Histoire du nucléaire

Les découvertes fondamentales (Pr. J. Foos)

Pierre et Marie Curie aux origines de l'énergie nucléaire

La genèse de l'énergie nucléaire (1939-1945)

Le premier réacteur et la première bombe

La maturité de l'énergie nucléaire (1945-1975)

Le développement des filières

Heurts et malheurs de l'énergie nucléaire

Radioprotection, accidents, et prolifération…

Les perspectives du nucléaire au XXI° siècle

La genèse de l'énergie nucléaire (1939-1945)

Etat des connaissances au 1° septembre 1939

Les connaissances scientifiques acquises et ce qui reste à faire

Etat des équipes de recherche au moment de la guerre

Le premier réacteur : la pile de Chicago (CP1)

Description du réacteur : les grands principes

L'aventure de Fermi et la première divergence

Le projet Manhattan (vendredi prochain)

Objectifs et moyens mis en place

Les réalisations : Alamogordo, Hiroshima et Nagasaki

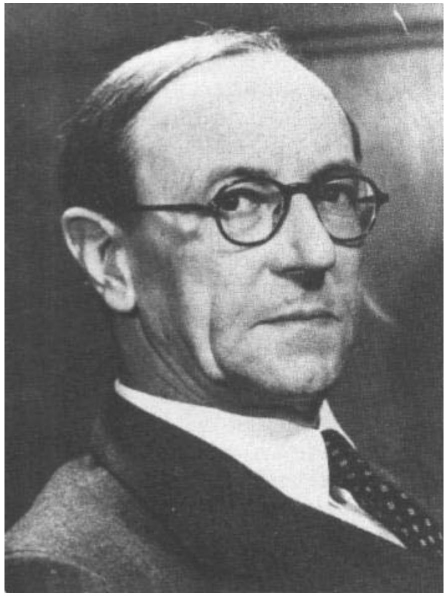
La communauté scientifique d'avant-guerre (1927)

Congrès de SOLVAY (1933)

H. A. Kramers N. F. Mott G. Gamow P. Blackett M. Cosyns A. Piccard
E. Stahel P.A. M. Dirac J. Errera C. D. Ellis E. O. Lawrence
E. Henriot F. Joliot W. Heisenberg E. Walton P. Debye B. Cabrera W. Bothe E. Bauer J. Verschaffelt J. Cockcroft L. Rosenfeld
F. Perrin E. Fermi M. Rosenblum W. Pauli E. Herzen R. Peierls
E. Schroedinger I. Joliot N. Bohr A. Joffe M. Curie O. Richardson E. Rutherford M. De Broglie L. Meitner J. Chadwick
P. Langevin T. De Donder L. De Broglie
Absent: A. Einstein and E. Guye

1932 : CHADWICK "naissance" du neutron $^{9}Be\ (\alpha, n)\ ^{12}C$.

Découverte du neutron par bombardement α du Béryllium 9



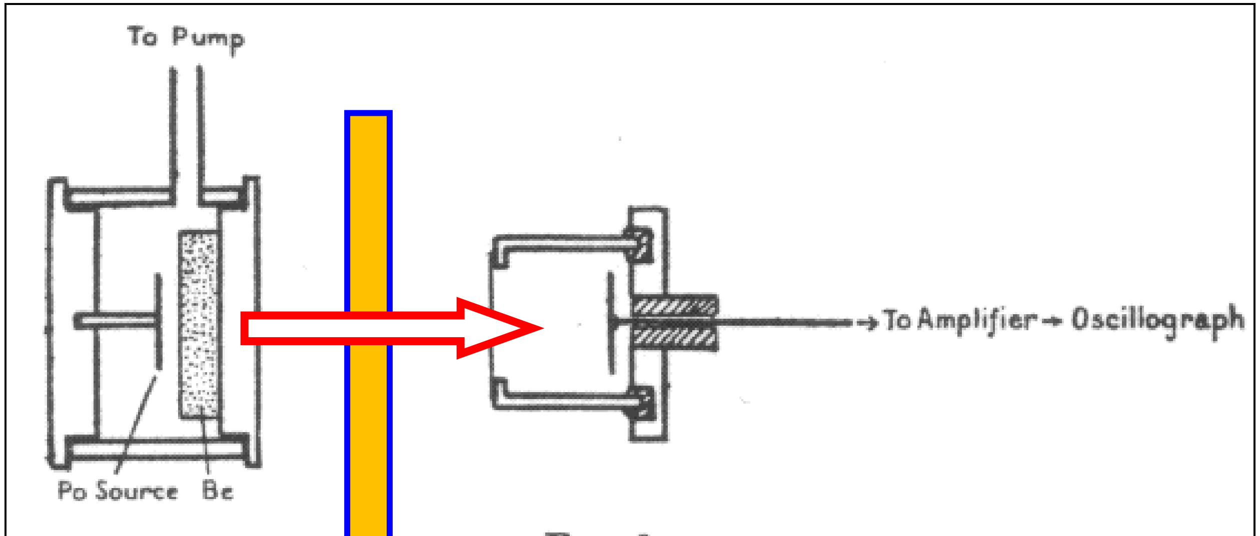
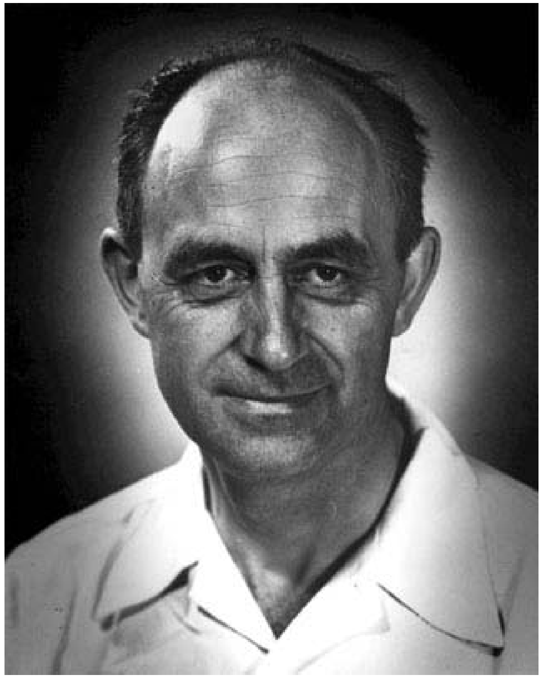


