaged when the two liquids in question are mixed together. Ammonia and sulphuric acid are, in themselves, chemically active compounds, a fact which makes itself unpleasantly apparent in that the materials of the plant are corroded by both substances, unless special care be devoted to the selection of the materials with which the liquid comes into contact.

The present invention provides a refrigerating machine in which—in contrast to existing machines of this kind—a liquid inert in itself is employed as the solvent medium in the absorber.

The vapour of a refrigerating medium is dissolved by the organic liquid in the absorber, without the existence of any special chemical affinity between the refrigerating medium and the solvent being necessary; and still less will chemical reaction take place between refrigerating medium and solvent, since, owing to the sluggish manner in which the reactions of the organic liquids proceed, such reaction is out of the question in the short time available. It is even preferable to employ, as solvent and refrigerating medium, homonegeous liquids, that is to say, liquids which are certain not to enter into mutual reaction—for example, methyl alcohol and octyl alcohol. The more readily volatile methyl alcohol forms the refrigerating medium, and the less readily volatile octyl alcohol the solvent.

Fig. 2 is approximately typical of the

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NOTE.—*The application for a Patent has become void. This print shows the Specification as it became open to public inspection under Section 91 (3) (a) of the Acts.*

PATENT SPECIFICATION

Convention Date (Germany): Oct. 17, 1927. **298,950**

Application Date (in United Kingdom): Oct. 16, 1928. No. 29,915/28.

Complete not Accepted.

COMPLETE SPECIFICATION.

Improvements in or relating to Electric Condensers.

Dr. LEO SZILARD, of 95, Prinzregentenstrasse, Berlin-Wilmersdorf, Germany, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to a condenser such as is frequently used for instance for weak currents as block condensers etc. and in which, as is now usual for condensers for low voltages, thin metallically conducting layers and thin non-metallic layers of solid structure (paper and the like) are arranged alternately. The invention has for its object to lower the alternating current resistance of such condensers, the condenser, or better the condenser set, remaining practically impassable for direct current below a given limit voltage. According to the invention, this lowering of the alternating current resistance of the condenser is effected by making the solid non-metallic layers (for instance paper) situated between the metal coverings or plates, electrolytically conducting, preferably by impregnating the porous or swelling intermediate layer with a suitable salt solution. The thickness of such intermediate layers such as are used at present in condensers for weak currents, is of the order of magnitude of ½ thousandth of a centimeter and even much smaller. Care must be taken therefore in impregnating it, that it should not be softened too much. The choice of the electrolyte is made with due consideration of the nature of the metal which constitutes the plates (preferably tin-foil paper or aluminium foils) and is made in such a manner that a finite decomposition voltage (polarisation voltage) is opposed to the passage of direct current. The lowering of the alternating current resistance is then based partly on the fact that the dielectric constant of the impregnating solution (for instance of water) is large, but partly on the fact that the intermediate layer is a conductor of alternating current. Direct current, in conditions set forth below cannot bring about an electrolytic decomposition of the intermediate layer.

Solid thin electrolytically conducting intermediate layers could also be obtained by oxidising the surface of the metal plates (or converting them into sulphides) and thereupon pressing the metal plates direct on each other; the oxide, if properly prepared, forms then a solid thin electrolytically conducting intermediate layer.

For the impregnation of thin porous or swelling intermediate layers (paper) could be used water, alcohols, nitrobenzol and the like, or solutions in these liquids.

As long as the intermediate layers used are not extraordinarily thin, the conditions are such that the increase of the dielectric constant of the intermediate layer produced by the impregnation of the latter, plays the smaller part, and the electrolytic conductivity of the intermediate layer has the greater share in the lowering of the alternating current resistance. The latter is however generally much higher than would result from the ohmic resistance of the intermediate layers, and is determined in the first place by the polarisation phenomena (polarisation capacity), that is to say, in the case of the exceedingly low alternating voltages which are on the condenser in the most important applications, the passing alternating current is smaller than that which would correspond to the ohmic resistance.

Condensers according to the invention are used either connected in series and combined to a condenser cell, or a construction is used which differs from the ordinary condensers by the arrangement between two metal plates each of which leads to one junction terminal of the cell, of further metal plates (intermediate plates). The direct current would then

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PATENT SPECIFICATION

Convention Date (Germany): July 14, 1927. 293,865.

Application Date (in United Kingdom): July 10, 1928. No. 20,043/28.

Complete Accepted: May 30, 1929.

COMPLETE SPECIFICATION.

Improvements in Refrigerating Processes and Apparatus.

I, LEO SZILARD, formerly of Faradayweg 16, Berlin-Dahlem, but now of Prinz Regentenstrasse, 95, Berlin-Wilmersdorf, Germany, of Hungarian nationality, on my own behalf and as Assignee of ALBERT EINSTEIN, of 5, Haberlandstrasse, Berlin, Germany, of German nationality, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The invention relates to an absorption refrigerating process and apparatus in which in known manner water soluble alcohol, in particular methyl alcohol is vapourised and the water supply used as the energy source. Whereas, however, the alcohol vapour has hitherto been drawn direct out of the evaporator into a water jet pump, according to the present invention, the vapours are dissolved in a suitable vessel (absorber) and the solution removed from the absorber and the whole apparatus against atmospheric pressure by a water jet pump. The water from the water supply is first led through this absorber and so distributed that it forms a large surface and can absorb the greater part of the vapours drawn off from the evaporator. There reaches the water jet pump therefore, not pure water and vapour as hitherto, but water in which alcohol vapour is dissolved. The air reaching the absorber from the evaporator can be drawn off by another water jet pump.

The refrigerant is advantageously fed into the evaporator from a container through a pipe by the air of the outer air pressure.

The accompanying drawing shows diagrammatically an example of apparatus embodying the invention. 1 is the absorber, 2 the evaporator of the refrigerator. The refrigerant is stored in a reservoir 3 from which the refrigerant rises through a pipe 4 into the evaporator 2 under the action of atmospheric pressure. From thence the vapours of the refrigerant are sucked into the absorber 1 through a pipe 5, and the aqueous solution flows out of the absorber through a pipe 6 to a water jet pump 7 located below. A second water jet pump 8, which in some circumstances may be omitted, continuously sucks a mixture of vapour and air out of the absorber. The amount of vapour sucked out in this way is clearly very small in comparison with the quantity of vapour dissolved in the water. In operation the water enters the absorber through a pipe 9 under the action of atmospheric pressure. An intermediate container 10 may be provided, which is connected to the water jet pump 8 through a pipe 11, and in which the water is relieved of air before entry to the absorber. The container 12 is continuously supplied with water from the mains. For preparing iced foods and the like the vaporiser is surrounded by a container 13 and to stir the cooled materials, a water turbine 14 is set in action. 15 is a cooling jacket which surrounds the absorber and which in most cases can be dispensed with.

Finally it may be mentioned that an absorbing chamber has already been used in refrigerating apparatus in which water vapour is absorbed by sulphuric acid, but in such cases the acid is circulated within the apparatus and not completely removed as is here the case.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. A refrigerating process wherein alcohol, in particular methyl alcohol, is vaporised, characterised by the vapours being dissolved in water in a suitable vessel (absorber) and the solution removed from the absorber and the whole refrigerating apparatus against atmospheric pressure by a water jet pump supplied from the mains.

2. An absorption refrigerating apparatus for carrying out the process of claim 1, in which a large vessel (the absorber) is provided between the evaporator and the water jet pump, through which absorber the water flows and is distributed over as large a surface as possible.

3. An absorption refrigerating appara-

[Price 1/-]

650 wds
1 sheet

PATENT SPECIFICATION

Convention Date (Germany): Oct. 31, 1927. 299,783

Application Date (in United Kingdom): Oct. 29, 1928. No. 31,364/28.

Complete Accepted: Jan. 23, 1930.

COMPLETE SPECIFICATION.

Improvements in and relating to Refrigerating Machines.

I, Dr. Leo Szilard, of 95, Prinz Regentenstrasse, Berlin-Wilmersdorf, Germany, of Hungarian Nationality, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The present invention relates to refrigerating machines, in which the heat must be carried away when the temperature rises above the temperature in the cooling chamber, as is the case for example, in refrigerating machines in which a liquid cooling medium is evaporated, compressed in any suitable manner and reliquefied in a condenser. The heat that is generated in the condenser during the process of liquefaction must then be carried away. In many cases this is effected by cooling with air.

According to the invention the condensing process can be confined to a period of one to two hours, even when the cooling in the condenser is not intense; in absorption machines the boiling period is thereby reduced, and in motor driven machines the heat corresponding to a sufficient production of cold for the whole day is dissipated in a short time. According to the invention, in a refrigerating machine in which heat is liberated during the intermittent condensation of the vapour of the cooling medium, at least a part of the heat evolved is transmitted to a solid substance surrounding the condenser, which substance is caused to melt and in this way to absorb the heat during the operative period in question. During the remainder of the time the substance cools slowly and again solidifies, giving up the heat that it has absorbed.

The invention is diagrammatically illustrated by way of example in the accompanying drawing.

In the drawing, 1 is the evaporator; the vapours are drawn off through the tube 2, compressed by the apparatus 3 and conveyed through the tube 4 into the condenser 5. The condenser 5 is disposed in the vessel 6, in which a solid substance —for example, phenol, or a mixture of phenol with other chemicals that lower the melting point of phenol— surrounds the condenser. The vessel 6 is provided with cooling ribs. If the device 3 is a compressor, it is easily possible in one to two hours to convert such a quantity of vapour, that the cold obtained which suffices for the whole day, is produced during this period. During this time the solid substance in the vessel 6 undergoes a change in its state and will absorb the heat which is liberated during condensation. If then the compressor is stopped after one to two hours, the vessel 6 gradually delivers up its heat to the air, the solid substance being regenerated. By this means not only can a fairly large quantity of ice be prepared immediately the machine is connected up, but the wear on the machine is reduced, because it is only necessary to keep the machine working for a short period each day.

If a periodically operating absorption device is employed, in place of the device 3, the so-called boiling period can be limited to a short time, during which a relatively large quantity of cold liquid collects in the evaporator 1 and during the whole day, drawn in by the absorber, produces the cold. Thus the cold is not produced here in a short working period but is spread over the whole day which is unlike the case which is referred to above and in which the device 3 represents a compressor.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. A refrigerating machine in which, during the intermittent condensation of the vapour of the cooling medium, heat is liberated, characterised in that at least a part of the heat liberated is transmitted to a solid substance surrounding the condenser which substance is thus melted and so absorbs the heat in order to deliver the heat up during a lengthy period, during which it re-solidifies.

2. A refrigerating process carried out in the manner and substantially as hereinbefore described.

Dated this 29th day of October, 1928.
EDWARD EVANS & Co.,
27, Chancery Lane, London, W.C. 2,
Agents for the Applicant.

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PATENT SPECIFICATION

Convention Date (Germany): Dec. 27, 1927. 303,065

Application Date (in United Kingdom): Dec. 24, 1928. No. 38,091/28.

Complete Accepted: May 26, 1930.

COMPLETE SPECIFICATION.

Electrodynamic Movement of Fluid Metals particularly for Refrigerating Machines.

We, Prof. ALBERT EINSTEIN, of Swiss Nationality, of 5, Haberlanderstrasse, Berlin, Germany, and Dr. LEO SZILARD, of Hungarian Nationality, of 95, Prinzregentenstrasse, Berlin-Wilmersdorf, Germany, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to apparatus in which fluid metal moves forward under the influence of a magnetic field on the liquid through which electric current is passing, more particularly in which fluid metal is pumped from a chamber that is under low pressure into a chamber under higher pressure. Such apparatus can be employed for pouring molten metal into a mould or it may be used in refrigerating machines for feeding mercury or other liquid metals to the device. If the electric current is not passed into the liquid through electrodes but is induced in it in such manner that the stream lines of the electric current are wholly in the liquid and form closed lines therein, difficulties are avoided that are inherent in the transmission resistance between electrode and liquid, but generally a field of ponderomotive force is created in the liquid which is not free from eddies. If this field of force in the fluid metal is not free from eddies, there is a great loss of energy owing to useless agitation of the liquid.

The invention relates to apparatus in which the field of ponderomotive force is free from eddies within the liquid; according to the invention the field of ponderomotive force, which acts upon the liquid, results from a magnetic field of which the lines of force cut or cross an annular chamber through which the liquid stream is caused to flow, the magnetic field being produced by at least two or more coils energized by electric current.

Figure 1 of the accompanying drawings illustrates diagrammatically a form of apparatus according to the invention, by way of example.

An iron core 2 is inserted into an iron cylinder 1. Mercury flows in the cylindrical annular chamber between the iron core and the tube 1, under the influence of the magnetic fields produced by the windings 4, 5, 6 and 7, in the direction of the longitudinal axis of the cylinder, and, if the polarity be suitably chosen, from top to bottom. The windings 4 to 7 surround the tube 1. The currents which flow in the adjacent windings are about 90° out of phase relatively to each other, while on the other hand the windings 4 and 6—likewise the windings 5 and 7—may be connected up in series. 8 and 9 are sheet iron plates shown in laminated form on the section line A—B. When the polarity is correctly chosen, the magnetic field in the mercury in the cylindrical annular chamber is moved from top to bottom; the rate of change of the magnetic field is obtained by multiplying the frequency by the identity distance apart of the windings. In the mercury an electric current is induced which circulates around the iron core 2. Such a line of force is shown in this figure of the drawings. The ponderomotive force that influences the mercury is at all points parallel to the axis of the cylinder, and the ponderomotive field is practically free from eddies.

A 90° displacement of phase between the currents in adjacent windings is produced in known manner as has been proposed for the production of the artificial phase for asynchronous motors.

Figure 2 illustrates diagrammatically a refrigerating machine according to the invention in which 10 is a device for causing mercury to move by electro-dynamic means. The mercury is forced into the tube 11 and fed to the mercury jet pump 12. The vapour of a cooling agent (for example, methyl alcohol or a suitable hydrocarbon) is drawn off through the pipe 13, compressed in a vertically extending pipe, and forced into the vapour separating chamber 15. The mercury passes out of this chamber, through the downwardly directed pipe 16, and back into the device 10, while the vapour of the cooling agent flows through the pipe 19 into the air-cooled condenser 17, where

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PATENT SPECIFICATION

Convention Date (Germany): Dec. 3, 1928.

344,881

Application Date (in United Kingdom): Dec. 3, 1929. No. 37,004/29.

Complete Accepted: March 3, 1931.

COMPLETE SPECIFICATION.

Pump, especially for Refrigerating Machines.

We, Prof. Dr. ALBERT EINSTEIN, of 5, Haberlandstrasse, Berlin, Germany, of Swiss Nationality, and Dr. LEO SZILARD, of 35, Prinz Regentenstrasse, Berlin-Wilmersdorf, Germany, of Hungarian Nationality, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The invention relates to a pump operating with a liquid medium and by means of which liquids, gases or vapours can be circulated or compressed, preferably in hermetically closed apparatus, especially refrigerating machines. The pumping with the aid of the operative liquid can be performed in any known manner, for example, in a jet pump.

According to the invention, such a pump is rendered highly efficient by employing as operative liquid an alkali metal in a liquid condition—for example, potassium—or a liquid alloy of an alkali metal. The transmission of energy to the operative liquid can be effected by electromagnetic means, without any solid moving machine parts, but nevertheless with a very good efficiency cycle, by allowing a magnetic field to act on the liquid metal while it is traversed by electric current. The high working efficiency is due, on the one hand, to the high electrical conductivity, and on the other hand, to the low density. Force is exerted on the liquid metal in a comparatively narrow space, where the flow is turbulent and when, in consequence, a considerable loss would occur, through friction, if mercury, for example, were employed as the operative medium.

In this sense the metals of small density are distinguished in comparison with mercury. If pumping be performed with such metals in a jet pump or similar apparatus, a far higher working efficiency—both in the absolute and with reference to the dimensions of the apparatus—is obtained than in the case of mercury, because, under the same conditions of pressure, far higher velocities are attained in the case of metals the density of which is small.

Another important point is the low vapour pressure of the alkali metals, which ensures that the operative medium will not distil over into the parts of the apparatus where it might give rise to trouble.

The alkali metals, when pure, are not liquid at room temperature, so that, when they are used in a pure state, the apparatus must be kept at a higher temperature, a condition which also restricts the condensation of vapours of the metals in the pump itself in a desirable manner. Moreover, according to the invention use may also be made of alloys of alkali metals with one another, for example, a sodium-potassium alloy.

According to the invention, use may also be made in particular of a potassium-sodium alloy which, when compounded with the two components in suitable proportions, remains liquid down to -12° C. This alloy does not solidify, even at the temperature obtaining in the evaporator of the refrigerating machine.

By subjecting the liquid metal to a magnetic field which induces electric currents in the metal itself, energy can be transmitted, in a very complete manner, to the liquid metal contained in a hermetically closed apparatus (such as a refrigerating machine), by means of coils disposed outside the apparatus; and, by this means, the liquid metal can be pumped without the use of any moving machine parts.

When direct current is employed, it must, of course, be introduced into the liquid metal by means of electrodes.

In order to avoid having to employ too many ampere windings, the arrangement must be so devised that the major portion of the lines of magnetic force passes through iron, and only permeates the liquid metal over a very narrow space; that is, the liquid metal will be subjected to the ponderomotive force only in a gap of very narrow width. Since the one dimension of the space is small by comparison with its other dimensions, in the part where the ponderomotive action on the liquid metal takes place, one may simplify the matter by saying that the metal travels over a superficies, and con-

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PATENT SPECIFICATION

Application Date: March 12, 1934. No. 7840/34.
" " July 4, 1934. No. 33540/35.
(No. 33540/35 being divided out of Application No. 19721/34.)
Application Date: Sept. 20, 1934. No. 27050/34.
One Complete Specification Left: April 9, 1935.
(Under Section 16 of the Patents and Designs Acts, 1907 to 1932.)
Specification Accepted: Dec. 12, 1935.

440,023

PROVISIONAL SPECIFICATION
No. 7840 A.D. 1934.

Improvements in or relating to the Transmutation of Chemical Elements

I, LEO SZILARD, a citizen of Germany and Hungary, c/o Claremont Haynes & Co., Vernon House, Bloomsbury, Square, London, W.C.1, do hereby declare the nature of this invention to be as follows:—

It has been demonstrated that if atoms or nuclei, e.g. hydrogen atoms (or protons), heavy hydrogen atoms, referred to from now onwards as diplogen, (or diplogen ions, referred to from now onwards as diplons) etc. are shot at chemical elements, a definite fraction of these shooting particles will cause transmutation in many elements. (How large this fraction is will depend on the nature of the element, the nature of the shooting particle, and its velocity.) If one uses the above mentioned particles and shoots them on light or heavy hydrogen lithium (6) or lithium (7) or other elements a certain proportion of the particles lose their energy through ionizing the substance through which they are shot, and only a fraction of the shooting particles will meet a nucleus of the substance before losing so much energy that the shooting particle is unable to cause transmutation in nuclei which it meets. Of these particles which meet a nucleus in their path (while still being in possession of a sufficiently large fraction of their initial energy) again only a further fraction will be able to penetrate the nucleus, (will be able to cause a transmutation); if the shooting particles are positively charged they are repulsed by the positively charged nucleus, and the probability of their penetrating the nucleus is a function of their relative velocity.

This probability rises rapidly with increasing velocity of the shooting particle and eventually reaches unity at a velocity which depends both on the nature of the shooting particle and the nature of the bombarded element.

However, even if this probability is equal to unity one still has to face the fact that a shooting particle has to travel for instance in air a large distance in order to encounter a nuclear collision (which may cause transmutation), but due to the energy loss which it suffers through ionizing the air its range is comparatively small if its initial velocity corresponds to several million volts energy. Only a fraction of the above mentioned shooting particles can therefore produce transmutation if shot into air or other substances or similar characteristics concerning ionization losses and nuclear collisions.

In accordance with the present invention radio-active bodies are generated by bombarding suitable elements with neutrons, which can be produced in various ways.

In accordance with one feature of the present invention nuclear transmutation leading to the liberation of neutrons and of energy may be brought about by heating up a small area filled with suitable elements very suddenly to high temperature by means of an electric discharge.

RADIO ACTIVE SUBSTANCES.

It is possible to produce elements capable of spontaneous transmutation by bombarding certain elements with fast charged nuclei, for instance by bombarding carbon with protons or aluminium, boron and magnesium with helium ions (particles). However, most of the radio active elements produced by the bombardment of these light elements with protons or alpha particles have a short existence (they disintegrate spontaneously in a time shorter than a few hours to half their amount), and it is not possible to use these charged nuclei for the transmutation of the heavier elements with good efficiency as the ionization loss gets too large. It is, however, possible to produce with good efficiency (both from lighter and heavier elements) radio active sub-

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PATENT SPECIFICATION

630,726

Application Date: June 28, 1934. No. 19157/34.
" " July 4, 1934. No. 19721/34.

One Complete Specification left (under Section 16 of the Patents and Designs Acts, 1907 to 1946): April 9, 1935.

Specification Accepted: March 30, 1936 (but withheld from publication under Section 30 of the Patent and Designs Acts 1907 to 1932)

Date of Publication: Sept. 28, 1949.

Index at acceptance: —Class 39(iv), P(1:2:3x).

PROVISIONAL SPECIFICATION
No. 19157 A.D. 1934.

Improvements in or relating to the Transmutation of Chemical Elements

I, LEO SZILARD, a citizen of Germany and subject of Hungary, c/o Claremont Haynes & Co., of Vernon House, Bloomsbury Square, London, W.C.1, do hereby declare the nature of this invention to be as follows:—

This invention has for its object the production of radio active bodies the storage of energy through the production of such bodies and the liberation of nuclear energy for power production and other purposes through nuclear transmutation.

In accordance with the present invention nuclear transmutation leading to the liberation of neutrons and of energy may be brought about by maintaining a chain reaction in which particles which carry no positive charge and the mass of which is approximately equal to the proton mass or a multiple thereof form the links of the chain.

I shall call such particles in this specification "efficient particles."

A way of bringing about efficiently transmutation processes is to build up transmutation areas choosing the composition and the bulk of the material so as to make chain reactions efficient and possible, the links of the chain being "efficient particles."

One example is the following. The chain transmutation contains an element C, and this element is so chosen that an efficient particle x when reacting with C may produce an efficient particle y, and the efficient particle y when reacting with C may produce either an efficient particle x or another efficient particle which in its turn is directly or indirectly when reacting with C capable of producing x. The bulk of the transmutation area, on the other hand, must be such that the linear dimensions of the area should sufficiently exceed the mean free path between two successive transmutations within the chain. For long chains composed of, say, 100 links the linear dimensions must be about ten times the mean free path.

I shall call a chain reaction in which two efficient particles of different mass number alternate a "doublet chain." An example for a doublet chain which is a neutron chain would be the following reaction, which might be set up in a mixture of a "neutron reducer element" (like lithium (6) or boron (10) or preferably some heavy "reducer" element), and a "neutron converter element" which yields $n(2)$ when bombarded by $n(1)$. An example for such a chain in which carbon acts as reducer and beryllium acts as converter would be the following:

$$C(12) + n(2) = C(13) + n(1)$$
$$Be(9) + n(1) = \text{"}\ Be(8)\ \text{"} + n(2)$$

("Be(8)" need not mean an existing element, it may break up spontaneously).

One can very much increase the efficiency of the hitherto mentioned neutron chain reactions by having a "neutron multiplicator" O mixed with the elements which take part in the chain reaction. A neutron multiplicator is an element which either splits up $n(2)$ into $n(1) + n(1)$ or an element which yields additional neutrons for instance $n(1)$ when bombarded by $n(1)$. A multiplicator need not be a meta-stable element. Beryllium may be a suitable multiplicator

$$Be(9) + n(1) = \text{"}\ Be(8)\ \text{"} + n(1) + n(1)$$

An efficient particle disappears (and a

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PATENT SPECIFICATION

630,726

Application Date: June 28, 1934. No. 19157/34.
" " July 4, 1934. No. 19721/34.

One Complete Specification left (under Section 16 of the Patents and Designs Acts, 1907 to 1946): April 9, 1935.

Specification Accepted: March 30, 1936 (but withheld from publication under Section 30 of the Patent and Designs Acts 1907 to 1932)

Date of Publication: Sept. 28, 1949.

Index at acceptance: —Class 39(iv), P(1:2:3x).

PROVISIONAL SPECIFICATION
No. 19157 A.D. 1934.

Improvements in or relating to the Transmutation of Chemical Elements

I, LEO SZILARD, a citizen of Germany and subject of Hungary, c/o Claremont Haynes & Co., of Vernon House, Bloomsbury Square, London, W.C.1, do hereby declare the nature of this invention to be as follows:—

This invention has for its object the production of radio active bodies the storage of energy through the production of such bodies and the liberation of nuclear energy for power production and other purposes through nuclear transmutation.

In accordance with the present invention nuclear transmutation leading to the liberation of neutrons and of energy may be brought about by maintaining a chain reaction in which particles which carry no positive charge and the mass of which is approximately equal to the proton mass or a multiple thereof form the links of the chain.

I shall call such particles in this specification " efficient particles."

A way of bringing about efficiently transmutation processes is to build up transmutation areas choosing the composition and the bulk of the material so as to make chain reactions efficient and possible, the links of the chain being " efficient particles."

One example is the following. The chain transmutation contains an element C, and this element is so chosen that an efficient particle x when reacting with C may produce an efficient particle y, and the efficient particle y when reacting with C may produce either an efficient particle x or another efficient particle which in its turn is directly or indirectly when reacting with C capable of producing x. The bulk of the transmutation area, on the other hand, must be such that the linear dimensions of the area should sufficiently exceed the mean free path between two successive transmutations within the chain. For long chains composed of, say, 100 links the linear dimensions must be about ten times the mean free path.

I shall call a chain reaction in which two efficient particles of different mass number alternate a " doublet chain." An example for a doublet chain which is a neutron chain would be the following reaction, which might be set up in a mixture of a " neutron reducer element " (like lithium (6) or boron (10) or preferably some heavy " reducer " element), and a " neutron converter element " which yields $n(2)$ when bombarded by $n(1)$. An example for such a chain in which carbon acts as reducer and beryllium acts as converter would be the following:

$$C(12) + n(2) = C(13) + n(1)$$
$$Be(9) + n(1) = \text{“ Be(8) ”} + n(2)$$

(" Be(8) " need not mean an existing element, it may break up spontaneously).

One can very much increase the efficiency of the hitherto mentioned neutron chain reactions by having a " neutron multiplicator " O mixed with the elements which take part in the chain reaction. A neutron multiplicator is an element which either splits up $n(2)$ into $n(1) + n(1)$ or an element which yields additional neutrons for instance $n(1)$ when bombarded by $n(1)$. A multiplicator need not be a meta-stable element. Beryllium may be a suitable multiplicator

$$Be(9) + n(1) = \text{“ Be(8) ”} + n(1) + n(1)$$

An efficient particle disappears (and a

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PATENT SPECIFICATION

817,571

Date of Application and filing Complete Specification: May 10, 1945.
No. 11801/45.
Application made in United States of America on May 8, 1944.
Complete Specification Published: Aug. 6, 1959.
(Under Section 6(1) (a) of the Patents &c. (Emergency) Act, 1939 the proviso to Section 91 (4) of the Patents and Designs Acts, 1907 to 1942 became operative on April 4, 1957.)

Index at acceptance:—Class 39(4), C4B2, P2.
International Classification:—G21.

COMPLETE SPECIFICATION

Means for Testing Materials

We, UNITED KINGDOM ATOMIC ENERGY AUTHORITY, of London, a British Authority, do hereby declare the nature of this invention, and in what manner the same is to be performed, to be particularly described in and by the following statement:—

The present invention relates generally to the subject of nuclear physics and more particularly to means for determining neutron absorption in graphite, or other neutron slowing material.

An artificial source of neutrons is employed, and these neutrons are emitted into a mass of neutron slowing material or moderator. The neutrons thus emitted are fast neutrons and are slowed down in the slowing medium by a diffusion process during which the neutrons collide many times with nuclei of the medium, resulting in the loss of energy until the neutrons are finally slowed to thermal energy. Neutrons which have reached thermal energy continue to diffuse through the moderator, but without further loss of energy until they are finally absorbed in the moderator or in some other element present as an impurity in the moderator. The length of the path of the thermal neutrons during diffusion depends upon the absorption characteristics of the particular mass of slowing material employed due to the various amounts of impurities in different kinds of moderators. The present invention has to do primarily with the absorption of neutrons that have reached thermal energy, and more particularly provides a method for comparing the absorption of these thermal neutrons in different grades of graphite.

According to the invention means for determining neutron absorption of a neutron slowing down medium comprising a regularly shaped mass of the slowing down medium, a source of neutrons in the said mass, an efficient thermal neutron absorber at least partially surrounding the mass substantially to prevent the escape from and entrance into the mass of thermal neutrons, the said mass being provided with means for selectively placing a neutron detector at positions in the mass at predetermined distances from the neutron source, a portion of the absorber being removable so that comparative reading may be made with and without the removable portion.

The source of neutrons may be backed with a neutron scattering material. The source may be backed with a neutron reflector which is preferably of graphite.

The means may be backed by means reflecting neutrons from the source into the mass.

The following are ways of carrying the invention into effect, reference being made to the accompanying drawings in which:

Fig. 1 is a front elevational view of a graphite column covered on five sides with cadmium;

Fig. 2 is a top plan view of the column shown in Fig. 1;

Fig. 3 is a vertical sectional view taken on the line 3—3 of Fig. 1, showing in broken lines the cadmium sheet partially removed from the upper face of the graphite;

Fig. 4 is a horizontal section view taken on the line 4—4 of Fig. 3;

Fig. 5 is a front elevational view of a second embodiment of the present invention wherein the graphite is arranged in the form of a sphere surrounded by a cadmium absorber and by a water or paraffin shield; and

Fig. 6 is a horizontal sectional view taken on the line 6—6 of Fig. 5.

For purposes of the formulae hereinafter set forth, the following symbols are defined:

n_1 is the density of thermal neutrons without cadmium;
n_2 is the density of thermal neutrons with cadmium in place;
n is the difference $n_1—n_2$;
λ is the mean free path for scattering of thermal neutrons by carbon;

[*Price 3s. 6d.*]

Price 4s 6d

817,751

PATENT SPECIFICATION

817,751

Date of Application and filing Complete Specification: Feb. 1, 1945.
No. 2617/45.
Application made in United States of America on Dec. 19, 1944.
Complete Specification Published: Aug. 6, 1959.
(Under Section 6 (1) (a) of the Patents &c. (Emergency) Act, 1939 the proviso to Section 91 (4) of the Patents and Designs Acts, 1907 to 1946 became operative on April 4, 1957.

Index at acceptance:—Classes 1(3), A1(D28:G36D28); **39(4),** C1(A:B), C2(A2:B1:B2:C1:C2:F:H:J), C3(C:E:F), C4(A1:A2:B2), C5C, Q; **82(1),** I4A(2:3X:4C); **82(2),** E3; **and 83(2),** A187.

International Classification:—B23p. C01g. C22b. C23g. G21.

COMPLETE SPECIFICATION

Nuclear Chain Reactions

We, UNITED KINGDOM ATOMIC ENERGY AUTHORITY, of London, a British Authority, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The present invention relates to the general subject of nuclear fission and particularly to the establishment of self-sustaining neutron chain fission reactions in systems embodying uranium having a natural isotopic content.

Experiments by Hahn and Strassman, the results of which were published in January 1939, in *Nature,* led to the conclusion that nuclear bombardment of natural uranium by slow neutrons causes explosion or fission of the nucleus, which splits into particles of smaller charge and mass with energy being released in the process. Later it was found that neutrons were emitted during the process and that the fission was principally confined to the uranium isotope U^{235} present as 1/139th part of the natural uranium.

When it became known that the isotope U^{235} in natural uranium could be split or fissioned by bombardment with thermal neutrons, i.e., neutrons at or near thermal equilibrium with the surrounding medium, many predictions were made as to the possibility of obtaining a self-sustaining chain reacting system operating at high neutron densities. In such a system, the fission neutrons produced give rise to new fission neutrons in sufficiently large numbers to overcome the neutron losses in the system. Since the result of the fission of the uranium nucleus is the production of two lighter elements with great kinetic energy, plus approximately 2 fast neutrons on the average for each fission along with beta and gamma radiation, a large amount of power could be made available if a self-sustaining system could be built.

The invention consists in a nuclear reactor comprising uranium bodies spaced apart in a neutron moderator, the bodies being of sufficient size to reduce resonance losses by an amount sufficient to yield a neutron reproduction constant of greater than unity, the neutron loss by impurities and the neutron loss by leakage from the interior of the reactor being insufficient to reduce the reproduction ratio of the reactor to unity.

The neutron moderator may be graphite or heavy or light water, the latter being used with uranium enriched in fissile isotopes, and the uranium bodies may be in the form of rods and may be of uranium metal or a uranium oxide.

To control the reactor a neutron absorbing control rod is provided.

In order to attain such a self-sustaining chain reaction in a system of practical size, the ratio of the number of neutrons produced in one generation by the fissions, to the original number of neutrons initiating the fissions, must be known to be greater than unity after all neutron losses are deducted, and this ratio is, of course, dependent upon the values of the pertinent constants.

In the co-pending application of Enrico Fermi, numbered 11190/45 (Serial No. 817,752) and entitled "Nuclear Chain Reacting Systems," there is described and claimed a means and method of determining the neutron reproduction ratio for any type of uranium containing structure, directly as a result of a simple measurement which can be performed with precision. Accurate values for all of the pertinent nuclear constants need not be known.

We have discovered certain essential principles required for the successful construction and operation of self-sustaining neutron chain reacting systems (known as nuclear reactors) with the production of power in the form of

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13,000 wds
7 sheets

PATENT SPECIFICATION

DRAWINGS ATTACHED

825,521

Date of Application and filing Complete Specification May 22, 1946.
No. 15575/46.
Application made in United States of America on May 29, 1945.
Complete Specification Published Dec. 16, 1959.
(Under Section 12 of the Atomic Energy Act, 1946 the proviso to Section 91 (4) of the Patents and Designs Acts, 1907 to 1946 became operative on April 14, 1958).

Index at acceptance: —Class 39(4), C(1A: 2A2: 2B1: 2B3A: 2C1: 2D: 3A: 3D: 3E: 3F: 4A1: 4B2: 4B3), Q.

International Classification: —G21.

COMPLETE SPECIFICATION

Gas-Cooled Nuclear Reactor

We, UNITED KINGDOM ATOMIC ENERGY AUTHORITY, of London, a British Authority, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The present invention relates to a nuclear chain reacting system which is capable of numerous uses but is particularly adapted to use for the production of the transuranic element 94^{239} and/or radioactive fission products by neutrons released during a self-sustaining nuclear chain reaction through fission of uranium with slow neutrons. More particularly, the invention relates to the removal of the heat of the nuclear reaction to such an extent that the reaction may be conducted at a more rapid rate and the production of element 94^{239} and/or fission products may be accelerated. Natural uranium may be used in the reaction and contains the isotopes 92^{238} and 92^{235} in the ratio of approximately 139 to 1. Hereinafter in the specification and the claims the term uranium is to be understood as referring to uranium and its chemical compositions of normal isotopic content or equivalent compositions, unless otherwise indicated by the context.