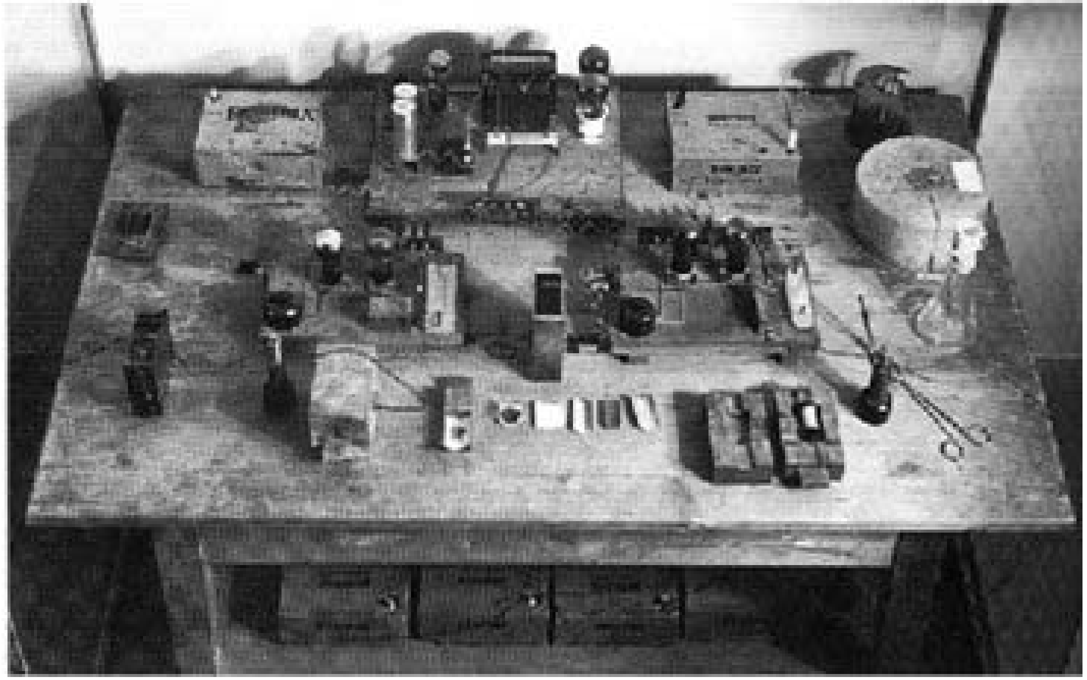
Fig. 1.

Curie montre que ce rayonnement est **particulaire neutre**

par déplacement d'un faisceau dirigé d'ion H+

1934 : Première réaction de fission de l'Uranium





Enrico FERMI bombarde des noyaux d'uranium avec des neutrons

Il obtient des transuraniens inconnus **au tableau de Mendeleiev**

Otto HAHN reprend l'expérience et analyse les produits

1938: Hahn et Strassman étudient le phénomène

"Verification of the Creation of Radioactive Barium Isotopes from Uranium and Thorium by Neutron Irradiation; Identification of Additional Radioactive Fragments from Uranium Fission"

O. HAHN AND F. STRASSMANN

Naturwissenschaften, Volume **27**, pp. 89–95
(10 February 1939)
translated by H. Graetzer

. . . Summary:

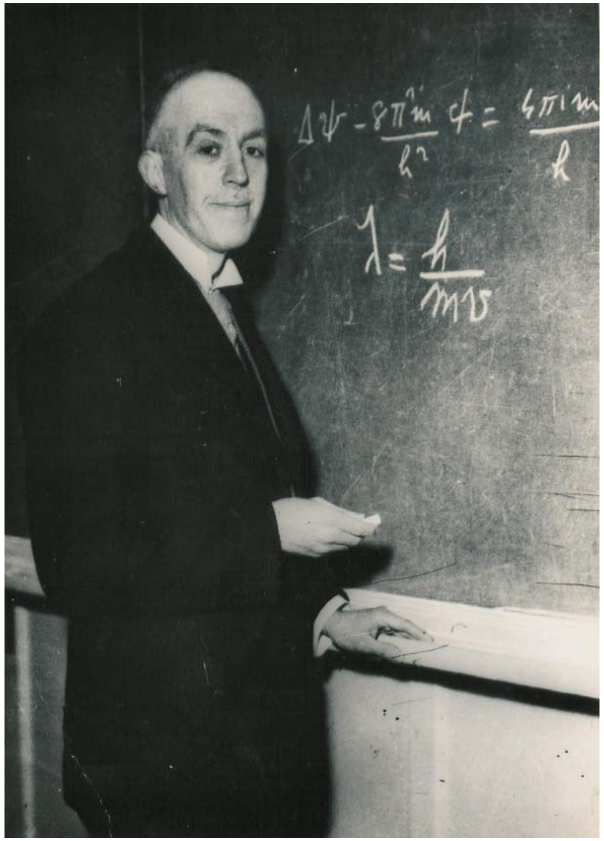
1. The creation of barium isotopes from uranium was conclusively demonstrated.
2. For thorium, the formation of barium isotopes was also established.
3. Some suggestions are made regarding the atomic weights of the barium isotopes.
4. Evidently, some of the barium isotopes produced from thorium and uranium are identical.
5. It is our belief that the "transuranic elements" still retain their placement without change, as previously described.
6. A second group of fission fragments, Strontium [element 38] and Yttrium [element 39], was determined.
7. By an appropriate experimental arrangement, the formation of a noble gas was established, which in turn decays into an alkali metal. It has not been possible yet to show if the substances in question are xenon-cesium or krypton-rubidium.

In a rather short time it has been possible to identify numerous new reaction products described above—with considerable certainty, we believe—only because of the previous experience we had gathered, in association with L. Meitner, from the systematic study of uranium and thorium reaction products.

Lise Meitner et Otto Frisch modélisent la réaction

Le phénomène dégage environ 200 MeV

et produit plus de neutron qu'il n'en consomme



L. de Broglie

Letters to the Editor

The Editor does not hold himself responsible for opinions expressed by his correspondents. He cannot undertake to return, or to correspond with the writers of, rejected manuscripts intended for this or any other part of NATURE. *No notice is taken of anonymous communications.*

NOTES ON POINTS IN SOME OF THIS WEEK'S LETTERS APPEAR ON P. 247.

CORRESPONDENTS ARE INVITED TO ATTACH SIMILAR SUMMARIES TO THEIR COMMUNICATIONS.