The invention consists in a nuclear chain reacting system comprising a nuclear reactor and means for conducting a gas through the reactor.

The system comprises a mass of neutron moderator having horizontal channels therein, uranium masses in the channels and means for moving a gas through the channels over the uranium masses.

The uranium masses are sufficiently smaller in diameter than the channels to allow passage of gas therethrough.

The uranium masses are preferably spaced along the channels.

The channels preferably extend from one face of the moderator to an opposite face of the moderator.

When it became known that the isotope U^{235} in natural uranium could be split or fissioned by bombardment with thermal neutrons, i.e., neutrons at or near thermal equilibrium with the surrounding medium, many predictions were made as to the possibility of obtaining a self-sustaining chain reacting system operating at high neutron densities. In such a system, the fission neutrons produced give rise to new fission neutrons in sufficiently large numbers to overcome the neutron losses in the system. Since the result of the fission of the uranium nucleus is the production of two lighter elements with great kinetic energy, plus approximately 2 fast neutrons on the average for each fission along with beta and gamma radiation, a large amount of power can be made available in a self-sustaining system.

It has been found that most of the neutrons arising from the fission process are set free with the very high energy of the order of one million electron volts and are therefore not immediately in condition to be utilized efficiently to create new thermal neutron fissions in U^{235} when it is mixed with a considerable quantity of U^{238}, as is the case with natural uranium. The energies of the fission-released neutrons are so high that most of the latter would tend to be absorbed by the U^{238} nuclei, and yet the energies are not generally high enough for production of fission by more than a small fraction of the neutrons so absorbed. For neutrons of thermal energies, however, the absorption cross section of U^{235}, to produce fission, is a great deal more than the simple capture cross section of U^{238}; so that under the stated circumstances the fast fission neutrons, after they are created, must be slowed down to thermal energies before they are most effective to pro-

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Price 4s 6d

Dear Mrs. Szilard: P 12

The following is a complete list of all of the patents in the United States which list your husband either as a sole inventor or as a co-inventor:

(16)

Inventor(s)	Patent No.	Issued	Title
Szilard	1,697,210	Jan. 1, 1929	Discharge Tube
✓Szilard	1,715,874	June 4, 1929	Discharge Tube
Einstein et al.	1,781,541	Nov.11, 1930	Refrigeration
Szilard	2,161,985	June 13, 1939	Process of Producing Radio-active Elements
✓ Fermi et al.	2,708,656	May 17, 1955	Neutronic Reactor
Szilard	2,778,792	Jan. 22, 1957	Method for Unloading Reactors
Szilard	2,796,396	June 18, 1957	Method of Intermittently Operating a Neutronic Reactor
✓ Fermi et al.	2,798.847	July 9, 1957	Method of Operating a Neutronic Reactor

- have

p. 12

Fermi et al.	2,807,581	Sept. 24,1957	Neutronic Reactor
Szilard et al.	2,825,686	March 4,1958	Neutronic Reactor and Fuel Element Therefor
✓ Szilard	2,832,733	April 29,1958	Heavy Water Moderated Neutronic Reactor
Fermi et al.	2,836,554	May 27, 1958	Air Cooled Neutronic Reactor
✓ Wigner et al.	2,872,401	Feb. 3, 1959	Jacketed Fuel Element
✓ Szilard et al.	2,886,503	May 12, 1959	Jacketed Fuel Elements for Graphite Moderated Reactors
Wigner et al.	2,986,510	May 30, 1961	Massive Leakage Irradiator
✓ Szilard	3,103,475	Sept.10, 1963	Reactor

Patented Nov. 11, 1930

1,781,541

UNITED STATES PATENT OFFICE

ALBERT EINSTEIN, OF BERLIN, AND LEO SZILARD, OF BERLIN-WILMERSDORF, GERMANY, ASSIGNORS TO ELECTROLUX SERVEL CORPORATION, OF NEW YORK, N. Y., A CORPORATION OF DELAWARE

REFRIGERATION

Application filed December 16, 1927, Serial No. 240,566, and in Germany December 16, 1926.

Our invention relates to the art of refrigeration and particularly to an apparatus and method for producing refrigeration wherein the refrigerant evaporates in the presence of an inert gas and more particularly to the type disclosed in Patent No. 1,685,764 granted September 25th, 1928, to Von Platen and Munters and our British Patent No. 282,428.

The objects and advantages of our invention will be apparent from the following description considered in connection with the accompanying drawing which shows, more or less diagrammatically, a preferred embodiment of our invention.

Referring to the drawing, reference character 1 designates an evaporator, which is ordinarily placed within a chamber to be cooled. A conduit 5 connects the upper part of evaporator 1 with the more intermediate portion of the condenser 6. A conduit 11 communicates with the bottom of evaporator 1 and extends within condenser 6 at a level below the point of communication of conduit 5 with the condenser. A cooling water jacket 12 surrounds the condenser and is adapted for the passage therethrough of water for the purpose of cooling the condenser.

A conduit 27 communicates with the bottom of condenser 6 and with the lower part of a heat exchanger jacket 28. The upper part of jacket 28 is connected to the lower part of generator 29. Generator 29 is heated in any suitable manner. A conduit 30 communicates with the upper part of generator 29 and extends within evaporator 1 to a point near the bottom thereof where it terminates in a distributor head 31. Conduit 30 extends within conduit 5 in order that the fluids passing through the respective conduits may be brought into heat exchange relationship with each other.

A conduit 32 extends upwardly from within the lower part of generator 29 and communicates with a container 33 placed at a level above that of condenser 6. A source of heat 36 is provided for heating conduit 32 at a point above generator 29. A conduit 37 extends downwardly from container 33 and passes within heat exchanger jacket 28 and thence upwardly to within the upper part of condenser 6 where it terminates in a distributor head 35. Conduit 37 passes within cooling water jacket 12 in order that fluid passing through this conduit may be cooled. A vent conduit 34 connects the upper part of container 33 with the upper part of condenser 6.

The operation of the above described apparatus is as follows:

A suitable refrigerant; for instance butane, in liquid form is contained within evaporator 1. An inert gas, for instance ammonia, is introduced into evaporator 1 through conduit 30 and distributor head 31. The refrigerant evaporates in the evaporator in the presence of the inert gas due to the fact that the partial pressure of the refrigerant is reduced thereby and the resulting gaseous mixture passes through conduit 5 to within condenser 6. Here the mixture comes in intimate contact with an absorption liquid, for example water, which is introduced into the condenser through conduit 37 and distributor head 35. Inasmuch as the ammonia gas is very soluble in water, while the butane is quite insoluble, the ammonia gas is absorbed by the water, thus freeing the butane from the gaseous mixture. Thus the butane assumes substantially the entire pressure within the condenser, which pressure is sufficient to cause its liquefaction at the temperature maintained therein by the cooling water.

The specific gravity of liquid butane is less than that of the solution of ammonia in water and hence stratification of the two liquids occurs, the liquid butane floating upon the ammonia solution. The latter solution is indicated by reference character 26. The liquid butane passes from condenser 6 through conduit 11 and returns to evaporator 1, where it is again evaporated and the cycle repeated.

The ammonia solution flows by gravity from condenser 6 through conduit 27 and heat exchanger jacket 28 to within generator 29. Here the application of heat causes the ammonia to be expelled as a gas from the solution and this ammonia gas passes through conduit 30 and distributor head 31 to within evaporator 1, where it reduces the partial pressure of the butane, wherefore the latter evaporates as previously described.

Patented Jan. 1, 1929. 1,697,210

UNITED STATES PATENT OFFICE.

LEO SZILARD, OF BERLIN, GERMANY, ASSIGNOR TO SIEMENS-SCHUCKERTWERKE AKTIENGESELLSCHAFT, OF BERLIN-SIEMENSSTADT, GERMANY, A CORPORATION OF GERMANY.

DISCHARGE TUBE.

Application filed April 20, 1925, Serial No. 24,575, and in Germany September 3, 1924.

This invention refers to a novel form of electronic discharge tube which allows of obtaining intense electronic currents in a high vacuum by comparatively simple means.

Hitherto considerable currents could only be obtained in a highly evacuated tube, such as for instance a triode by means of incandescent cathodes, requiring very large heating currents. On the other hand an electron discharge produced in a less high vacuum for instance by a mercury vapor arc while allowing large currents to pass, cannot be controlled by grids or similar means in a way which is possible with discharges in high vacuum triode tubes. For instance if a grid is interposed between cathode and anode of a mercury vapor rectifier it is possible to retard or to prevent the starting of the discharge by bringing the grid to a sufficiently high negative potential but it is impossible to influence or to suppress the arc once produced.

The present invention comprises a vacuum discharge tube divided into two main parts which are connected by a narrow communication path. In one part which contains the cathode a sufficiently high gas pressure is maintained so as to obtain an arc discharge. The electrons discharged in this part of the tube pass through the communication path to the other part of the tube where a high vacuum is maintained. The electron current can be influenced and interrupted in this part of the tube by means of grids charged at suitable potentials or by magnets much the same as in the well known, vacuum tubes.

In the annexed drawing the subject matter of the invention is represented in two embodiments. Figure 1 shows diagrammatically the simplest form, and Figure 2 shows another embodiment.

Referring to Figure 1, 1 is the first compartment of the tube containing gas at fairly low pressure, suitable to maintain an arc; 2 is a small tube through which small quantities of gas are continually admitted into compartment 1; 3 is a cathode; 4 is a second compartment; 5 is a communicating passage way between compartments 1 and 4; 6 is an outlet connected to a high vacuum pump (not shown); 7 is a grid set up in compartment 4; and 8 is an anode arranged in compartment 4.

This arrangement allows a small gas pressure to be maintained in compartment 1 and at the same time a high vacuum in compartment 4. If a discharge is caused between electrodes 3 and 8, this discharge will exhibit in compartment 1 the character of an arc according to the prevailing gas pressure; it will then by passing through communication 5 gradually change into a pure electronic current. This current can be controlled in compartment 4 by means of the grid 7 much the same as in an ordinary triode.

Another embodiment of the invention is shown in Fig. 2. It consists of a mercury vapor jet high vacuum pump of a well known type. Here again 1 represents the compartment having suitable low pressure for maintaining an arc discharge and the mercury pool 3 of which is used as a cathode. Compartment 1 discharges the vapor in a jet through nozzle 1^a, into condenser 9 which is cooled by a cooling jacket 10. 4 is the high vacuum compartment in which the vacuum is maintained by the well-known action of mercury jet pumps. The narrow throat formed between nozzle 1^a and the jacket wall forms the small communicating passage 5, equivalent to passage 5 in Figure 1 for the discharge between compartments 1 and 4. The latter contains grid 7 and anode 8.

When the pump is working the pressure of mercury vapor in compartment 1 and in the stream of the vapor is high enough to allow of an arc discharge, while in compartment 4 a very high vacuum can be obtained. The arc discharge passing from the low pressure compartment through the gap 5 into compartment 4 now assumes the character of an electronic current and can then be controlled by the grid 7 as effectively as in a triode. If a suitable negative potential with respect to the cathode is applied to the grid, the current can be reduced to any value or be even stopped. The grid current will be small at the same time.

In the arrangement described above it is essential that the mercury vapor be prevented from entering the high vacuum part. In order to obtain this effect the width of the cooled gap should be of the same order or less than the width of the mean free path of the mercury molecules under the prevailing conditions. This is essential in order to obtain a sufficiently low mercury vapor pressure in the high vacuum part of the pump. Similar restrictive devices are used in every type of mercury vapor pump. Indeed any type of mercury vapor pump different in its detail

Patented June 4, 1929. 1,715,874

UNITED STATES PATENT OFFICE.

LEO SZILARD, OF BERLIN-DAHLEM, GERMANY, ASSIGNOR TO SIEMENS-SCHUCKERT-WERKE GESELLSCHAFT MIT BESCHRÄNKTER HAFTUNG, OF SIEMENSSTADT, NEAR BERLIN, GERMANY, A CORPORATION OF GERMANY.

DISCHARGE TUBE.

Application filed October 28, 1925, Serial No. 65,394, and in Germany November 5, 1924.

My invention refers to thermionic discharge tubes provided with means for controlling the electron current between the anode and cathode, and it refers in particular to the type of discharge tubes in which, for the purpose of obtaining a large current between the anode and cathode, an arc-like discharge occurs at the cathode.

One of the objects of my invention is to provide an electric discharge tube which is suitable to furnish a heavy current between the anode and cathode which can be effectively controlled by a controlling device.

A further object of the invention is the placing of the anode into one of the vapor spaces of a mercury vapor pump (either into the vaporizing space or into the vapor condensing space) and to arrange the control means of the anode current in the low pressure or vacuum chamber of the pump.

Lastly an object of the invention is in arranging in tubes of the above described character the anode in the vapor space of one mercury vapor pump and the cathode in the vapor space of a second mercury pump and to control the current between the anode and cathode in an evacuated space which is common to the two pumps.

I have illustrated in the accompanying drawings two forms in which my invention may be reduced to practice, without thereby wishing to limit the forms in which my invention may be effectively carried out. In these drawings—

Fig. 1 represents a partial longitudinal vertical section and partially a view of a pair of electric discharge vessels in accordance with the present invention and

Fig. 2 represents a modification thereof in which one vessel is made of annular shape suitable to surround the other discharge vessel.

Referring to Fig. 1, 1 represents the vaporizing chamber of a mercury vapor jet pump, 2 is the condensing chamber of the pump and 3 represents the nozzle. 4 is the return pipe connection through which the mercury 12 which has been condensed in chamber 2 is returned into chamber 1. Chamber 2 is jacketed as shown at 13 and suitable cooling fluid is led through the jacket for the purpose of condensing the mercury in chamber 2. The mercury in vaporizing chamber 1 may be continuously vaporized by heating the mercury 10 in the lower portion of the chamber by any suitable means known in the art.

A second similar mercury vapor jet pump is provided consisting of the vaporizing chamber 5, a condensing chamber 7 and the nozzle 6, condensing chamber 7 being similarly cooled by a jacket 13 as the previously described chamber 2. The mercury 12 which condenses in chamber 7 is also similarly returned to the vaporizing chamber 5 by means of a return pipe 4, and the lower portion of chamber 5, like that of chamber 1, is assumed to be heated by suitable known means. Between the two pumps extends a suction chamber 8, preferably also jacketed as shown, this chamber being in common with both vaporizing chambers 1 and 5, so that both pumps tend to evacuate chamber 8. Consequently, a substantially lower pressure exists in chamber 8 than in chambers 1 and 5.

The mercury 10 in chamber 1 constitutes the cathode of the system and the mercury 11 in chamber 5 constitutes the anode. 19 and 20 are respectively the two inlead connections for the cathode and the anode. With low loads a gas discharge, such as an arc discharge, may preferably also be maintained in the vapor jet between chambers 1 and 2, by means of an auxiliary source of current which may be connected between the terminals 19 and 15 to have a sufficient number of negative charge carriers available for the current passage. Only the terminals 19 and 15, to which this auxiliary source may be connected are shown.

In the vacuum chamber 8 is disposed a control grid 9 which has an inlead connection 18 and which is arranged in that chamber so that it stands in the path of the current passing between the cathode 10 and the anode 11. Since now in view of the greater pressure prevailing in the vaporizing chamber 1, an arc-like discharge occurs, a sufficient number of electrons are discharged from cathode 10 which are drawn over to the anode by way of the two nozzles 3 and 6. The positive charges which compensate the negative space

UNITED STATES PATENT OFFICE

2,161,985

PROCESS OF PRODUCING RADIO-ACTIVE ELEMENTS

Leo Szilard, New York, N. Y.

Application March 11, 1935, Serial No. 10,500
In Great Britain March 12, 1934

9 Claims. (Cl. 204—31)

This invention concerns methods and apparatus for the generation of radio-active bodies.

According to one feature of my invention, radio-active elements may be produced from natural elements by bombarding a natural element or compounds of natural elements with neutrons produced in various ways, more particularly, by subjecting the natural elements to neutrons emanating from a target containing lithium, which target is subjected to a bombardment with fast deuterons. Another feature of the invention is directed to the production of radio-active elements from natural elements by exposing the natural elements to an irradiation with neutrons which are liberated from certain elements under the action of X-rays. Another feature of the invention is directed to chemically concentrating radio-active elements produced from natural elements if the radio-active element is isotopic with the natural element from which it is produced.

Other features of the invention will appear in the following detailed description referring to the drawings, and will be more particularly pointed out in the claims.

In the drawings,

Figure 1 represents a sectional elevation of an apparatus for carrying out the invention.

Figure 2 shows a more constructional lay-out of the apparatus of Figure 1.

Figure 3 shows the circuit arrangements for further modified apparatus and,

Figure 4 is a sectional view of apparatus intended to co-operate with that shown in Figure 3.

Referring first to Figure 1 of the drawings, 11 is an electrical discharge tube adapted to project a beam 12 of fast deuterons. The tube 11 is filled with deuterium and an anode A and cathode B are provided for connection to a source of high voltage. The deuterons are thus projected at high speed and pass through the cathode B. The deuterons fall on a substance 13 in a sealed container 13A. The substance 13 consists, for instance, of lithium. The collision of the fast diplogen ions with the substance 13 causes transmutation, i. e. a nuclear reaction of the deuteron with an atom of the target. The substance 13 is surrounded by a thick layer 14 containing the element which it is desired to transmute into a radio-active element. In order to have a high efficiency, the thickness of the layer 14 has to be sufficiently great, compared with the mean free path of the neutron, to prevent escape of any of the neutrons.

Figure 2 shows in more detail the electrical discharge tube 11 referred to in Figure 1. The tube essentially consists of a main portion 16 serving to accelerate the deuterons and an auxiliary tube 11T for initiating the flow. 11A is the anode and 15 the cathode of the auxiliary tube, deuterium being admitted thereto through the inlet 13B and being pumped away through the outlet 14A. The flow initiated by the auxiliary tube is accelerated by passage through the main tube 16 which is maintained exhausted by suction outlets 14^1 and 14^2, and which has a high potential gradient, there being a million volt potential difference between the ends of the tube. The accelerated deuterons emerge through the neck 14^3 of the tube 16 and collide with the substance 13 as described with reference to Figure 1 of the drawings.

If the substance 13 is a light element for instance lithium, then the bombardment by the accelerated deuterons results in emission of uncharged particles of mass of the order of magnitude of the mass of a proton. Such uncharged nuclei i. e. neutrons, penetrate even substances containing the heavier elements without ionisation losses, and will cause the formation of radio-active substances in the layer 14 exposed to them. It is to be noted that by the method so far described, the ionisation losses suffered by the deuterium nuclei are comparatively small in light elements and also that the substance to be made radio-active is irradiated with neutrons i. e. uncharged nuclei, which pass through even heavy elements without ionising them. The substance 14 exposed for treatment by the neutron radiation may be in the form of an organic compound for the purpose of carrying out separation of the generated radio-active element, as described more fully hereinafter.

Neutron radiation may also be produced by the action of X-rays upon an element having a dissociable neutron at the prevailing voltage, and apparatus for carrying out this process will now be described with reference to Figure 3 of the drawings.

In Figure 3, 1 is the primary of a transformer, the secondary 2 of which is connected to the junctions 3 and 4. The junction 3 is connected to the cathode 8 of the rectifier tube 5 and to the anode 7 of the rectifier tube 6. The junction 4 is connected to the cathode 9 of the rectifier tube 10 and to the anode 11 of the rectifier tube 12. The cathodes 13 and 14 are connected to each other and to earth. The anodes 15 and 16 are connected at 17, and fom this point are connected to the pole 18 of the impulse generator 20,

transmute into their own radio- [illegible] irradiating with neutrons an

United States Patent Office

2,708,656

Patented May 17, 1955

1

2,708,656

NEUTRONIC REACTOR

Enrico Fermi, Santa Fe, N. Mex., and Leo Szilard, Chicago, Ill., assignors to the United States of America as represented by the United States Atomic Energy Commission

Application December 19, 1944, Serial No. 568,904

8 Claims. (Cl. 204—193)

The present invention relates to the general subject of nuclear fission and particularly to the establishment of self-sustaining neutron chain fission reactions in systems embodying uranium having a natural isotopic content.

Experiments by Hahn and Strassman, the results of which were published in January 1939. Naturwissenschaften, vol. 27, page 11, led to the conclusion that nuclear bombardment of natural uranium by slow neutrons causes explosion or fission of the nucleus, which splits into particles of smaller charge and mass with energy being released in the process. Later it was found that neutrons were emitted during the process and that the fission was principally confined to the uranium isotope U^{235} present as $1/139$ part of the natural uranium.

When it became known that the isotope U^{235} in natural uranium could be split or fissioned by bombardment with thermal neutrons, i. e., neutrons at or near thermal equilibrium with the surrounding medium, many predictions were made as to the possibility of obtaining a self-sustaining chain reacting system operating at high neutron densities. In such a system, the fission neutrons produced give rise to new fission neutrons in sufficiently large numbers to overcome the neutron losses in the system. Since the result of the fission of the uranium nucleus is the production of two lighter elements with great kinetic energy, plus approximately 2 fast neutrons on the average for each fission along with beta and gamma radiation, a large amount of power could be made available if a self-sustaining system could be built.

In order to attain such a self-sustaining chain reaction in a system of practical size, the ratio of the number of neutrons produced in one generation by the fissions, to the original number of neutrons initiating the fissions, must be known to be greater than unity after all neutron losses are deducted, and this ratio is, of course, dependent upon the values of the pertinent constants.

In the co-pending application of Enrico Fermi, Serial No. 534,129, filed May 4, 1944, and entitled "Nuclear Chain Reacting Systems," there is described and claimed a means and method of determining the neutron reproduction ratio for any type of uranium-containing structure, directly as a result of a simple measurement which can be performed with precision. Accurate values for all of the pertinent nuclear constants need not be known.

We have discovered certain essential principles required for the successful construction and operation of self-sustaining neutron chain reacting systems (known as neutronic reactors) with the production of power in the form of heat. These principles have been confirmed with the aid of measurements made in accordance with the means and method set forth in the above-identified application, and neutronic reactors have been constructed and operated at various power outputs, in accordance with these principles, as will be more fully brought out hereinafter.

In a self-sustaining chain reaction of natural uranium with slow neutrons, as presently understood, reactions occur involving the isotopes U^{238} and U^{235}. Thus, 92^{238} is converted by neutron capture to the isotope 92^{239}. The latter is converted by beta decay to 93^{239} and this 93^{239} in turn is converted by beta decay to 94^{239}. Other isotopes of 93 and 94 may be formed in small quantities. By slow or thermal neutron capture, 92^{235}, on the other hand, can undergo nuclear fission to release energy appearing as heat and gamma and beta radiation, together with the formation of fission fragments appearing as radioactive isotopes of elements of lower mass numbers, and with the release of secondary neutrons.

The secondary neutrons thus produced by the fissioning of the 92^{235} nuclei have a high average energy, and must be slowed down to thermal energies in order to be in condition to cause slow neutron fission in other 92^{235} nuclei. This slowing down, or moderation of the neutron energy, is accomplished by passing the neutrons through a material where the neutrons are slowed by collision. Such a material is known as a moderator. While some of the secondary neutrons are absorbed by the uranium isotope 92^{238} leading to the production of element 94, and by other materials such as the moderator, enough neutrons can remain to sustain the chain reaction, when proper conditions are maintained.

Under these proper conditions, the chain reaction will supply not only the neutrons necessary for maintaining the neutronic reaction, but also will supply the neutrons for capture by the isotope 92^{238} leading to the production of 94, and excess neutrons for use as desired.

As 94 is a transuranic element, it can be separated from the unconverted uranium by chemical methods, and as it is fissionable by slow neutrons in a manner similar to the isotope 92^{235}, it is valuable, for example, for enriching natural uranium for use in other chain reacting systems of smaller overall size. The fission fragments are also valuable as sources of radioactivity.

The ratio of the fast neutrons produced in one generation by the fissions to the original number of fast neutrons in a theoretical system of infinite size where there can be no external loss of neutrons is called the reproduction of multiplication factor or constant of the system, and is denoted by the symbol K. For any finite system, some neutrons will escape from the periphery of the system. Consequently a system of finite size may be said to have a K constant, even though the value thereof would only exist if the system as built were extended to infinity without change of geometry or materials. Thus when K is referred to herein as a constant of a system of practical size, it always refers to what would exist in the same type of system of infinite size. If K can be made sufficiently greater than unity to indicate a net gain in neutrons in the theoretical system of infinite size, and then an actual system is built to be sufficiently large so that this gain is not entirely lost by leakage from the exterior surface of the system, then a self-sustaining chain reacting system of finite and practical size can be built to produce power and related by-products by nuclear fission of natural uranium. The neutron reproduction ratio in a system of finite size therefore differs from K by the external leakage factor, and by a factor due to the neutron absorption by localized neutron absorber, and the reproduction ratio must still be sufficiently greater than unity to permit the neutron density to rise exponentially with time in the system as built.

Progressive empirical enlargement of any proposed system for which the factor K is not accurately known, in an attempt to attain the overall size of a structure of finite size above which the rate of loss of neutrons by diffusion through the periphery of the structure is less than the rate of production of neutrons in the system, leads only to an expensive gamble with no assurance of success. The fact that K is greater than unity and the fact that the critical size is within practical limits must

United States Patent Office

2,796,396

Patented June 18, 1957

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2,796,396

METHOD OF INTERMITTENTLY OPERATING A NEUTRONIC REACTOR

Leo Szilard, Chicago, Ill., assignor to the United States of America as represented by the United States Atomic Energy Commission

Application April 16, 1946, Serial No. 662,512

2 Claims. (Cl. 204—154)

This invention relates to neutronic reactors and more particularly to a method and apparatus for removing heat from a neutronic reactor in a form to convert a fluid into a vapor to produce power in a useful form.

In neutronic reactors, a neutron fissionable isotope such as U^{233}, U^{235}, or 94^{239} or mixtures thereof is subjected to fission by absorption of neutrons and a self-sustaining chain reaction is established by the neutrons evolved by the fission. In general, such reactors comprise bodies of compositions containing such fissionable material, for example, natural uranium, disposed in a neutron slowing material which slows the neutrons to thermal energies. Such a slowing material is termed a neutron moderator. Carbon, beryllium, and D_2O (heavy water) are typical moderators suitable for such use. Heat is evolved during the reaction which is removed by passage of a coolant through the reactor in heat exchange relationship therewith. Specific details of the theory and essential characteristics of such reactors are set forth in U. S. Patent No. 2,708,656 of Enrico Fermi and Leo Szilard, dated May 17, 1955.

In a fluid cooled reactor only certain coolants in certain amounts can be present at any one time because the neutron absorption of the coolant cannot exceed a predetermined maximum or the chain reaction will not take place. For this reason heat abstraction is limited. However, if the reactor is operated without coolant therein to store heat in the reactor, a coolant of high capture cross section can be passed through the reactor to remove the stored heat. While this is being done, the reaction will cease. If the coolant is then drained from the reactor the reaction can again start. By thus intermittently operating the device, any desired coolant can be used to remove the heat. The present invention is directed toward using a coolant of high neutron cross section passed through the reactor while inoperative to remove heat generated by a previous operation of a self sustaining chain reaction in the device.

Therefore, a principal object of this invention is to utilize in a novel manner reactors similar to those disclosed in the above-mentioned Fermi and Szilard patent by intermittently operating such a reactor and flowing a fluid coolant of high neutron absorption therethrough in heat absorbing relationship, and then passing the coolant in heat exchange relationship with another fluid to vaporize the second fluid to produce power or heat energy in a useful form.

Another object of the invention is to control a neutronic reactor in a novel manner by intermittently flowing a coolant fluid having a high capture cross-section through the reactor in a predetermined cycle.

In the invention herein contemplated to accomplish the above objects, a reactor is used with tubes having large coolant capacity. Preferably, mercury is circulated through the reactor until the uranium temperatures fall to 400° C. The hot mercury is passed to a heat exchanger or steam boiler through which the hot mercury passes slower than through the reactor. The boiler thus

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operates continuously during intermittent action of the reactor. Steam is produced at a desired temperature-pressure ratio consistent with the mercury heat loss.

Control of the mercury is either by a timer or by a thermostat in the mercury outlet from the reactor. The neutronic reaction starts as the mercury coolant is drained from the reactor. When the uranium rods or other fissionable material within the reactor reach a desired temperature, such as 600° C., a pump starts flooding the reactor with mercury, stopping the neutronic reaction. For further safety, the control rod can be timed for the shut-down operation.

It is thus possible to operate a neutronic reactor on a 50–50 time schedule so that one-half the power of the pile should be available in the form of steam from a heat exchanger in combination therewith, at a usable temperature and pressure. By adjusting the hot mercury flow in the boiler to give hot mercury storage, it is possible to have the steam boiler operate continuously.

Other objects and advantages of the present invention will be more readily understood by reference to the following specification and attached drawing wherein the single figure in the drawing is a schematic view illustrating a neutronic reactor in combination with a heat exchange device wherein the neutronic reactor and heat exchange device are actuated in a predetermined cycle for the heat transfer embodying the teachings of the present invention.

A neutronic reactor 10, preferably of the type in which a coolant is passed therethrough, such as those that are disclosed and claimed in the above-mentioned patent of Enrico Fermi and Leo Szilard, may be used in carrying out the objects of this invention with the exception, however, that it is preferred to modify the usual coolant passages to provide enlarged coolant passages 11 about sheathed uranium rods 12 so that an annular passage approximately .635 cm. across will separate the sheathed uranium rods 12 from the interiors of the tubes forming passages 11. It is preferred to use a graphite moderator although other forms of moderator may be used, such as deuterium oxide or beryllium oxide, depending upon the type of reactor used and the conditions under which it is desired to operate the reactor. The neutronic reaction is controlled by a suitable control rod 14. For the particular structure of the control rod as well as the construction of the safety rods for use with a neutronic reactor of this type, reference is made to the above-mentioned Fermi and Szilard patent.

The neutronic reactor 10 includes a mercury distributing inlet header 15 and a mercury outlet header 16. The mercury inlet header 15 is connected to a cool mercury storage sump 17 through piping 18 connected to a suitable pump 19 which in turn is connected to the mercury distributing inlet headed 15 through piping 20.

The mercury pump 19 is preferably actuated by an electric motor 21 controlled through a timer mechanism 22 operating from a suitable source of electric power 23. Any type of timing mechanism 22 may be used as is well known in the art, and no particular mechanism will be described since this is not necessary for the understanding of this invention. However, the timing mechanism 22 must be such that it may control the motor 21 for the mercury pump 19 in a predetermined cycle or cycles in synchronism with a motor 24 actuating the control rod 14 through suitable control rod mechanism 25. The motors 21 and 24 are connected to the timer through suitable wiring 26 and 27, respectively. Hence, the operation cycle of the reactor 10 broadly includes the steps of permitting the reaction to come to a desired power level and operating thereat until the temperature reaches a predetermined level, as 600° C., stopping the neutronic reaction by substantially simultaneously driv-

United States Patent Office

2,778,792

Patented Jan. 22, 1957

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2,778,792

METHOD FOR UNLOADING REACTORS

Leo Szilard, Chicago, Ill., assignor to the United States of America as represented by the United States Atomic Energy Commission

Application April 19, 1946, Serial No. 663,452

1 Claim. (Cl. 204—154)

This invention relates to neutronic reactors and more particularly to a novel method for removing the fissionable material from such a reactor whereby said material may be treated to recover the element 94 and fission products of the reaction.

In neutronic reactors a neutron fissionable isotope such as U^{233}, U^{235}, or 94^{239} or mixtures thereof is subjected to fission by absorption of neutrons, and a self-sustaining chain reaction is established by the neutrons evolved by the fission. In general, such reactors comprise bodies of compositions containing such fissionable material, for example, natural uranium, disposed in a neutron slowing material which slows the neutrons to thermal energies. Such a slowing material is termed a neutron moderator. Carbon, beryllium, and D_2O (heavy water) are typical moderators suitable for such use. Heat is evolved during the reaction which is removed by passage of a coolant through the reactor or in heat exchange relationship therewith. Specific details of the theory and essential characteristics of such reactors are set forth in U. S. Patent 2,708,656 of Enrico Fermi and Leo Szilard, Serial No. 568,904, filed December 19, 1944.

An object of the invention is to provide a novel method for unloading the fissionable material from a neutronic reactor.

A specific object of the invention is to provide a novel method for unloading the fissionable material from a neutronic reactor and recovering products of fission by dissolving the fissionable material in situ, or in the reactor, and withdrawing the solution from the reactor, thus dispensing with necessity for complicated and expensive apparatus such as heretofore utilized in removing said material from reactors of this type.

A further object of the invention is to provide a novel method for removing fissionable material from a neutronic reactor in which a solvent is continuously pumped therethrough, whereby said material is dissolved and pumped from the reactor.

Other objects and advantages will be apparent from the following description taken with the accompanying drawings, in which:

Fig. 1 is a flow diagram illustrating a preferred embodiment of the invention;

Fig. 2 is a fragmentary vertical sectional view through a neutronic reactor with the reactive composition illustrated in elevation;

Fig. 3 is an enlarged fragmentary vertical sectional view partially in elevation through the reactor shown in Fig. 2;

Fig. 4 is an enlarged fragmentary sectional view in elevation through the lower portion of the reactive composition of the reactor shown in Fig. 2, said view illustrating in detail the construction of the uranium-containing cartridges or units utilized in this embodiment;

Fig. 5 is a flow diagram illustrating the invention applied to a different type neutronic reactor wherein the

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reactive composition comprises fissionable material suspended in stainless tubes extending through a heavy water moderator;

Fig. 6 is a vertical sectional view through a neutronic reactor of the type utilized in the arrangement of Fig. 5, said section being taken approximately in the longitudinal vertical plane indicated by the line 6—6 of Fig. 7, portions of the structure being shown in elevation;

Fig. 7 is a sectional view taken in the transverse vertical plane indicated by the line 7—7 of Fig. 6;

Fig. 8 is a sectional view through one of the uranium-carrying steel tubes shown in Figs. 6 and 7, said view being taken in the plane indicated by the line 8—8 of Fig. 6;

Figs. 9 and 10 are sectional views comparable to Fig. 8 but illustrating modifications of the structure shown therein; and

Fig. 11 is a vertical sectional view through a still different neutronic reactor to which the invention is applied.

Describing the invention in detail and referring first to Fig. 1, which illustrates diagrammatically a preferred embodiment of the invention, a coolant is circulated through a reactor 2 by a system including a pump 4 having its suction side connected to a coolant reservoir 6 through a conventional three-way operating valve 8. The discharge side of the pump 4 is connected to the reactor 2 through an inlet line 10 which communicates, as is hereinafter described in detail, with passages or ducts extending through neutron moderator such as graphite blocks forming part of the reactor 2. Slugs or units of fissionable material, such as uranium, are dispersed throughout said ducts to form a geometric arrangement hereinafter described and particularly conducive to a nuclear fission chain reaction, as more fully discussed in the above-mentioned U. S. Patent 2,708,656.

The coolant passes from the discharge side of the reactor 2 through an outlet line 12 and a two-way operating valve 14 connected to a coolant outlet line 16 and to an oxidant outlet line 18, said coolant line 16 being equipped with a conventional heat exchanger device 20 comprising conventional means, not shown, for passing a cooling fluid in heat exchange relationship with the coolant passing through the line 16 which is connected to the beforementioned reservoir 6.