Disintegration of Uranium by Neutrons: a New Type of Nuclear Reaction

ON bombarding uranium with neutrons, Fermi and collaborators[1] found that at least four radioactive substances were produced, to two of which atomic numbers larger than 92 were ascribed. Further investigations[2] demonstrated the existence of at least nine radioactive periods, six of which were assigned to elements beyond uranium, and nuclear isomerism had to be assumed in order to account for their chemical behaviour together with their genetic relations.

In making chemical assignments, it was always assumed that these radioactive bodies had atomic numbers near that of the element bombarded, since only particles with one or two charges were known to be emitted from nuclei. A body, for example, with similar properties to those of osmium was assumed to be eka-osmium ($Z = 94$) rather than osmium ($Z = 76$) or ruthenium ($Z = 44$).

Following up an observation of Curie and Savitch[3], Hahn and Strassmann[4] found that a group of at least three radioactive bodies, formed from uranium under neutron bombardment, were chemically similar to barium and, therefore, presumably isotopic with radium. Further investigation[5], however, showed that it was impossible to separate these bodies from barium (although mesothorium, an isotope of radium, was readily separated in the same experiment), so that Hahn and Strassmann were forced to conclude that *isotopes of barium* ($Z = 56$) *are formed as a consequence of the bombardment of uranium* ($Z = 92$) *with neutrons.*

that the surface tension of a charged droplet is diminished by its charge, and a rough estimate shows that the surface tension of nuclei, decreasing with increasing nuclear charge, may become zero for atomic numbers of the order of 100.

It seems therefore possible that the uranium nucleus has only small stability of form, and may, after neutron capture, divide itself into two nuclei of roughly equal size (the precise ratio of sizes depending on finer structural features and perhaps partly on chance). These two nuclei will repel each other and should gain a total kinetic energy of *c.* 200 Mev., as calculated from nuclear radius and charge. This amount of energy may actually be expected to be available from the difference in packing fraction between uranium and the elements in the middle of the periodic system. The whole 'fission' process can thus be described in an essentially classical way, without having to consider quantum-mechanical 'tunnel effects', which would actually be extremely small, on account of the large masses involved.

After division, the high neutron/proton ratio of uranium will tend to readjust itself by beta decay to the lower value suitable for lighter elements. Probably each part will thus give rise to a chain of disintegrations. If one of the parts is an isotope of barium[5], the other will be krypton ($Z = 92 - 56$), which might decay through rubidium, strontium and yttrium to zirconium. Perhaps one or two of the supposed barium-lanthanum-cerium chains are then actually strontium-yttrium-zirconium chains.

It is possible[3], and seems to us rather probable,

It might be mentioned that the body with half-life 24 min.[2] which was chemically identified with uranium is probably really ^{239}U, and goes over into an eka-rhenium which appears inactive but may decay slowly, probably with emission of alpha particles. (From inspection of the natural radioactive elements, ^{239}U cannot be expected to give more than one or two beta decays; the long chain of observed decays has always puzzled us.) The formation of this body is a typical resonance process[8]; the compound state must have a life-time a million times longer than the time it would take the nucleus to divide itself. Perhaps this state corresponds to some highly symmetrical type of motion of nuclear matter which does not favour 'fission' of the nucleus.

LISE MEITNER.

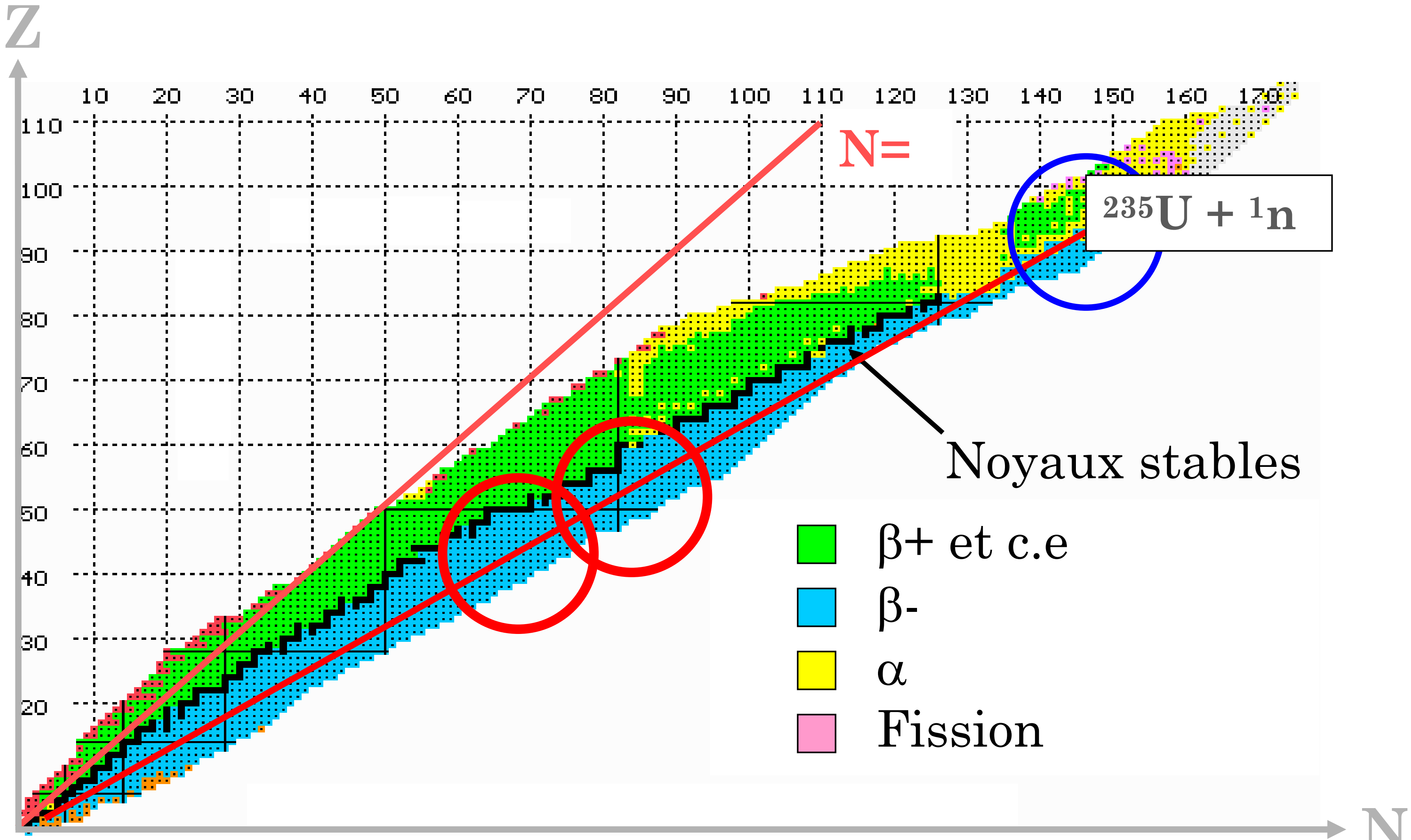
Physical Institute,
Academy of Sciences,
Stockholm.