The ducts within the reactor also communicate with a dump line 22 including a drain valve 24, said line communicating with a dump chamber 26 serving a purpose hereinafter described in detail.

Describing briefly an operating cycle of the system shown in Fig. 1, the reactor 2, which is preferably so designed as to operate at a power value of at least 10^8 kw., is operated at that value for approximately 6 months to produce 94 and fission products. During this period a coolant such as helium having a low neutron capture cross-section is circulated through the reactor 2 by the pump 4, said coolant passing through a normally open shut-off valve 27 in the inlet line 10 and through the reactor 2 into the valve 14 which is so actuated as to direct the coolant through the line 16 into the reservoir 6. Inasmuch as the valve 8, at this stage of the cycle is so actuated as to open reservoir 6 to communication with the suction side of the pump 4, it will be understood that a closed circuit is established through which the coolant is continuously circulated.

After approximately 6 months, the reaction is terminated by control means hereinafter described, and preferably the reactor is thereafter cooled for approximately 1 month by circulating the coolant therethrough, as above described.

At the end of the cooling period, the pump 4 is connected to a solvent line 28 by means of the valve 8, said line being connected to a source (not shown) of a ura-

United States Patent Office

2,798,847

Patented July 9, 1957

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2,798,847

METHOD OF OPERATING A NEUTRONIC REACTOR

Enrico Fermi and Leo Szilard, Chicago, Ill., assignors to the United States of America as represented by the United States Atomic Energy Commission

Application December 1, 1952, Serial No. 323,452

1 Claim. (Cl. 204—154)

The present invention relates to the general subject of nuclear fission and particularly to the establishment of self-sustaining neutron chain fission reactions in systems embodying uranium having a natural isotopic content.

Experiments by Hahn and Strassman, the results of which were published in Naturwissenshaften, vol. 27, page 11, in January 1939, led to the conclusion that nuclear bombardment of natural uranium by slow neutrons causes explosion or fission of the nucleus, which splits into particles of smaller charge and mass with energy being released in the process. Later it was found that neutrons were emitted during the process and that the fission was principally confined to the uranium isotope U^{235} present as 1/139 part of the natural uranium.

When it became known that the isotope U^{235} in natural uranium could be split or fissioned by bombardment with thermal neutrons, i. e., neutrons at or near thermal equilibrium with the surrounding medium, many predictions were made as to the possibility of obtaining a self-sustaining chain reacting system operating at high neutron densities. In such a system, the fission neutrons produced give rise to new fission neutrons in sufficiently large numbers to overcome the neutron losses in the system. Since the result of the fission of the uranium nucleus is the production of two lighter elements with great kinetic energy, plus approximately 2 fast neutrons on the average for each fission along with beta and gamma radiation, a large amount of power could be made available if a self-sustaining system could be built.

In order to attain such a self-sustaining chain reaction in a system of practical size, the ratio of the number of neutrons produced in one generation by the fissions, to the original number of neutrons initiating the fissions, must be known to be greater than unity after all neutron losses are deducted, and this ratio is, of course, dependent upon the values of the pertinent constants.

In the co-pending application of Enrico Fermi, Serial No. 534,129, filed May 4, 1944, now Patent No. 2,780,595, dated February 5, 1957, and entitled "Nuclear Chain Reacting Systems," there is described and claimed a means and method of determining the neutron reproduction ratio for any type of uranium containing structure, directly as a result of a simple measurement which can be performed with precision. Accurate values for all of the pertinent nuclear constants need not be known.

We have discovered certain essential principles required for the successful construction and operation of self-sustaining neutron chain reacting systems (known as neutronic reactors) with the production of power in the form of heat. These principles have been confirmed with the aid of measurements made in accordance with the means and method set forth in the above-identified application, and neutronic reactors have been constructed and operated at various power outputs, in accordance with these principles, as will be more fully brought out hereinafter.

In a self-sustaining chain reaction of uranium with slow neutrons, as presently understood, 92^{238} is converted

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by neutron capture to the isotope 92^{239}. The latter is converted by beta decay to 93^{239} and this 93^{239} in turn is converted by beta decay to 94^{239}. Other isotopes of 93 and 94 may be formed in small quantities. By slow or thermal neutron capture, 92^{235} on the other hand, can undergo nuclear fission to release energy appearing as heat, gamma and beta radiation, together with the formation of fission fragments appearing as radioactive isotopes of elements of lower mass numbers, and with the release of secondary neutrons.

The secondary neutrons thus produced by the fissioning of the 92^{235} nuclei have a high average energy, and must be slowed down to thermal energies in order to be in condition to cause slow neutron fission in other 92^{235} nuclei. This slowing down, or moderation of the neutron energy, is accomplished by passing the neutrons through a material where the neutrons are slowed by collision. Such a material is known as a moderator. While some of the secondary neutrons are absorbed by the uranium isotope 92^{238} leading to the production of element 94, and by other materials such as the moderator, enough neutrons can remain to sustain the chain reaction, when proper conditions are maintained.

Under these proper conditions, the chain reaction will supply not only the neutrons necessary for maintaining the neutronic reaction, but also will supply the neutrons for capture by the isotope 92^{238} leading to the production of 94, and excess neutrons for use as desired.

As 94 is a transuranic element, it can be separated from the unconverted uranium by chemical methods, and as it is fissionable by slow neutrons in a manner similar to the isotope 92^{235}, it is valuable, for example, for enriching natural uranium for use in other chain reacting systems of smaller overall size. The fission fragments are also valuable as sources of radioactivity.

The ratio of the fast neutrons produced in one generation by the fissions to the original number of fast neutrons in a theoretical system of infinite size where there can be no external loss of neutrons is called the reproduction or multiplication factor or constant of the system, and is denoted by the symbol K. For any finite system, some neutrons will escape from the periphery of the system. Consequently a system of finite size may be said to have a K constant, even though the value thereof would only exist if the system as built were extended to infinity without change of geometry or materials. Thus when K is referred to herein as a constant of a system of practical size, it always refers to what would exist in the same type of system of infinite size. If K can be made sufficiently greater than unity to indicate a net gain in neutrons in the theoretical system of infinite size, and then an actual system is built to be sufficiently large so that this gain is not entirely lost by leakage from the exterior surface of the system, then a self-sustaining chain reacting system of finite and practical size can be built to produce power and related by-products by nuclear fission of natural uranium. The neutron reproduction ratio in a system of finite size therefore, differs from K by the external leakage factor, and by a factor due to the neutron absorption by localized neutron absorber, and the reproduction ratio must still be sufficiently greater than unity to permit the neutron density to rise exponentially with time in the system as built.

Progressive empirical enlargement of any proposed system for which the factor K is not accurately known, in an attempt to attain the overall size of a structure of finite size above which the rate of loss of neutrons by diffusion through the periphery of the structure is less than the rate of production of neutrons in the system leads only to an expensive gamble with no assurance of success. The fact that K is greater than unity and the fact that the critical size is within practical limits must be known rather ac-

United States Patent Office

2,807,581

Patented Sept. 24, 1957

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2,807,581

NEUTRONIC REACTOR

Enrico Fermi, Santa Fe, N. Mex., and Leo Szilard, Chicago, Ill., assignors to the United States of America as represented by the United States Atomic Energy Commission

Application October 11, 1945, Serial No. 621,838

2 Claims. (Cl. 204—193.2)

The present invention relates to the general subject of nuclear fission and particularly to the establishment of self-sustaining neutron chain fission reactions in systems embodying uranium having a natural isotopic content.

This application is a continuation in part of our co-pending application Serial Number 568,904 filed December 19, 1944, now matured into U. S. Patent 2,708,656, issued on May 17, 1955.

When it became known that the isotope U^{235} in natural uranium could be split or fissioned by bombardment with thermal neutrons, i. e., neutrons at or near thermal equilibrium with the surrounding medium, many predictions were made as to the possibility of obtaining a self-sustaining chain reacting system operating at high neutron densities. In such a system, the fission neutrons produced give rise to new fission neutrons in sufficiently large numbers to overcome the neutron losses in the system. Since the result of the fission of the uranium nucleus is the production of two lighter elements with great kinetic energy, plus approximately 2 fast neutrons on the average for each fission along with beta and gamma radiation, a large amount of power could be made available if a self-sustaining system could be built.

In order to attain such a self-sustaining chain reaction in a system of practical size, the ratio of the number of neutrons produced in one generation by the fissions, to the original number of neutrons initiating the fissions, must be known to be greater than unity after all neutron losses are deducted, and this ratio is, of course, dependent upon the values of the pertinent constants.

In the co-pending application of Enrico Fermi, Serial Number 534,129, filed May 4, 1944, and entitled "Nuclear Chain Reacting Systems," now Patent No. 2,780,595, dated February 5, 1957, there is described and claimed a means and method of determining the neutron reproduction ratio for any type of uranium containing structure, directly as a result of a simple measurement which can be performed with precision. Accurate values for all of the pertinent nuclear constants need not be known.

In a self-sustaining chain reaction of uranium with slow neutrons, as presently understood, 92^{238} is converted by neutron capture to the isotope 92^{239}. The latter is converted by beta decay to 93^{239} and then to 94^{239}, also by beta decay. Other isotopes of 93 and 94 may be formed in small quantities. By slow or thermal neutron capture, 92^{235} on the other hand, can undergo nuclear fission to release energy appearing as heat, gamma and beta radiation together with the formation of fission fragments appearing as radioactive isotopes of elements of lower mass numbers, and with the release of secondary neutrons.

The secondary neutrons thus produced by the fissioning of the 92^{235} nuclei have a high average energy, and must be slowed down to thermal energies in order to be in condition to cause slow neutron fission in other 92^{235} nuclei. This slowing down, or moderation of the neutron energy, is accomplished by passing the neutrons through a material where the neutrons are slowed by collision.

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Such a material is known as a moderator. While some of the secondary neutrons are absorbed by the uranium isotope 92^{238} leading to the production of element 94, and by other materials such as the moderator, enough neutrons can remain to sustain the chain reaction, when proper conditions are maintained.

Under these proper conditions, the chain reaction will supply not only the neutrons necessary for maintaining the neutronic reaction, but also will supply the neutrons for capture by the isotope 92^{238} leading to the production of 94, and excess neutrons for use as desired.

As 94 is a transuranic element, it can be separated from the unconverted uranium by chemical methods, and as it is fissionable by slow neutrons in a manner similar to the isotope 92^{235}, it is valuable, for example, for enriching natural uranium for use in other chain reacting systems of smaller overall size. The fission fragments are also valuable as sources of radioactivity.

An initial number of fast neutrons in the system by going through the process of absorption and fission produce in the next generation a number of neutrons generally different from the initial number. The ratio of the number produced after one generation to the initial number for a system of infinite size is called the reproduction or multiplication factor of the system and is denoted by the symbol K. For any finite system, some neutrons will escape from the periphery of the system. Consequently a system of finite size may be said to have a K constant, even though the value thereof would only exist if the system as built were extended to infinity without change of geometry or materials. Thus, when K is referred to herein as a constant of a system of practical size, it always refers to what would exist in the same type of system of infinite size. If K can be made sufficiently greater than unity to indicate a net gain in neutrons in the theoretical system of infinite size, and an actual system is built to be sufficiently large so that this gain is not entirely lost by leakage from the exterior surface of the system, then a self-sustaining chain reacting system of finite and practical size can be built to produce power and related by-products by nuclear fission of natural uranium. The neutron reproduction ratio in a system of finite size, therefore, differs from K by the external leakage factor, and by a factor due to the neutron absorption by localized neutron absorbers, and the reproduction ratio must still be sufficiently greater than unity to permit the neutron density to rise exponentially with time in the system as built.

Progressive empirical enlargement of any proposed system for which the factor K is not accurately known in an attempt to attain the overall size of a structure of finite size above which the rate of loss of neutrons by diffusion through the periphery of the structure is less than the rate of production of neutrons in the system leads only to an expensive gamble with no assurance of success. The fact that K is greater than unity and the fact that the critical size is within practical limits must be known rather accurately in advance, as otherwise a proposed structure having a K factor less than unity, or even a K factor greater than but close to unity, might not sustain a chain reaction even if all of the uranium in the world were included.

The earliest attempts to predict a structure capable of sustaining a chain reaction, using natural uranium, involved the use of fine uranium particles such as uranium oxide powder, dispersed in hydrogen in combined form as the slowing agent. However, these attempts were not successful, and analysis of experiments made has indicated that the neutron losses in such a system when natural uranium is used, will prevent a chain reaction from being sustained, irrespective of the size of the system, due

United States Patent Office

2,825,689

Patented Mar. 4, 1958

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2,825,689

NEUTRONIC REACTOR AND FUEL ELEMENT THEREFOR

Leo Szilard, Chicago, Ill., and Gale J. Young, Hawthorne, N. Y., assignors to the United States of America as represented by the United States Atomic Energy Commission

Application April 25, 1946, Serial No. 664,732

2 Claims. (Cl. 204—193.2)

This invention relates to neutronic reactors and to novel articles of manufacture used in and in combination with such reactors. In neutronic reactors a neutron fissionable isotope such as U^{233}, U^{235} or 94^{239} or mixtures thereof is subjected to fission by absorption of neutrons and a self-sustaining chain reaction is established by the neutrons evolved by the fission. In general such reactors comprise bodies of compositions containing such fissionable material, for example, natural uranium, disposed in a neutron slowing material which slows the neutrons to thermal energies. Such a slowing material is termed a neutron moderator. Carbon, beryllium, and D_2O are typical moderators suitable for such use. Heat is evolved during the reaction which is removed by passage of a coolant through the reactor or in heat exchange relationship therewith. Specific details of the theory and essential characteristics of such reactors are set forth in co-pending application of Enrico Fermi and Leo Szilard, Serial No. 568,904, filed December 19, 1944, now U. S. Patent No. 2,708,656.

In the operation of neutronic reactors at a substantial power, for example, 1000 kilowatts or more, for more than a few minutes, difficulty has been encountered due to the fact that the moderator and/or coolant became radioactive during the operation of the reactor. This seriously complicates operation of the reactor since the radioactivity of the coolant and moderator may constitute a serious hazard to personnel.

In accordance with the present invention, an improved neutronic reactor has been produced whereby the tendency of the moderator and/or coolant to become radioactive is substantially minimized. It has been found that this result may be secured by interposing a solid non-fissioning barrier between the fissioning isotope and the coolant or moderator or both. Notwithstanding the fact that introduction of non-fissioning material into a neutronic reactor absorbs neutrons and therefore may tend to prevent establishment of a neutron chain reaction, it has been discovered that it is possible to insert non-fissioning barriers into the reactor, and to so proportion the thickness of the barrier to prevent passage of all or a preponderant amount of fission fragments from the fissioning isotope into the moderator and/or coolant while yet avoiding use of such a quantity of barrier that the neutron absorption thereof prevents establishment or maintenance of the neutron chain reaction. The barrier itself should be constructed of a material or materials having a low neutron capture cross-section. Metallic aluminum and beryllium are particularly good materials for this purpose.

While the barrier may be interposed in various ways, a particularly advantageous structure involves the use of a non-fissioning enclosure about the fissioning isotope. In order to promote heat transfer from the fissioning isotope through the barrier to the contacting moderator and/or coolant, the barrier should be in close intimate contact with the fissioning composition. Generally, special precautions are observed for this purpose. Thus, a shell forming the non-fissioning barrier may be shrunk

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upon the fissioning component which preferably is in the metallic state. These enclosed fissionable components may be used as the active component of a neutronic reactor, and frequently are located in contact with a coolant such as a gas or liquid coolant for removal of heat from the reactor. Where the coolant has a corrosive effect upon the fissionable metal or other material, the non-fissioning sheath also serves to protect the fissionable material. In such a case, every precaution must be taken to prevent the existence of pores in the sheath through which the coolant may enter. Frequently sheaths are hermetically sealed about the fissionable material in order to seal the material from the coolant. In a particularly advantageous modification of the invention, the enclosed fissionable bodies are disposed within channels in the moderator through which the coolant is permitted to flow. This coolant may flow externally or internally or externally and internally of the fissionable component.

Lengths or rod segments of the fissionable bodies generally are disposed in channels extending through or at least into the moderator. During the chain reaction the central interior portion of these bodies frequently rises to a temperature much above the temperature of the body exterior which is in close relationship with the coolant. This condition may lead to serious difficulty in a system where a plurality of fissionable bodies are laid end to end through the channels in the moderator and where coolant, particularly a liquid coolant such as water, is passed in contact with the fissionable bodies or sheathed fissionable bodies. In such a case the ends of each length may be at a temperature substantially higher than the temperature of the sides thereof, and thus the coolant contacting the ends may become seriously overheated and caused to boil. Such boiling could produce an exceedingly hazardous condition in an operating neutronic reactor.

In accordance with the present invention, this difficulty may be avoided or at least partially eliminated by providing the ends of such lengths of fissionable material with means to prevent the temperature of the ends from reaching an excessive value. This may be done by providing the ends with highly conductive end caps or other means for facilitating heat transfer to the circumference of the elongated bodies. Such intervening segments of heat conductive material improve the heat transfer to the coolant and prevent overheating. An especially effective embodiment of the invention comprises a neutron moderator with channels therein, coolant passing through the channels and fissionable bodies in the form of elongated segments laid end to end in the channels and enclosed in a non-fissioning enclosure and heat conducting means between adjoining segments.

Accomplishment of the foregoing constitutes some of the principal objects and advantages of the invention, others of which will become apparent from the following description and drawings, in which:

Fig. 1 is a diagrammatic, longitudinal sectional view, partly in elevation, of a liquid cooled neutronic reactor;

Fig. 2 is an enlarged fragmentary longitudinal sectional view through one of the cooling tubes disposed in the neutronic reactor showing partially in section and partly in elevation at least portions of three bodies of fissionable material disposed in the tube; and

Fig. 3 is a transverse sectional view through the tube, the view being taken on the line 3—3 of Fig. 2.

A complete description of a neutronic reactor in which the present invention is applicable is not given herein as the details of the reactor form no part of the present invention. The invention has to do with the body of fissionable material that is disposed in the reactor, and for a more thorough understanding of the reactor details, reference may be had to the aforementioned co-pending application of Enrico Fermi and Leo Szilard.

United States Patent Office

2,832,733

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2,832,733

HEAVY WATER MODERATED NEUTRONIC REACTOR

Leo Szilard, Chicago, Ill., assignor to the United States of America as represented by the United States Atomic Energy Commission

Application April 23, 1946, Serial No. 664,145

1 Claim. (Cl. 204—193.2)

The present invention relates to the subject of neutronics, and more particularly to a liquid cooled neutron chain reacting system, also referred to as a neutronic reactor, or pile, the latter name having been originally adopted for the active portions of systems employing uranium or other fissionable bodies geometrically arranged in graphite or other moderator in the form of lattice structures. More specifically the invention has to do with liquid cooled neutronic reactors in which a coolant passes over or through bodies of fissionable material inside the reactor, and this is cooled and recirculated in a closed sysem. For purposes of illustration, molten bismuth has been selected as one liquid coolant and water another.

As a result of the chain reaction, when U^{238} is present (as in natural uranium), transuranic element 94^{239}, known as plutonium, is produced. This material is fissionable and is valuable when added to natural uranium or thorium for use in a chain reacting system, as a fissionable body in lieu of or in conjunction with U^{235}.

Natural uranium contains both uranium isotopes U^{235} and U^{238} in the ratio of 1 to 139. The U^{235} is the isotope fissionable by slow neutrons.

When fission occurs in the U^{235} isotope, the following reaction takes place:

$$_{92}U^{235} + \text{neutron} \rightarrow A + B + \text{about 2 neutrons (average)}$$

where "A" represents "light" fission fragments having atomic masses ranging from 83 to 99 inclusive and atomic numbers from 34 to 45 inclusive; for example, Br, Kr, Rb, Sr, Y, Zr, Cb, Mo, Ma, Ru, and Rh; and "B" represents "heavy" fission fragments having atomic masses ranging from 127 to 141 inclusive, and atomic numbers from 51 to 60 inclusive; for example, Sb, Te, I, Xe, Ca, Ba, La, Ce, Pr, and Nd. The elements resulting from the fission are unstable and radioactive, with half-lives varying in length in accordance with the element formed.

The absorption of thermal or resonance neutrons by the U^{238} isotope gives rise to the conversion of U^{238} to U^{239} which ultimately decays to transuranic element 94^{239}. The reaction is as follows:

$$_{91}^{238} + n \longrightarrow {}_{92}^{239} \text{ [plus 6 m. e. v. of } \gamma \text{ rays, not necessarily all of one frequency]}$$

$$_{92}^{239} \xrightarrow{23 \text{ min.}} {}_{93}^{239} + \beta^- \text{[1 m. e. v. } \beta^-\text{, no } \gamma \text{ rays]}$$

$$_{93}^{239} \xrightarrow{2.3 \text{ days}} {}_{94}^{239} + \beta^- \text{[600 kv. upper } \beta^- \text{ energy limit. Also 2 } \gamma \text{ rays, 400 kv., and 270 kv., about ½ of which are converted to electrons]}$$

Most of the neutrons arising from the fission process are set free with the very high energy of above one million electron volts average and are therefore not in condition to be utilized efficiently to create new thermal neutron fissions in a fissionable body such as U^{235} when it is mixed with a considerable quantity of U^{238}, particularly as in the case of natural uranium. The energies of the fission-released neutrons are so high that most of the latter would tend to be absorbed by the U^{238} nuclei, and yet the energies are not generally high enough for production of fission by more than a small fraction of the neutrons so absorbed. For neutrons of thermal energies, however, the absorption cross section of U^{235}, to produce fission, is a great deal more than the simple capture cross-

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section of U^{238}; so that under the stated circumstances the fast fission neutrons, after they are created, must be slowed down to thermal energies before they are most effective to produce fresh fisssion by reaction with additional U^{235} atoms. When a system is built in which neutrons are slowed down without excessive absorption until they reach thermal energies and then mostly enter into uranium rather than into any other element, a self-sustaining nuclear chain reaction is obtained, even with natural uranium. Light elements, such as deuterium, beryllium, oxygen or carbon, the latter in the form of graphite, can be used as slowing agents or moderators. A special advantage of the use of the light elements mentioned for slowing down fast fission neutrons is that fewer collisions are required for slowing than is the case with heavier elements, and furthermore, the above-enumerated elements have very small neutron capture probabilities, even for thermal neutrons. Carbon in the form of graphite is a relatively inexpensive, practical, and readily available agent for slowing fast neutrons to thermal energies. Deuterium while more expensive is especially valuable because of its low absorption of neutrons, and its compounds such as deuterium oxide have been used with very effective results.

However, in order for the premise to be fulfilled that the fast fission neutrons be slowed to thermal energies in a slowing medium without too large an absorption in the U^{238} isotope of the uranium, certain types of physical structure should be utilized for the most efficient reproduction of neutrons, since unless precautions are taken to reduce various neutron losses and thus to conserve neutrons for the chain reaction the rate of neutron reproduction may be lowered and in certain cases lowered to a degree such that a self-sustaining reaction is not attained.

The ratio of the number of fast neutrons produced by the fissions, to the original number of fast neutrons creating the fissions, in a system of infinite size using specific materials is called the reproduction or multiplication factor of the system and is denoted by the symbol K. If K can be made sufficiently greater than unity to create a net gain in neutrons and the system made sufficiently large so that this gain is not entirely lost by leakage from the exterior surface of the system, then a self-sustaining chain reacting system can be built to produce power by nuclear fission of natural uranium. The neutron reproduction ratio in a system of finite size differs from K by the leakage factor and by localized neutron absorbers such as neutron absorbing controls, and must be sufficiently greater than unity to permit the neutron density to rise exponentially. Such a rise will continue if not controlled at a desired density corresponding to a desired power output.

During the interchange of neutrons in a system comprising bodies of uranium of any size in a slowing medium, neutrons may be lost in four ways, by absorption in the uranium metal or compound without producing fission, by absorption in the slowing down material, by absorption in impurities present in the system, and by leakage from the system. These losses will be considered in the order mentioned.

Natural uranium, particularly by reason of its U^{238} content, has an especially strong absorbing power for neutrons when they have been slowed down to moderate energies. The absorption in uranium at these energies is termed the uranium resonance absorption or capture. It is caused by the isotope U^{238} and does not result in fission but creates the isotope U^{239} which by two successive beta emissions forms the relatively stable nucleus 94^{239}. It is not to be confused with absorption or capture of neutrons by impurities, referred to later. Neutron resonance absorption in uranium may take place either

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2,836,554

Patented May 27, 1958

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2,836,554

AIR COOLED NEUTRONIC REACTOR

Enrico Fermi, Santa Fe, N. Mex., and Leo Szilard, Chicago, Ill., assignors to the United States of America as represented by the United States Atomic Energy Commission

Application May 29, 1945, Serial No. 596,465

3 Claims. (Cl. 204—193.2)

The present invention relates to a neutronic reactor which is capable of numerous uses but is particularly adapted to use for the production of the transuranic element 94^{239} and/or radioactive fission products by neutrons released during a self-sustaining nuclear chain reaction through fission of uranium with slow neutrons. More particularly, our invention relates to the removal of the heat of the neutronic reaction to such an extent that the reaction may be conducted at a more rapid rate and the production of element 94^{239} and/or fission products may be accelerated. Natural uranium may be used in the reaction and contains the isotopes 92^{238} and 92^{235} in the ratio of approximately 139 to 1. Hereinafter in the specification and the claims the term uranium is to be understood as referring to uranium and its chemical compositions of normal isotopic content or equivalent compositions, unless otherwise indicated by the context.

When it became known that the isotope U^{235} in natural uranium could be split or fissioned by bombardment with thermal neutrons, i. e., neutrons at or near thermal equilibrium with the surrounding medium, many predictions were made as to the possibility of obtaining a self-sustaining chain reacting system operating at high neutron densities. In such a system, the fission neutrons produced give rise to new fission neutrons in sufficiently large numbers to overcome the neutron losses in the system. Since the result of the fission of the uranium nucleus is the production of two lighter elements with great kinetic energy, plus approximately 2 fast neutrons on the average for each fission along with beta and gamma radiation, a large amount of power can be made available in a self-sustaining system.

It has been found that most of the neutrons arising from the fission process are set free with the very high energy of the order of one million electron volts and are therefore not immediately in condition to be utilized efficiently to create new thermal neutron fissions in U^{235} when it is mixed with a considerable quantity of U^{238}, as is the case with natural uranium. The energies of the fission-released neutrons are so high that most of the latter would tend to be absorbed by the U^{238} nuclei, and yet the energies are not generally high enough for production of fission by more than a small fraction of the neutrons so absorbed. For neutrons of thermal energies, however, the absorption cross section of U^{235}, to produce fission, rises a great deal more than the simple capture cross section of U^{238}; so that under the stated circumstances the fast fission neutrons, after they are created, must be slowed down to thermal energies before they are most effective to produce fresh fission by reaction with additional U^{235} atoms. When a system larger than critical size is made in which neutrons are slowed down without much absorption until they reach thermal energies and then mostly enter into uranium rather than into any other element, a self-sustaining nuclear chain reaction is obtained, even with natural uranium. Light elements, such as deuterium, beryllium, oxygen or carbon, the latter in the form of graphite, can be used as slowing agents or neutron moderators. A special advantage of the use of the light elements mentioned for slowing down fast fission neutrons is that fewer collisions are required for slowing than is the case with heavier elements, and furthermore, the above-enumerated elements have very small neutron capture probabilities, even for thermal neutrons. Hydrogen would be most advantageous were it not for the fact that there may be a relatively high probability of neutron capture by the hydrogen nucleus. Carbon in the form of graphite is a relatively inexpensive, practical, and readily available agent for slowing fast neutrons to thermal energies. Recently, beryllium has been made available in sufficiently large quantities for test as to suitability for use as a neutron slowing material in a system of the type to be described. It has been found to be in every way as satisfactory as carbon. Deuterium compounds such as deuterium oxide while more expensive are even more satisfactory.

However, in order for the premise to be fulfilled that the fast fission neutrons be slowed to thermal energies in a slowing medium without too large an absorption in the U^{238} isotope of the uranium, certain types of physical structure are utilized for the most efficient reproduction of neutrons, as precautions must be taken to reduce various neutron losses and thus to conserve neutrons for the chain reaction if a self-sustaining system is to be attained.

An initial number of fast neutrons in the system by going through the process of absorption and fission reproduces in the next generation a number of neutrons generally different from the initial number. The ratio of the number produced after one generation to the initial number for a system of infinite size is called the reproduction or multiplication factor of the system and is denoted by the symbol K. If K can be made sufficiently greater than unity to create a net gain in neutrons for the system of infinite size and the system made smaller but still sufficiently large so that this gain is not entirely lost by leakage from the exterior surface of the system, then a self-sustaining chain reacting system can be built to produce power (in the form of heat) by nuclear fission of natural uranium. The neutron reproduction ratio in a system of finite size differs from K by the leakage factor (neutrons lost from the system through leakage), and must be sufficiently greater than unity to permit the neutron density to rise exponentially. Such a rise will continue indefinitely if not controlled at a desired density corresponding to a desired power output.

During the interchange of neutrons in a system comprising bodies of uranium of any size in a slowing medium, neutrons may be lost in four ways, by absorption in the uranium metal or compound without producing fission, by absorption in the slowing down material, by absorption in impurities present in the system, and by leakage from the system. These losses will be considered in the order mentioned.

Natural uranium, particularly by reason of its U^{238} content, has an especially strong absorbing power for neutrons when they have been slowed down to moderate energies. The absorption in uranium at these energies is termed the uranium resonance absorption or capture. It is caused by the isotope U^{238} and does not result in fission but creates the isotope U^{239} which by two successive beta emissions forms the relatively stable nucleus 94^{239}. It is not to be confused with absorption or capture of neutrons by impurities referred to later. Neutron resonance absorption in uranium may take place either on the surface of the uranium bodies, in which case the absorption is known as surface resonance absorption, or it may take place further in the interior of the uranium

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2,872,401

JACKETED FUEL ELEMENT

Eugene P. Wigner and Leo Szilard, Chicago, Ill., and Edward C. Creutz, Pittsburgh, Pa., assignors to the United States of America as represented by the United States Atomic Energy Commission

Application May 8, 1946, Serial No. 668,110

2 Claims. (Cl. 204—193.2)

This invention relates to neutronic reactors and to novel articles of manufacture used in and in combination with such reactors. In neutronic reactors a neutron fissionable isotope such as U^{233}, U^{235}, 94^{239} or mixtures thereof is subjected to fission by absorption of neutrons and a self-sustaining chain reaction is established by the neutrons evolved by the fission. In general such reactors comprise bodies of compositions containing such fissionable material, for example, natural uranium, disposed in a neutron slowing material which slow the neutrons to thermal energies. Such a slowing material is termed a neutron moderator. Carbon, beryllium, and D_2O are typical moderators suitable for such use. Heat is evolved during the reaction which is removed by passage of a coolant through the reactor or in heat exchange relationship therewith. Specific details of the theory and essential characteristics of such reactors are set forth in Fermi et al. Patent 2,708,656, dated May 17, 1955.

In the operation of neutronic reactors at a substantial power, for example, 1000 kilowatts or more, for more than a few minutes difficulty has been encountered due to the fact that the moderator and/or coolant became radioactive during the operation of the reactor. This seriously complicates operation of the reactor since the radioactivity of the coolant and moderator may constitute a serious hazard to personnel.

It has been found that this difficulty may be substantially minimized by interposing a solid non-fissioning barrier between the fissioning isotope and the coolant or moderator or both. Notwithstanding the fact that introduction of non-fissioning isotopes into a neutronic reactor absorbs neutrons and therefore may tend to prevent establishment of a neutron chain reaction, it has been discovered that it is possible to insert non-fissioning barriers into the reactor, and to so proportion the thickness of the barrier to prevent passage of all or a preponderant amount of fission fragments from the fissioning isotope into the moderator and/or coolant while yet avoiding use of such a quantity of barrier that the neutron absorption thereof prevents establishment or maintenance of the neutron chain reaction. The barrier itself should be constructed of a material or materials having a low neutron capture cross-section as will be more fully explained hereinafter. Metallic aluminum and beryllium are particularly good materials for this purpose.

While the barrier may be interposed in various ways, a particularly advantageous structure involves the use of a non-fissioning enclosure about the fissioning isotope. An especially effective neutronic reactor may be constructed by providing a neutron moderator with spaced rods, tubes, or other convenient form of solid fissionable material enclosed in a non-fissioning enclosure and extending into or through the moderator.

In order to promote heat transfer from the fissioning isotope through the barrier to the contacting moderator and/or coolant, the barrier should be in close intimate contact with the fissioning composition. Generally, special precautions are observed for this purpose. Thus, a shell forming the non-fissioning barrier may be shrunk upon the fissioning component which preferably is in the metallic state. These enclosed fissionable components may be used as the active component of a neutronic reactor, and frequently are located in contact with a coolant such as a gas or liquid coolant for removal of heat from the reactor. Where the coolant has a corrosive effect upon the fissionable metal or other material, the non-fissioning sheath also serves to protect the fissionable material. In such a case, every precaution must be taken to prevent the existence of pores in the sheath through which the coolant may enter. Frequently sheaths are hermetically sealed about the fissionable material in order to seal the material from the coolant. In a particularly advantageous modification of the invention, the enclosed fissionable bodies are disposed within channels in the moderator through which the coolant is permitted to flow. This coolant may flow externally or internally or externally and internally of the fissionable component.

Not infrequently, difficulty is encountered in securing a satisfactory transfer of heat through the non-fissioning barrier or sheath. This is particularly true after prolonged operation of the reactor at various temperatures. In such a case the sheath may tend to shrink or otherwise become detached from the uranium or other fissioning component making heat transfer difficult.

In accordance with this invention, this difficulty may be substantially avoided by bonding the aluminum or similar sheath to the uranium by means of a suitable bonding agent. This bonding agent should be sufficiently ductile to withstand a tendency to crack or rupture due to thermal expansion of the uranium or other composition, and also should have a low neutron absorption cross-section. Beryllium, zinc and aluminum-silicon alloys have been found to be suitable where the operating temperature is not unduly high. The bonding layer not only serves to improve transfer of heat but also provides an additional protection against corrosion of the uranium or similar fissioning element by the coolant or moderator. The bonding layer also localizes any possibile corrosion by preventing travel of corrosive material along the surface of the fissioning element.

Accomplishment of the foregoing constitutes some of the principal objects and advantages of the invention, others of which will become apparent from the following description and drawings in which:

Fig. 1 is a diagrammatic longitudinal sectional view partly in elevation of a liquid cooled neutronic reactor;

Fig. 2 is a vertical sectional view diagrammatically illustrating the reactor of Fig. 1 taken as indicated by the line 2—2;

Fig. 3 is a fragmentary cross-sectional view through the reactor illustrating the relationship of the channels in the reactor of Fig. 1;

Fig. 4 is a fragmentary cross-sectional view similar to Fig. 3 and showing a modification thereof;

Fig. 5 is a fragmentary cross-sectional view similar to Figs. 3 and 4 but showing a further modification thereof;

Fig. 6 is a longitudinal sectional view of a fissionable body enclosed in a sheath of non-fissionable material wherein the sheath is bonded to the fissionable body;

Fig. 7 is a sectional view of a fissionable body enclosed in a double sheath of non-fissionable material; and

Fig. 8 is a sectional view of a fissionable body having an internal sheath of non-fissionable material bonded thereto.