O. R. FRISCH.

Institute of Theoretical Physics,
University,
Copenhagen.
Jan. 16.

[1] Fermi, E., Amaldi, F., d'Agostino, O., Rasetti, F., and Segrè, E. *Proc. Roy. Soc.*, A, **146**, 483 (1934).
[2] See Meitner, L., Hahn, O., and Strassmann, F., *Z. Phys.*, **106**, 249 (1937).
[3] Curie, I., and Savitch, P., *C.R.*, **208**, 906, 1643 (1938).
[4] Hahn, O., and Strassmann, F., *Naturwiss.*, **26**, 756 (1938).
[5] Hahn, O., and Strassmann, F., *Naturwiss.*, **27**, 11 (1939).
[6] Bohr, N., NATURE, **137**, 344, 351 (1936).
[7] Bohr, N., and Kalckar, F., *Kgl. Danske Vid. Selskab, Math. Phys. Medd.*, **14**, Nr. 10 (1937).
[8] See Meitner, L., Strassmann, F., and Hahn, O., *Z. Phys.*, **109**, 538 (1938).
[9] Bethe, A. H., and Placzek, G., *Phys. Rev.*, **51**, 450 (1937).

Les fragments de fission sont trop riches en neutrons



1939 : Frédéric Joliot-Curie quantifient la réaction en chaîne

Dépôts des premiers brevets secrets... (1939-1940)

SERVICE
de la PROPRIÉTÉ INDUSTRIELLE

Gr. 12. — Cl. 2. N° 971.384

Perfectionnement aux dispositifs producteurs d'énergie.

MM. HANS HEINRICH VON HALBAN, JEAN-FRÉDÉRIC JOLIOT et LEW KOWARSKI résidant en France (Seine).

Demandé le 30 avril 1940, à 11h 6m, à Paris.
Délivré le 12 juillet 1950. — Publié le 16 janvier 1951.

SERVICE
de la PROPRIÉTÉ INDUSTRIELLE

Gr. 12. — Cl. 2. N° 971.386

Perfectionnements apportés aux dispositifs de production d'énergie.

MM. HANS HEINRICH VON HALBAN, JEAN-FRÉDÉRIC JOLIOT et LEW KOWARSKI résidant en France (Seine).

Demandé le 1er mai 1940, à 11h 30m, à Paris.
Délivré le 12 juillet 1950. — Publié le 16 janvier 1951.

SERVICE
de la PROPRIÉTÉ INDUSTRIELLE

Gr. 5. — Cl. 2. N° 976.541

Dispositif de production d'énergie.

CAISSE NATIONALE DE LA RECHERCHE SCIENTIFIQUE résidant en France (Seine).

Demandé le 1er mai 1939, à 16h 55m, à Paris.
Délivré le 1er novembre 1950. — Publié le 19 mars 1951.

SERVICE
de la PROPRIÉTÉ INDUSTRIELLE

Gr. 12. — Cl. 2. N° 976.542

Procédé de stabilisation d'un dispositif producteur d'énergie.

CAISSE NATIONALE DE LA RECHERCHE SCIENTIFIQUE résidant en France (Seine).

Demandé le 2 mai 1939, à 14h 12m, à Paris.
Délivré le 1er novembre 1950. — Publié le 19 mars 1951.

RÉPUBLIQUE FRANÇAISE

MINISTÈRE
DE L'INDUSTRIE ET DU COMMERCE

BREVET D'INVENTION

SERVICE
de la PROPRIÉTÉ INDUSTRIELLE

Gr. 14. — Cl. 3. N° 971.324

Perfectionnements aux charges explosives.

CAISSE NATIONALE DE LA RECHERCHE SCIENTIFIQUE résidant en France (Seine).

Demandé le 4 mai 1939, à 15h 35m, à Paris.
Délivré le 12 juillet 1950. — Publié le 16 janvier 1951.

(Brevet d'invention dont la délivrance a été ajournée en exécution de l'article 11, § 7, de la loi du 5 juillet 1844 modifiée par la loi du 7 avril 1902.)

On sait que l'absorption d'un neutron par un noyau d'uranium peut provoquer la rupture de ce dernier avec dégagement d'énergie et émission de nouveaux neutrons en nombre en moyenne supérieur à l'unité. Parmi les neutrons ainsi émis, un certain nombre peuvent à leur tour provoquer sur des noyaux d'uranium, de nouvelles ruptures, et les ruptures de nouveau

en utilisant la formule suivante, valable pour une masse sphérique :

$$M = \frac{4}{3} \times \pi^4 \left[3 D (n P - A)\right]^{-\frac{3}{2}}$$

dans laquelle :

D est la somme, pour tous les corps simples

Etat des connaissances...

Que reste-t-il à découvrir...

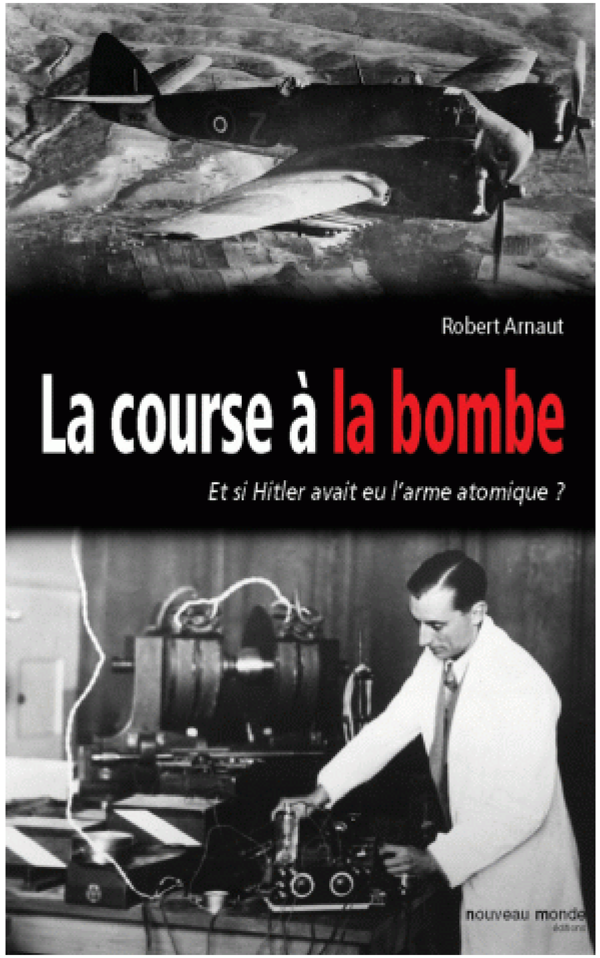
Où sont les centres de recherche...