In order that a self-sustaining neutronic chain reaction can be established and maintained, the losses of neutrons must be held to a value so low that at least one neutron is available for a new fission, after losses have been de-

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2,886,503

JACKETED FUEL ELEMENTS FOR GRAPHITE MODERATED REACTORS

Leo Szilard, Chicago, Ill., Eugene P. Wigner, Princeton, N.J., and Edward C. Creutz, Santa Fe, N. Mex., assignors to the United States of America as represented by the United States Atomic Energy Commission

Application February 20, 1946, Serial No. 649,080

4 Claims. (Cl. 204—193.2)

This invention relates to neutronic reactors and to novel articles of manufacture used in and in combination with such reactors. In neutronic reactors of any type a neutron fissionable isotope such as U^{233}, U^{235}, or 94^{239} or a mixture thereof is subjected to fission by adsorption of neutrons and a self-sustaining chain reaction is established by the neutrons evolved by the fission. Such isotopes are designated thermally fissionable isotopes. The term "thermally fissionable isotope" is used herein, as is common in the art, to refer to an isotope which is fissionable by thermal neutrons. As an example, such reactors may comprise bodies or compositions containing such fissionable material, for example, natural uranium, disposed in a neutron slowing material which slow the neutrons to thermal energies. Such a slowing material is termed a neutron moderator. Carbon, beryllium, and D_2O are typical moderators suitable for such use. Heat is evolved during the reaction which is removed by passage of a coolant through the reactor or in heat exchange relationship therewith. Specific details of the theory and essential characteristics of such slow neutron reactors are set forth in copending application of Enrico Fermi and Leo Szilard, Serial No. 568,904, filed December 19, 1944, now Patent No. 2,708,656, granted May 17, 1955. It will be understood that the choice of fissionable and moderator materials, the pattern of distribution of the fissionable material in the moderator, the critical size of the reactive composition comprising fissionable material and moderator required to maintain a self-sustaining reaction, and the means employed to remove the heat generated in the reaction in themselves constitute no part of the present invention, being now known to persons skilled in the art, as exemplified in the above-mentioned co-pending application.

In the operation of neutronic reactors at a substantial power, for example 1000 kilowatts or more, for more than a few minutes difficulty has been encountered due to the fact that the moderator and/or coolant become radioactive during the operation of the reactor. This seriously complicates operation of the reactor since the radioactivity of the coolant may constitute a serious hazard to personnel.

In accordance with the present invention, an improved neutronic reactor has been produced whereby the tendency of the moderator and/or coolant to become radioactive is substantially minimized. It has been found that this result may be secured by interposing a solid nonfissioning barrier between the fissioning isotope and the coolant or moderator or both. Notwithstanding the fact that introduction of nonfissioning isotopes into a neutronic reactor absorbs neutrons and therefore may tend to prevent establishment of a neutron chain reaction, it has been discovered that it is possible to insert nonfissioning barriers into the reactor, and to so proportion the thickness of the barrier to prevent passage of all or a preponderant amount of fission fragments from the fissioning isotope into the moderator and/or coolant while yet avoiding use of such a quantity of barrier that the neutron

absorption thereof prevents establishment or maintenance of the neutron chain reaction. The barrier itself should be constructed of a material or materials having a low neutron capture cross section as will be more fully explained hereinafter. Metallic aluminum and beryllium are particularly good materials for this purpose.

While the barrier may be interposed in various ways, a particularly advantageous structure involves the use of a nonfissioning enclosure about the fissioning isotope. An especially effective neutronic reactor may be constructed by providing a neutron moderator with spaced rods, tubes, or other convenient form of solid fissionable material enclosed in a nonfissioning enclosure and extending into or through the moderator.

In order to promote heat transfer from the fissioning isotope through the barrier to the contacting moderator and/or collant, the barrier should be in close intimate contact with the fissioning composition. Generally, special precautions are observed for this purpose. Thus, a shell forming the nonfissioning barrier may be shrunk upon the fissioning component which preferably is in the metallic state. These enclosed fissionable components may be used as the active component of a neutronic reactor, and frequently are located in contact with a coolant such as a gas or liquid coolant for removal of heat from the reactor. Where the coolant has a corrosive effect upon the fissionable metal or other material, the nonfissioning sheath also serves to protect the fissionable material. In such a case, every precaution must be taken to prevent the existence of pores in the sheath through which the coolant may enter. Frequently sheaths are heremetically sealed about the fissionable materal in order to seal the material from the coolant. In a particularly advantageous modification of the invention, the enclosed fissionable bodies are disposed within channels in the moderator through which the coolant is permitted to flow. This coolant may flow externally or internally or externally and internally of the fissionable component.

Not infrequently, difficulty may be encountered in securing a satisfactory transfer of heat through the nonfissioning barrier or sheath. This is particularly true after prolonged operaton of the reactor at various temperatures. In such a case the sheath may tend to shrink from the uranium or other fissioning component making heat transfer difficult. In accordance with a further modification of the invention, this difficulty may be substantially avoided by bonding the aluminum or similar sheath to the uranium by means of a suitable bonding agent. This bonding agent should be sufficiently ductile to withstand a tendency to crack or rupture due to thermal expansion of the uranium or other composition, and also should have a low neutron absorption cross section. Zinc and aluminum-silicon alloys have been found to be suitable where the operating temperature is not unduly high. The bonding layer not only serves to improve transfer of heat but also provides an additional protection against corrosion of the uranium or similar fissioning element by the coolant or moderator.

As previously noted, lengths of the fissionable bodies generally are disposed in channels extending through or at least into the moderator. During the chain reaction the central interior portion of these bodies frequently rises to a temperature much above the temperature of the body exterior which is in close relationship with the coolant. This condition may lead to serious difficulty in a system where a plurality of fissionable bodies are laid end to end through the channels in the moderator and where coolant, particularly a liquid coolant, such as water, is passed in contact with the fissionable bodies or sheathed fissionable bodies. In such a case the ends of each length may be at a temperature substantially higher than the temperature of the sides thereof, and thus the

United States Patent Office

2,986,510

Patented May 30, 1961

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2,986,510

MASSIVE LEAKAGE IRRADIATOR

Eugene P. Wigner, Princeton, N.J., Leo Szilard, Chicago, Ill., Robert F. Christy, Santa Fe, N. Mex., and Francis Lee Friedman, Chicago, Ill., assignors to the United States of America as represented by the United States Atomic Energy Commission

Filed May 14, 1946, Ser. No. 669,524

1 Claim. (Cl. 204—193.2)

This invention relates to neutronic reactors and to novel articles of manufacture used in and in combination with such reactors. In neutronic reactors a neutron fissionable isotope such as U^{233}, U^{235}, or 94^{239} or mixtures thereof is subjected to fission by absorption of neutrons, and a self-sustaining chain reaction is established by the neutrons evolved by the fission. In general such reactors comprise bodies of compositions containing such fissionable material, for example, natural uranium, disposed in a neutron slowing material which slows the neutrons to thermal energies. Such a slowing material is termed a neutron moderator. Carbon, beryllium, and D_2O (heavy water) are typical moderators suitable for such use. Heat is evolved during the reaction which is removed by passage of a coolant through the reactor or in heat exchange relationship therewith. Specific details of the theory and essential characteristics of such reactors are set forth in copending application of Enrico Fermi and Leo Szilard, Serial No. 568,904, filed December 19, 1944, now Patent No. 2,708,656.

This invention is particularly concerned with neutron bombardment of various target isotopes. As the result of such bombardment, many substances absorb neutrons to form various useful isotopes. For example, radioactive atoms may be prepared by fission or neutron absorption which may be used as tracers in chemical and biochemical or biological work. Moreover, fissionable isotopes such as U^{233} may be produced by neutron bombardment of an isotope such as Th^{232}.

While a neutronic reactor is an excellent source of neutrons, the problem of using neutrons developed in a reactor for bombardment of target isotopes frequently is rather difficult. Insertion of neutron absorbing target isotopes directly into a neutronic reactor for bombardment purposes offers certain difficulties since the neutron absorption of the inserted isotope may be so great that the chain reaction is stopped unless but a limited amount of such isotope is inserted.

In accordance with the present invention, it has been found that a target isotope or target isotopes may be bombarded with neutrons from a neutronic reactor by disposing the isotope to be irradiated around the exterior of the reactor in association with a neutron moderating or scattering material. In such a process the problem of stopping the reaction is minimized and neutrons which might otherwise be lost are used in the bombardment.

The target isotope or compositions containing such isotope may be disposed as a more or less uniform suspension or dispersion in the neutron moderator. Thus a solution or slurry of the target isotope in a liquid moderator may be used for this purpose. Alternately lumps or granules of the target isotope or a composition containing this isotope may be dispersed in a moderator which may be solid or liquid.

Thus an object of this invention is to provide a novel means for bombarding substances with neutrons. Other objects and advantages of the invention will become apparent by reference to the following disclosure and the accompanying drawings in which

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Fig. 1 is a flow diagram showing the invention as embodied in a system wherein the reactive composition as well as the bombarded composition is in fluid form;

Fig. 2 is a diagrammatic plan view of a system with the upper portion of the shield broken away wherein the reactive composition and the bombarded composition are solid in form; and

Fig. 3 is a sectional view taken on the line 3—3 of Fig. 2.

In order that a self-sustaining neutronic chain reaction can be established and maintained, the losses of neutrons must be held to a value so low that at least one neutron is available for a new fission, after losses have been deducted, per neutron consumed in production of fission. In fission of U^{235} and similar isotopes, more neutrons are evolved per fission than are required to produce the fission. For example, about 2.3 neutrons are evolved per neutron consumed in fission of U^{235}, and about 2.8 neutrons are evolved per neutron consumed in fission of 94^{239}. These evolved neutrons are used up in fission of further U^{235} or 94^{239} atoms or are lost. If losses do not reduce the ratio of neutrons evolved to neutrons consumed or lost below one, the chain reaction will continue.

Losses may be external, as when neutrons escape from the reactor, or internal. Internal losses are caused by absorption of neutrons by atoms which do not fission when the neutron has been absorbed.

U^{238} present in natural uranium absorbs substantial quantities of neutrons to produce 94^{239}. This loss may be substantially reduced by use of uranium aggregates. Thus, it has been found that U^{238} absorbs neutrons to an appreciable degree at energies (resonance energies) greater than thermal energies due to its relatively high capture cross-section with respect to that of U^{235} at such resonance energies. However, this type of absorption, known as resonance absorption, may be reduced by decreasing the amount of neutrons which pass into a uranium body until these neutrons have been slowed to thermal energy. This may be done by reducing the ratio of surface area per unit weight of uranium, i.e., by using natural uranium in the form of aggregates preferably having a minimum thickness of about 0.5 cm. Moreover, this loss may be rendered negligible by use of a concentrate of a fissionable isotope which contains greater than natural concentration of fissionable material.

Neutron moderators also absorb neutrons. Generally speaking, it is desirable to use as a moderator an element (or compound thereof) of low atomic weight and low neutron capture cross-section. The ability to slow down neutrons may be expressed by what is known as the scattering cross-section whereas the ability to absorb or capture neutrons may be expressed as the capture cross-section. The ratio of absorption cross-section to scattering cross-section of various materials are approximately as follows:

Light water (H_2O)	0.00478
Diphenyl	0.00453
Beryllium	0.00127
Graphite	0.000726
Heavy water (D_2O)	0.00017

For natural uranium it is preferred to use materials wherein the above ratio is below about 0.004. However, with enriched uranium compositions containing more than natural amounts of U^{235}, a greater latitude is permissible. Using carbon or deuterium oxide as moderators and natural uranium as the fissionable composition, only about 1.1 or 1.3, respectively, neutrons are obtained per neutron consumed due to neutron losses in the U^{238} and the

United States Patent Office

3,103,475

Patented Sept. 10, 1963

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3,103,475
REACTOR

Leo Szilard, Chicago, Ill., assignor to the United States of America as represented by the United States Atomic Energy Commission

Filed Sept. 20, 1946, Ser. No. 698,334
3 Claims. (Cl. 204—193.2)

This invention relates to nuclear physics and more particularly to a novel method and means for establishing and controlling a fast neutron nuclear fission chain reaction.

It is known in the art that a controlled slow neutron chain reaction may be established by combining fissionable material and neutron moderator to form a reactive mass, the moderator being effective to reduce the average neutron energy to a value at which the fission cross section of said material is relatively great.

In slow neutron reactors a neutron fissionable isotope such as U^{233}, U^{235}, or Pu^{239} or mixtures thereof is subjected to fission by absorption of neutrons and a self-sustaining chain reaction is established by the neutrons evolved by the fission. In general, such reactors comprise bodies of compositions containing fissionable material such, for example, as natural uranium, disposed in a neutron slowing material which slows the neutrons to thermal energies. Such a slowing material is termed a neutron moderator. Carbon and D_2O (heavy water) are typical moderators suitable for such use. Heat is evolved during the reaction which is removed by passage of a coolant through the reactor or in heat exchange relationship therewith. Specific details of the theory and essential characteristics of such reactors are set forth in U.S. Patent 2,708,656 of Enrico Fermi and Leo Szilard, Serial No. 568,904, filed December 19, 1944.

In reactors of the above-described type a substantial portion of neutrons is lost to the chain reaction by absorption in nonfissionable material and by absorption in fissionable material without fission thereof. Consequently the amount of nonfissionable material in the reactor must be carefully limited. This practice has been disadvantageous, inasmuch as it has required limitation of the amount of coolant, the number of cooling conduits, and the quantity of other neutron absorbent structural components, thereby imposing limitations upon the power output of the reactor and upon the structural quality thereof. Moreover, the use of nonfissionable neutron absorbent coolants and other neutron absorbent equipment within the reactor has resulted in a serious loss of neutrons which might otherwise have been available for effecting further fissions or producing fissionable isotopes from nonfissionable isotopes, as hereinafter discussed.

In accordance with the present invention it has been found that neutron absorption losses may be greatly minimized by establishing and maintaining a self-sustaining nuclear fission chain reaction while avoiding the slowing of evolved neutrons below an average energy of about 1,000 ev., and preferably below about 10,000 ev. At such high energies, it has been discovered that the elements of atomic number of 11 to 83, which are generally used as structural, cooling, or other elements in a reactor, have neutron absorption cross sections which are substantially lower than their absorption cross sections for neutrons at thermal energies. In contrast, the absorption cross section for neutrons at high energies of certain heavy isotopes, such as Th^{232} or U^{238}, which are converted to thermally fissionable isotopes upon neutron bombardment, are not so greatly reduced; and hence their tendency for neutron absorption is correspondingly higher than for lower atomic number elements. Thus, a substantial saving of neutrons may be effected by maintenance of the high energy level.

2

Similar advantages may accrue by operating neutronic reactors at lower energies, as for example, as low as 10 ev. or even as low as 0.3 ev., which energies are substantially above the energy of thermal neutrons at room temperature, that is about 0.03 ev. However, the higher energizes of 1,000 ev. and above are preferred, inasmuch as nonmoderating neutron reflectors may be utilized with reactors operating at these values. For example, as hereinafter discussed in detail, the isotopes U^{238} and Th^{232} may be utilized for this purpose, particularly in view of the fact that whatever neutron absorption occurs in these isotopes results in the production of thermally fissionable isotopes, as for example, 94^{239} from U^{238} and U^{233} from Th^{232}.

In neutronic reactors, the ratio of the fast neutrons produced in one generation by the fissions to the original number of fast neutrons in a theoretical system of infinite size where there can be no external loss of neutrons is called the reproduction or multiplication factor or constant of the system, and is denoted by the symbol K. For any finite system, some neutrons will escape from the periphery of the system. Consequently, a system of finite size may be said to have a K constant, even though the value thereof would only exist if the system as built were extended to infinity without change of geometry or materials. Thus, when K is referred to herein as a constant of a system of practical size, it always refers to what would exist in the same type of system of infinite size. If K can be made sufficiently greater than unity to indicate a net gain in neutrons in the theoretical system of infinite size, and then an actual system is built to be sufficiently large so that this gain is not entirely lost by leakage from the exterior surface of the system, then a self-sustaining chain reacting system of finite and practical size can be built to produce power and related by-products by nuclear fission of natural uranium. The neutron reproduction ratio in a system of finite size, therefore, differs from K by the external leakage factor, and by a factor due to the neutron absorption by localized neutron absorber, and the reproduction ratio, R, must still be sufficiently greater than unity to permit the neutron density to rise exponentially with time in the system as built.

During the interchange of neutrons in a neutron-moderated system of finite size, comprising bodies of any size disposed in a neutron moderator, neutrons may be lost to the chain reaction in four ways: by absorption or capture in the uranium content of the bodies without producing fission; by absorption or capture in the moderator material; by absorption or capture by the impurities present in both the uranium bodies and the moderator; and by leakage out of the system through the periphery thereof. In a fast reactor all of these losses, except the last, are either substantially eliminated or are greatly reduced.