Existe-t-il une théorie

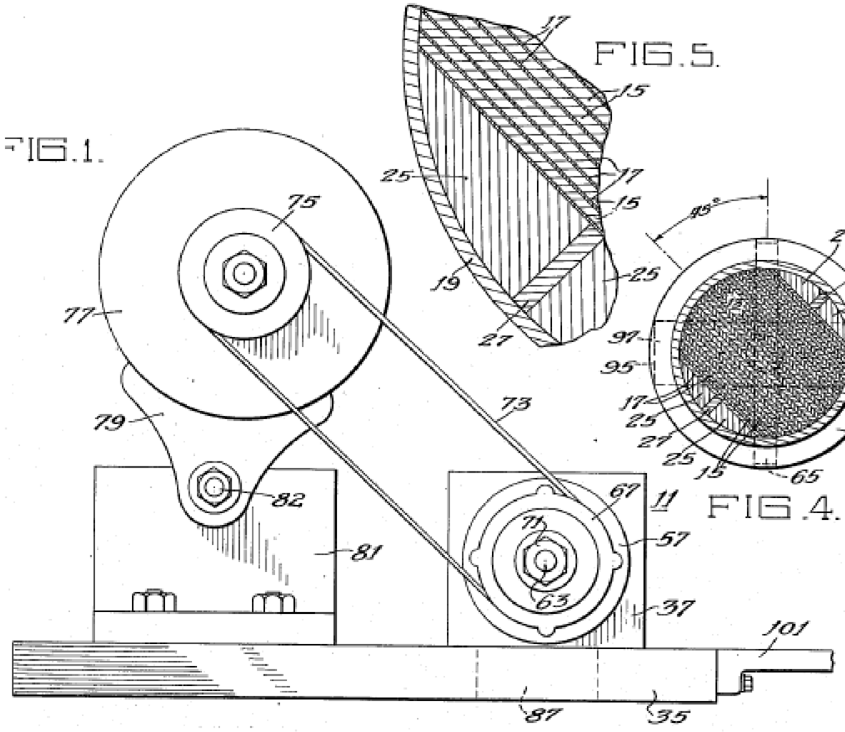
et un modèle de réacteur...

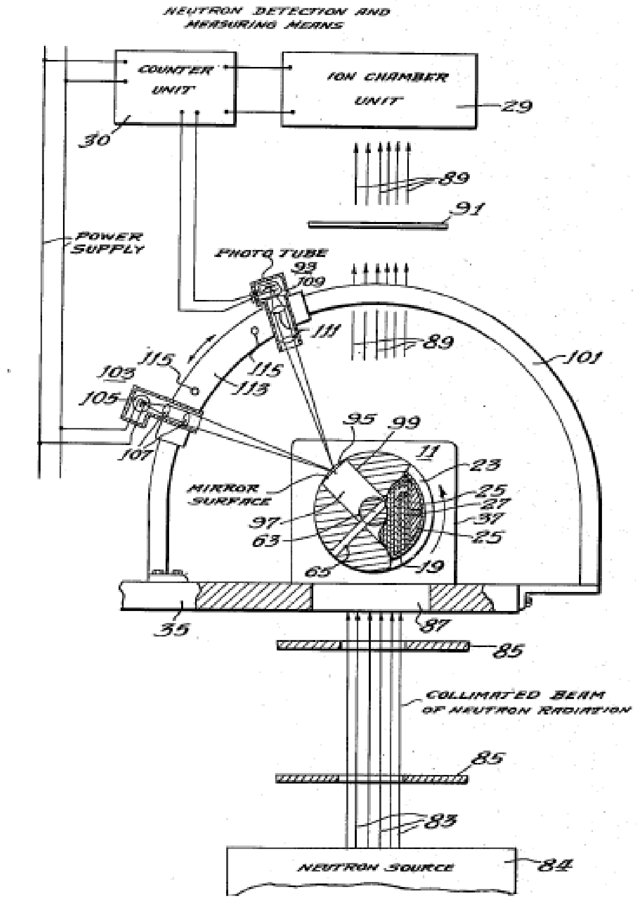
Réacteur ou arme ?

Le grand dilemme...



Prévoir les interactions : mesures de sections efficaces





Le Chopper de Fermi et Szilard

Les premiers résultats... (cours de Fermi 1945)

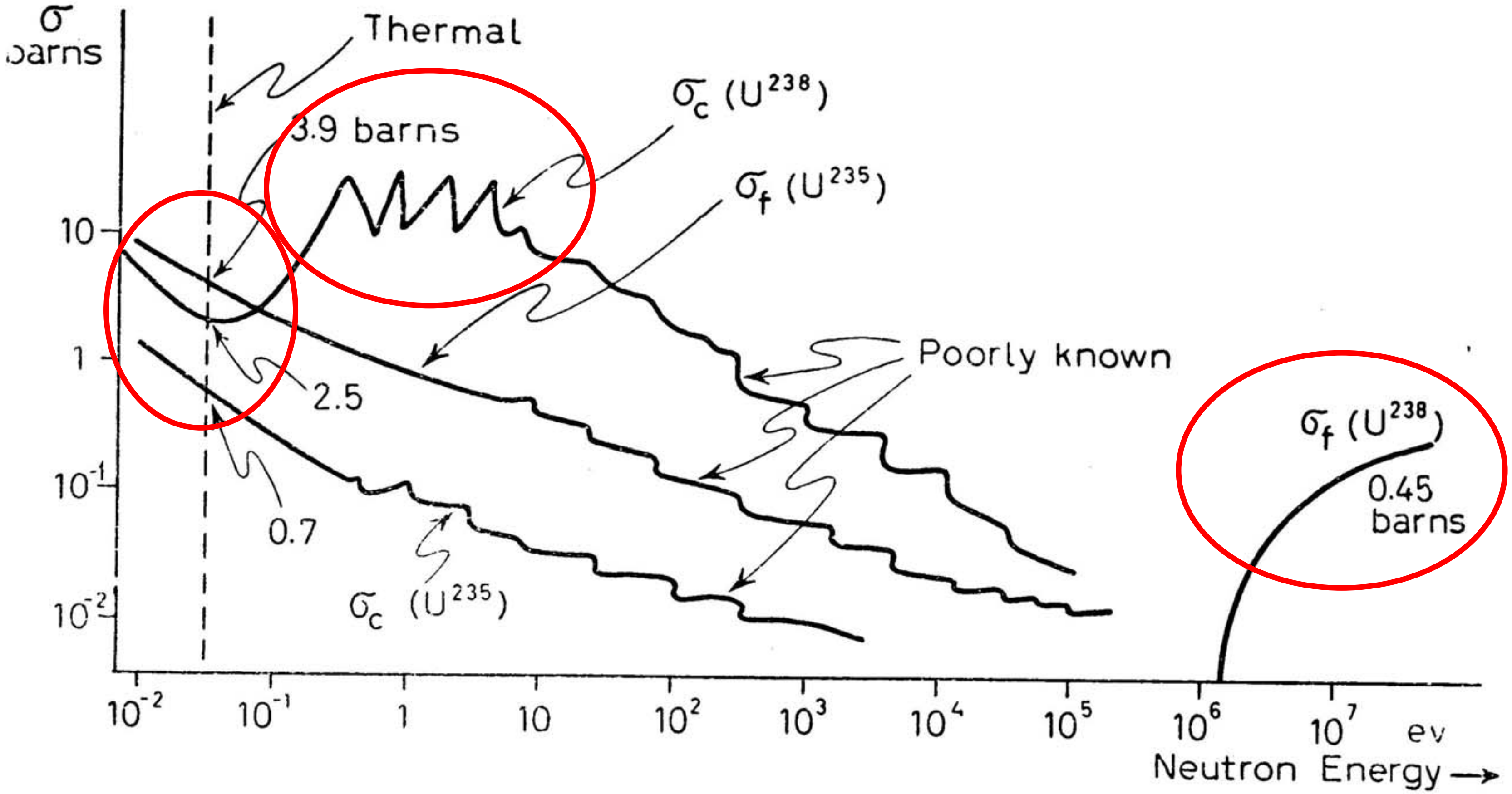
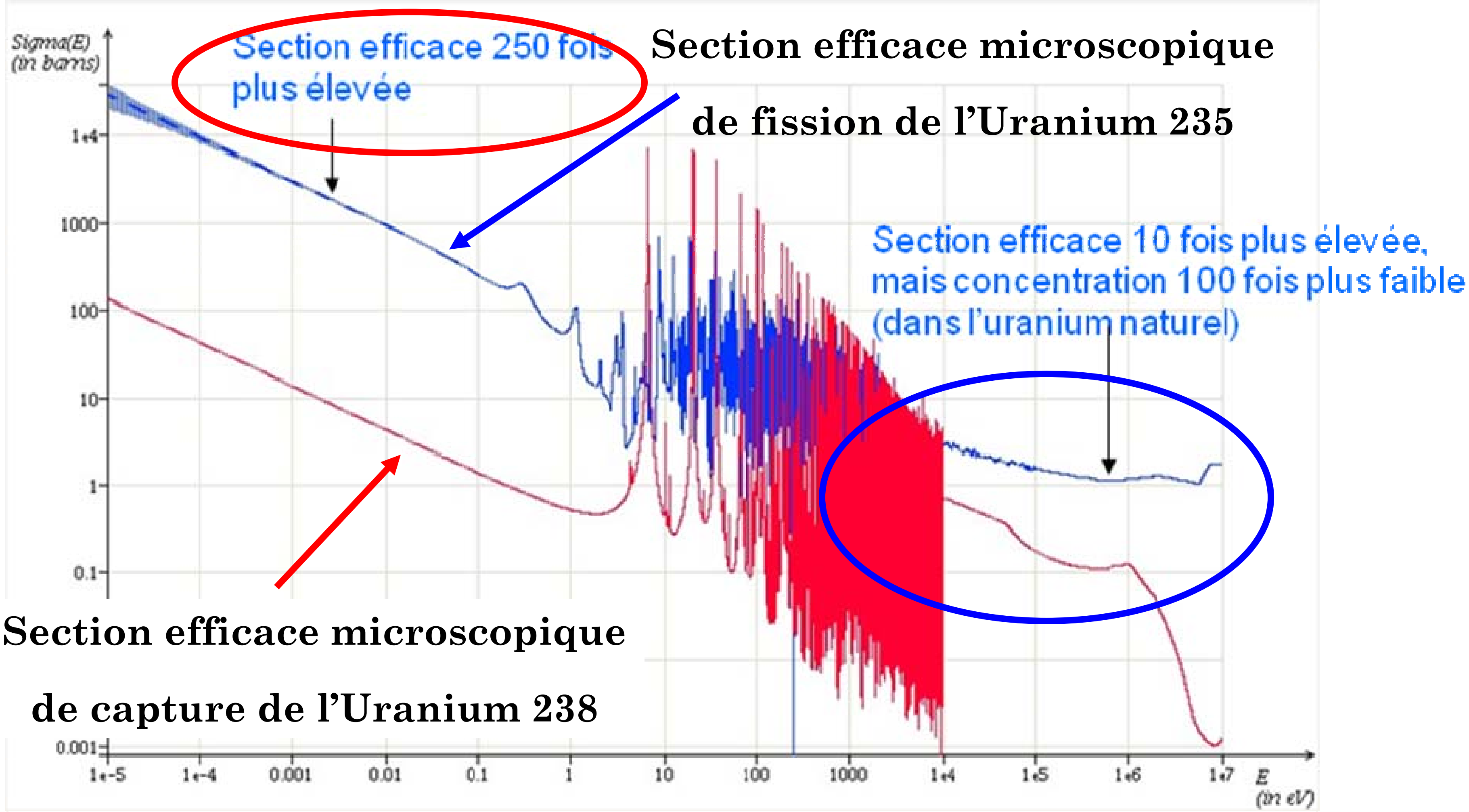


Fig. 77. – Uranium cross sections (separated isotopes).

Les mesures actuelles…



Comprendre et modéliser la matière...

E=mc², Einstein

Modèle du noyau (Bohr, 1935)

Le modèle de la goutte...

Niveaux d'énergie et résonances

Faciliter la fission...