It has been discovered that stabilization of a fast neutron chain reaction is possible in view of the fact that a potentially chain reacting mass of this type has two definite critical dimensions, a smaller one at which the total neutron emission, including the delayed neutron emission, is capable of sustaining a reaction, and a larger critical dimension at which the instantaneous neutron emission alone is sufficient to sustain a chain reaction. If the chain reacting mass or reactor is operated at a size slightly greater than the smaller of these two values and considerably smaller than the larger of these two values (neutron reproduction ratio greater than 1.0 but not above about 1.01 or 1 plus the fraction of neutrons evolved which are delayed neutrons), the intensity of the chain reaction rises exponentially with time at a rate which is practically independent of the life time of the

DEUTSCHES PATENTAMT
Auskunftsstelle

8000 MÜNCHEN 2, den 24.Juni 1965
Zweibrückenstraße 12
Fernruf 22 94 51, Fernschreiber 05-23534
Fernrufdurchwahl über 22 94 5 Hausruf 3402
Postscheckkonto der Amtskasse: München 791 91
Girokonto der Amtskasse: Landeszentralbank München 6/154

PA-Nr.: 312 995 (W)
Ihr Zeichen: -.-
Eingabe vom: 15.Juni 1965

Frau
Dr.Gertrud Weiss Szilard M.D.
Dell Charro
2380 Torrey Pines Road
LA JOLLA CALIFORNIA 92038

Sehr geehrte Frau Weiss-Szilard!

In den Unterlagen des Deutschen Patentamts konnte für Herrn Dr.Leo Szilard nur eine Anmeldung ermittelt werden, auf die das Patent Nr. 965 522 erteilt wurde.

Die Unterlagen der bis zum 8.Mai 1945 beim ehemaligen Reichspatentamt eingereichten Anmeldungen befinden sich bei der Treuhandstelle Reichspatentamt, Berlin 61, Gitschiner Strasse 97-103. Ihre Anfrage vom 15.Juni 1965 wurde daher zur weiteren Erledigung dorthin weitergeleitet.

Hochachtungsvoll

(Großmann)

Pa

Uitgegeven 15 December 1928.

Auteursrecht voorbehouden.

Dagteekening octrooi 16 October 1928.

OCTROOIRAAD

NEDERLAND

OCTROOI N°. 19092.

KLASSE 21 *g*. GROEP 21.

SIEMENS-SCHUCKERTWERKE GESELLSCHAFT MIT BESCHRÄNKTER HAFTUNG, te Berlijn-Siemensstadt en Dr. LEO SZILARD, te Berlijn-Dahlem.

Ontladingsbuis voor regelbare ontlading.

Aanvrage 31155 Ned., ingediend 2 September 1925, 2 u. 38 m. n.m.; openbaar gemaakt 15 Juni 1928; voorrang van 3 September 1924 af (Duitschland).

De uitvinding heeft betrekking op een ontladingsbuis voor dergelijke doeleinden als van de bekende buizen met gloeikathoden. Bij deze laatste geschiedt de stroomdoorgang door de electronen, welke als gevolg van de hooge temperatuur van een gloeienden draad deze verlaten. Het is moeilijk op deze wijze hooge anodestroomsterkten te verkrijgen. Ook is de levensduur van den gloeidraad beperkt. Voorts is een belangrijke hoeveelheid energie voor de verhitting van den gloeidraad benoodigd, waardoor het nuttig effect van de buis gering blijft.

Bij een ontlading met geleidende gaskolom kunnen op veel voordeeliger wijze groote stroomen in stand worden gehouden en men kan hooge stroomsterkten zeer gemakkelijk in de boogontlading opwekken. Echter kunnen hier tengevolge van de vereischte hoogere drukken, die methoden voor regeling van den anodestroom, welke bij de hoog-vacuumbuizen worden toegepast, niet worden gevolgd.

Er is reeds een ontladingsbuis bekend met middelen voor het regelen van den stroom tusschen de anode en de kathode langs electrostatischen weg, waarbij de kathode door een kwikzilverdamphulpontlading gevormd wordt. De ruimte waarin de hulpontlading plaats vindt, staat daarbij met de anode- en regelroosterruimte door een vernauwd gedeelte in verbinding. De kwikzilverdamp van de hulpontlading stroomt door deze vernauwde plaats in de anoderuimte en condenseert aan de gekoelde anode den gekoelden regelrooster, en aan de wanden der anoderuimte. Met een dergelijke inrichting kan men echter het voor een werkzame regeling van den anodestroom noodige vacuum tusschen den regelrooster en de anode niet bereiken, aangezien bij het condenseeren van den kwikzilverdamp steeds nog een te hooge dampdruk van het kwikzilver in de regelruimte aanwezig is.

De uitvinding betreft een ontladingsbuis met middelen voor het regelen van den stroom tusschen anode en kathode langs electrostatischen of electromagnetischen weg, waarbij de inlaat van de kathoderuimte naar de ruimte, in welke de regeling plaats vindt, eveneens door vernauwde gedeelten plaats heeft (bij voorbeeld door een nauwe buis of door één of meer spleten). Volgens de uitvinding wordt ondanks het feit, dat een geleidende gasbaan van voldoend hoogen druk in de kathoderuimte aanwezig is, in de regelruimte door straalwerking of diffusiewerking en koeling der vernauwde gedeelten een voldoend vacuum verkregen, om aan het regelgedeelte van de buis het karakter van een electronenontlading te geven. De op zichzelf bekende vernauwing van den inlaat in de regelruimte is niet voldoende om dit te bereiken, er is nog de dampstraalwerking, zooals bij de op zichzelf bekende dampstraalpompen optreedt, of de diffusiewerking en de koeling der vernauwde gedeelten (van de spleet), zooals bij de op zichzelf bekende diffusiepompen optreedt, noodzakelijk.

Volgens de uitvinding kan verder een ontlading tusschen twee hulpelectroden in de geleidende gaskolom als kathode voor de hoofdontlading dienst doen.

Men krijgt op deze wijze een buis met de voordeelen van hoogvacuumbuizen, zonder de genoemde nadeelen daarvan. Opgemerkt wordt, dat het bij kwikzilverdampgelijkrichters, dus bij een ontladingsvat zonder regelwerking, bekend is den van de kathode opstijgenden dampstraal te benutten om aan de anoden het vacuum te verhoogen en het omkeeren van de stroomrichting of kortsluiting tusschen de anoden te verhinderen.

Verkrijgbaar bij het Bureau voor den Industrieelen Eigendom, te 's-Gravenhage.
Prijs per ex[illegible] f 2.50

Uitgegeven 15 November 1933.
Dagteekening 17 October 1933.

C. D. 621.57

Auteursrecht voorbehouden.

OCTROOIRAAD

NEDERLAND

OCTROOI N°. 31163.

KLASSE 17 *a*. 20.

Prof. Dr. ALBERT EINSTEIN, en Dr. LEO SZILARD,
beiden te Berlijn.

Werkwijze voor het comprimeeren van den damp van het koudmakend middel in een koelmachine en koelmachine, geschikt voor de toepassing van deze werkwijze.

Aanvrage 44262 Ned., ingediend 27 December 1928, 14 u. 52 m.; openbaar gemaakt 15 Juni 1933, voorrang van 27 December 1927 af, voor de conclusies 1, 3 en 4, en van 3 December 1928 af, voor conclusie 2, (Duitschland).

De uitvinding heeft betrekking op een werkwijze en een koelmachine van de in den titel omschreven bekende soort en bestaat daarin, dat de compressie van den damp van het koudmakend middel in een koelmachine wordt bewerkstelligd door een onder de heerschende bedrijfsomstandigheden vloeibaar metaal of vloeibare legeering van metalen, dat (die) door middel van daarin opgewekte electrische stroomen door inwerking van een magnetisch veld wordt bewogen.

Bij voorkeur wordt volgens de uitvinding als het de compressie bewerkstelligende vloeibare metaal een vloeibaar alkalimetaal of een legeering hiervan of een overeenkomstige lichte metallische vloeistof toegepast. Men kan voor de doeleinden der uitvinding met voordeel kalium of natrium of legeeringen daarvan gebruiken.

De koelmachine geschikt voor toepassing der werkwijze, is ter vermijding van wervelingen, welke verliezen met zich mede zouden brengen, volgens de uitvinding voorzien van een ringvormige ruimte, gevormd door deelen van twee coaxiale cylinder- of kegelmantels, waardoorheen het, de compressie bewerkstelligende, vloeibare metaal stroomt en waarbij twee of meer electrische wikkelingen zijn aangebracht, waardoor in de ringvormige ruimte een radiaal magnetisch veld met hierin circuleerende electrische stroomen kan worden opgewekt, een en ander zoodanig, dat de richting der ponderomotorische kracht op het vloeibare metaal overeenkomt, met die der beschrijvende lijn van het cylinder- of kegeloppervlak.

Door deze constructie ontstaan geen wervelingen, zooals kan blijken door het toepassen van de stelling van Stokes, waarbij de lijnintegraal langs een gesloten kromme gelijk is aan de oppervlakte-integraal van de rotatie van de betreffende krachten, besloten door genoemde kromme.

Het is op zichzelf bekend om een vloeibaar metaal door de inwerking van een magnetisch veld in beweging te brengen.

Zoo wordt volgens het Duitsche octrooischrift No. 363.720 in een kwikdampgelijkrichter kwik uit de kathoderuimte geleid, gekoeld en weer teruggevoerd. De beweging van het kwik geschiedt hier door de inwerking van een magnetisch veld. In tegenstelling met de koelmachine volgens de uitvinding bevindt zich hierbij de bedrijfsvloeistof niet in een ringvormige ruimte, doch in een platgedrukte buis. Dientengevolge moeten de in het kwik geïnduceerde stroomlijnen, die in het midden van de platte buis loodrecht op de buisas verloopen, aan de beide randen omkeeren. De krachtlijnen van het electrische veld loopen dus aan de beide randen evenwijdig met de as. Onder deze omstandigheden is echter aan de beide randen geen bewegende kracht in de richting van de buis aanwezig. Hierdoor en door het hooge specifieke gewicht van kwik ontstaat het gevaar, dat in het kwik wervelingen ontstaan, die het nuttig effect nadeelig beïnvloeden. Dit nadeel wordt door de bovengenoemde constructie van de koelmachine volgens de uitvinding vermeden. In bepaalde gevallen wordt met voordeel volgens de uitvinding de stroomingsrichting van de de compressie bewerkstelligende vloeistof intermitteerend omgekeerd.

De toepassing van een vloeibaar alkalimetaal volgens de uitvinding brengt het voordeel met zich mede, dat de dampdruk van de de compressie bewerkstelligende vloeistof laag is. Hierdoor zal het bedrijfsmiddel niet in die deelen van de apparatuur overdestilleeren, waarin het storingen zou kunnen veroorzaken.

Zuivere alkalimetalen zijn bij kamer-

Verkrijgbaar bij het Bureau voor den Industrieelen Eigendom, te 's-Gravenhage.
Prijs per ex[redacted] f 2.50

TREUHANDSTELLE
REICHSPATENTAMT **Informationsamt für gewerbliche Schutzrechte**

Auskunftsstelle Pat/GM.
Gesch.-Z.: W 1/ 728- W/Gt.-
(Angabe bei Antwort erbeten)
Ihr Zeichen: --

1 Berlin 61, den 30. Juli 1965
Gitschiner Str. 97 - 103 · Fernsprecher: 61 03 61 App.
Fernschreiber: 01 83 604 dtpatamtdst bln
Postscheckkonto: Berlin West Nr. 70 für
Kasse der Treuhandstelle Reichspatentamt
Bankkonto: Landeszentralbank in Berlin, Girokonto Nr. 1/1542

278

Madame
Dr. Gertrud Weiss Szilard, M.D.
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Betr.: Professor Dr. Leo Szilard
Vorg.: Ihre Schreiben vom 15.6. u. 24.7.1965
- Unser Schreiben vom 8.7.1965 -

Sehr geehrte Frau Doktor Weiss-Szilard!

Auf den Namen

Dr. Leo Szilard, Berlin-Dahlem
bzw. Berlin-Wilmersdorf, bzw. London,

wurden in dem Zeitraum von 1920 bis 8.5.1945 die folgenden deutschen Schutzrechte ermittelt:

1. P a t e n t e :

Patent-Nr. Kl./Gr.:	v o m:	Bezeichnung:
562 300/17a, 1/01	15. 4. 30	Kältemaschine Berlin Inhaber: Dr. Albert Einstein und Dr. Leo Szilard, Berlin-Wilmersdorf
533 945/17a, 3/02	25. 4. 29	Pumpe
531 581/17a,3/04	4. 6. 29	Pumpe, insbesondere zur Verdichtung von Gasen und Dämpfen in Kältemaschinen
543 214/17a,3/04	4. 6. 29	Vorrichtung zur Bewegung von flüssigen Metallen

-Bl. 2 -

Patente-Nr.Kl./Gr.:	v o m:	Bezeichnung:
548 136 / 17a, 3/04	7. 1. 31	Kältemaschine
554 959/17a, 3/04	28.12. 27	Vorrichtung zur Bewegung von flüssigem Metall, insbesondere zur Verdichtung von Gasen und Dämpfen in Kältemaschinen Inhaber: Dr. Leo Szilard, Berlin-Wilmersdorf u n d Dr. Albert Einstein, Berlin
555 141 " "	4. 6. 29	Vorrichtung zur Bewegung von flüssigen Metallen
555 413 " "	4.12. 28	Pumpe, vorzugsweise für Kältemaschinen Inhaber: Dr.Albert Einstein, Berlin und Dr. Leo Szilard, Berlin-Wilmersdorf
556 535 " "	15. 4. 30	Pumpe, vorzugsweise für Kältemaschinen Inhaber: wie vor - Zusatz zum Patent 555 413 -
556 536 " "	4. 6. 29	Kältemaschine
561 904 " "	15. 4. 30	Kältemaschine Inhaber: Dr.Albert Einstein, Berlin und Dr. Leo Szilard, Berlin-Wilmersdorf
563 403 " "	13.11. 27	Kältemaschine Inhaber: wie vor
564 680 " "	7. 1. 31	Kältemaschine
565 614 " "	11. 9. 29	Kompressor Inhaber: Dr. Albert Einstein, Berlin und Dr. Leo Szilard, Berlin-Wilmersdorf
568 680 " "	7. 1. 31	Stator für Kältemaschinen
570 959 " "	4. 6. 29	Vorrichtung zur Bewegung von flüssigem Metall
581 780 " "	3. 1. 31	Kompressor, im besonderen für Kältemaschinen
494 810/17a, 12	13. 6.28	Intermittierend wirkende Kältemaschine mit getrenntem Kocher und Absorber

Patent-Nr. Kl.:/Gr.:	v o m:	Bezeichnung:
508 486/17a, 13/03	1. 11. 27	Kältemaschine
562 898/17a, 13/03	10. 9. 30	Wärmeübertrager
562 523 ", 14	26. 6. 31	Absperrorgan
480 037/17c,3/11	9.10. 27	Kältespeicher
562 040 /21d[1], 22	1. 6. 28	Elektromagnetische Vorrichtung zur Erzeugung einer oszillierenden Bewegung Inhaber: Dr. Leo Szilard, Berlin-Wilmersdorf und Dr. Albert Einstein, Berlin
504 545/21g, 12/03	13.11. 24	Entladungsröhre mit Steuerung des Anodenstromes
515 054/21g, 12/03	4. 9. 24	Entladungsröhre, bei welcher eine Gasentladung als Elektronenquelle dient
579 679/21g, 12/03	4. 9. 24	Entladungsröhre bei welcher eine Gasentladung als Elektronenquelle dient
399 056/21g, 18/02	9.10. 23	Für Röntgenstrahlen empfindliche Zelle Inhaber: Dr. Leo Szilard, Berlin-Dahlem und Dipl.-Ing. Imre Patai, Budapest
476 812/31c, 26/01	20.1. 26	Verfahren zum Gießen von Metallen in Formen unter Anwendung elektrischer Ströme
600 162/42g, 11/01	17.5. 31	Verfahren zum elektrochemischen Aufzeichnen von Sprechströmen

2. bekanntgemachte Patentanmeldungen

S 89 172 der Klasse 21g, Gruppe 21 vom 24.12.1928
Bez.: " Verfahren zur Beschleunigung des Zerfalls schwach aktiver oder radioaktiver Substanzen"
- bekanntgemacht: 28.4.1932 -
-zurückgezogen: 3.11.1932-

S 99 399 der Klasse 42 k, Gruppe 30/01 vom 25.6.1931
Bez.: " Einrichtung zur Dichtigkeitsprüfung von luftdicht zu verschließenden Apparaten, insbesondere von Kältemaschinen mit dünnwandigen Behältern"
- bekanntgemacht: 16.3.1933 -
-zurückgezogen: 6.4.1933 -
Anmelder: Leo Szilard, London

S 105 894 der Klasse 17a, Gruppe 9/01 vom 19.8.1932
Bez.: " Intermittierend wirkende Absorptions-kältemaschine "
- bekanntgemacht: 18.10.1934 -
- zurückgezogen: 14.2.1935 -

3. eingetragene Gebrauchsmuster:

nicht ermittelt.

- - - - - - - - -

Unterlagen sind hier in größerem Umfange noch bis 8.5.1945 vorhanden.
Bekanntmachungen von Patentanmeldungen wurden jedoch nur bis 30.9.1943 veröffentlicht.

Diese Auskunft wird ohne Gewähr für Vollständigkeit erteilt.

Von den genannten Patentschriften können Druckexemplare zum Preise von je 1,30 DM bzw. - falls vergriffen - Ablichtungen zum Preise von 0,60 DM je Seite von unserer Lichtbildstelle bezogen werden.

Hochachtungsvoll
Im Auftrage

Anl.:
1 Gebührenrechnung

(Warnatsch)

PS. Die in Ihrem Schreiben vom 15.6.1965 erwähnten Patentanmeldungen S 89.028 bezw. S 89.288 konnten hier nicht ermittelt werden, desgleichen die Anmeldung vom 5.11.1924 (Kathodenröhre). Bei der Patentanmeldung vom 27.12.1927 (elektrodynamische Bewegung von flüssigen Metallen) dürfte es sich um das auf Seite 2 unserer Aufstellung erwähnte Patent 554.959, 17a, 3/04, handeln.
D.O.

Luftpost