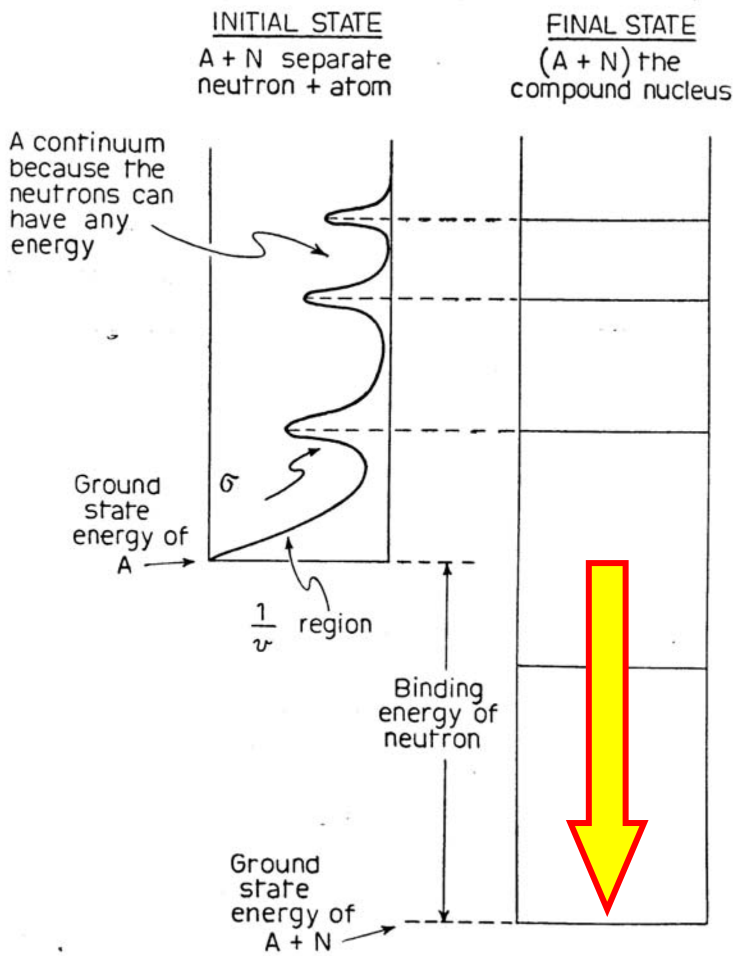


Fig. 24. – Nuclear energy levels.

Quel modérateur choisir ?

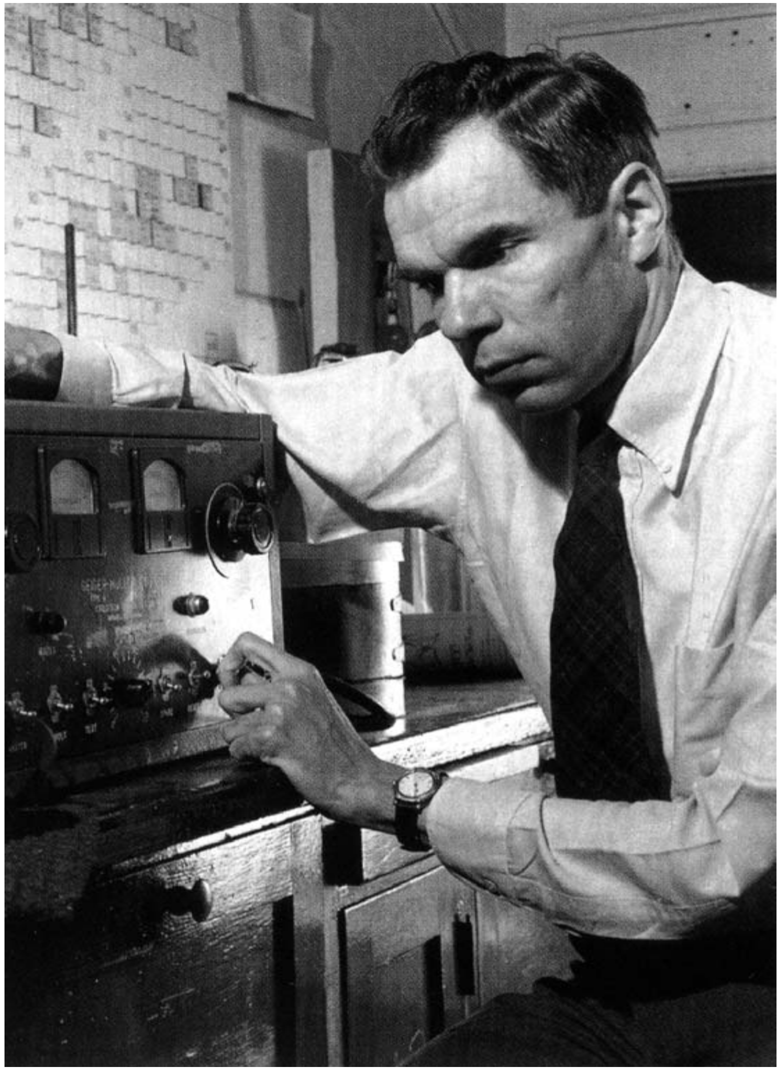
Eau lourde ou graphite ?

La découverte du Plutonium (1940)

$$ {}^{2}_{1}\mathbf{H} + {}^{238}_{92}\mathbf{U} \longrightarrow 2\,{}^{1}_{0}\mathbf{n} + {}^{238}_{93}\mathbf{Np} $$

puis

$$ {}^{238}_{93}\mathbf{Np} \longrightarrow {}^{0}_{-1}\mathbf{e} + {}^{0}_{0}\bar{\nu} + {}^{238}_{94}\mathbf{Pu} \quad (\mathrm{T}_{1/2} = 2{,}1\ \mathrm{j}) $$



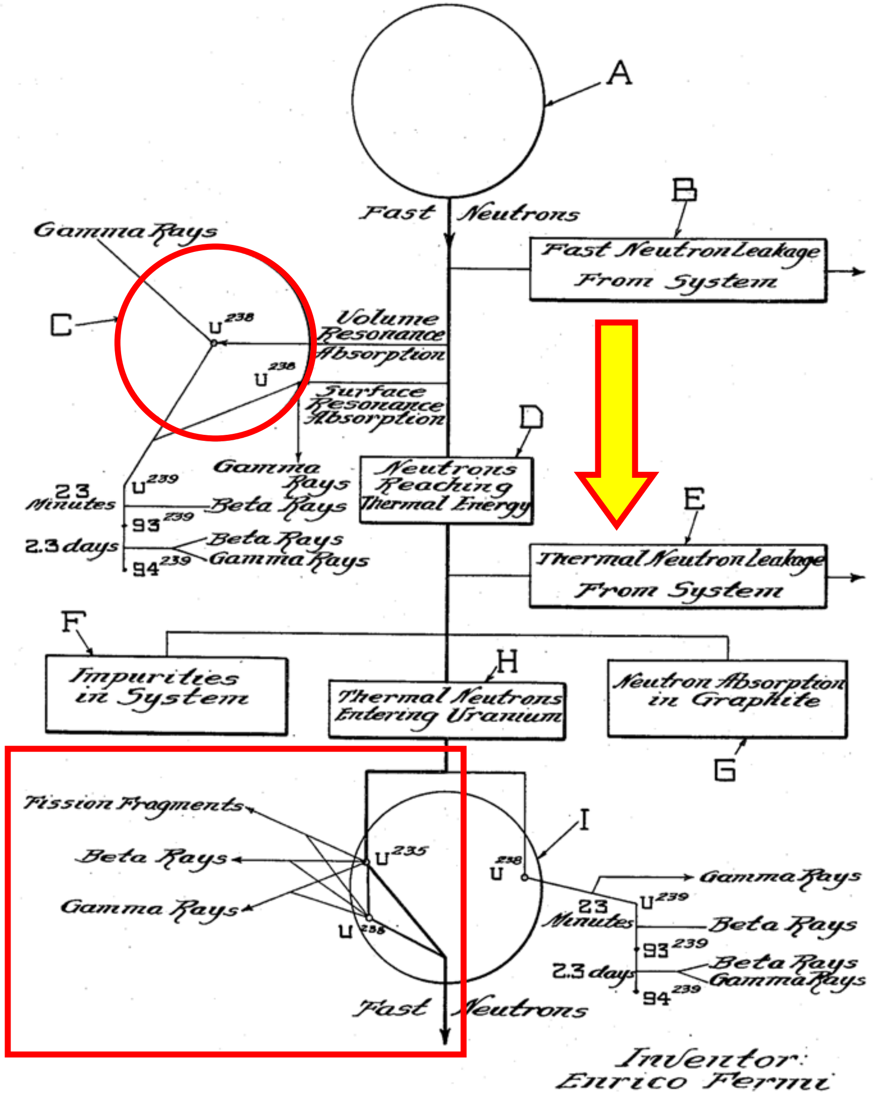
La formule des quatre facteurs (E. Fermi, 1940)

De la matière fissile…

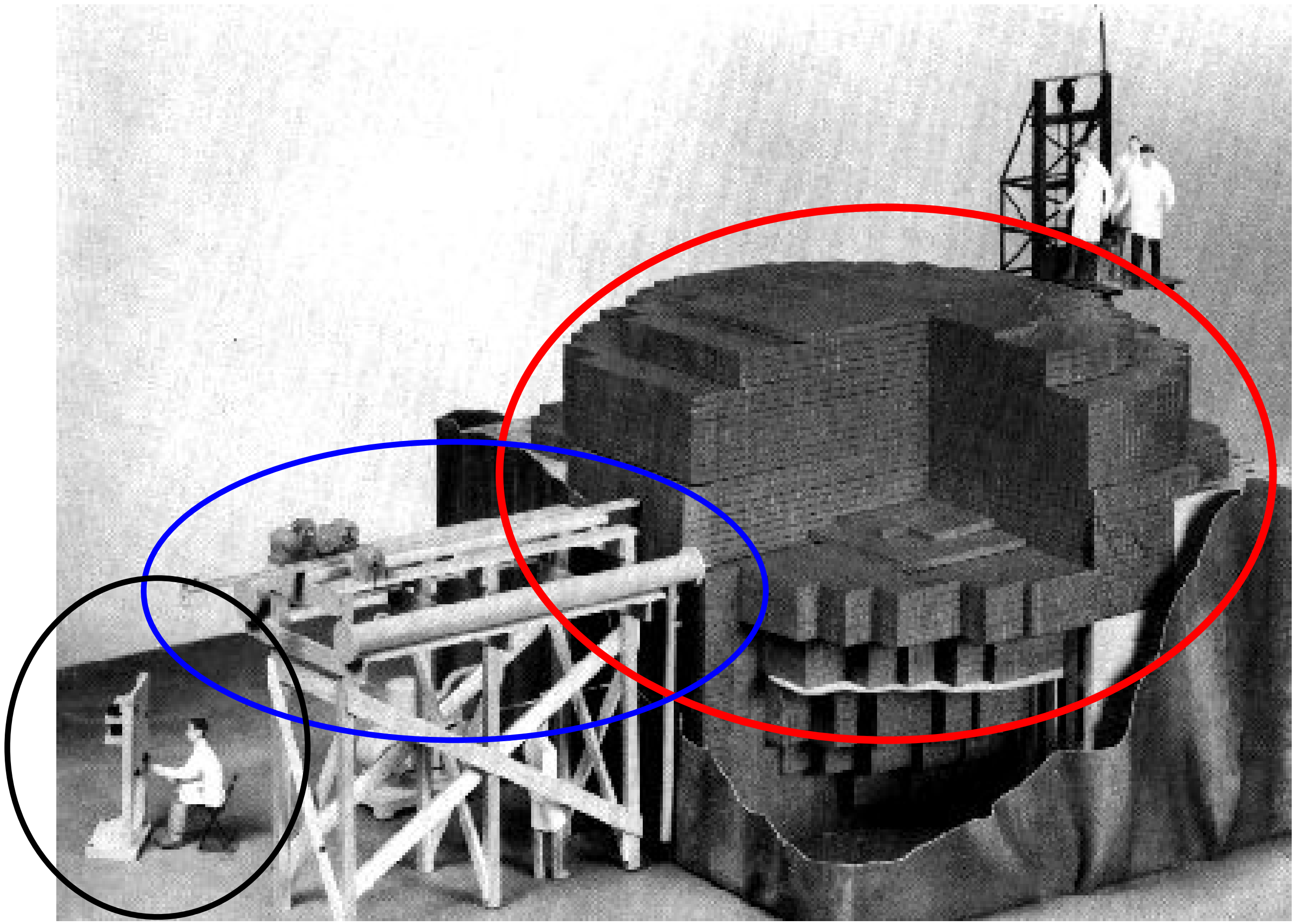
Un modérateur…

Des absorbants…

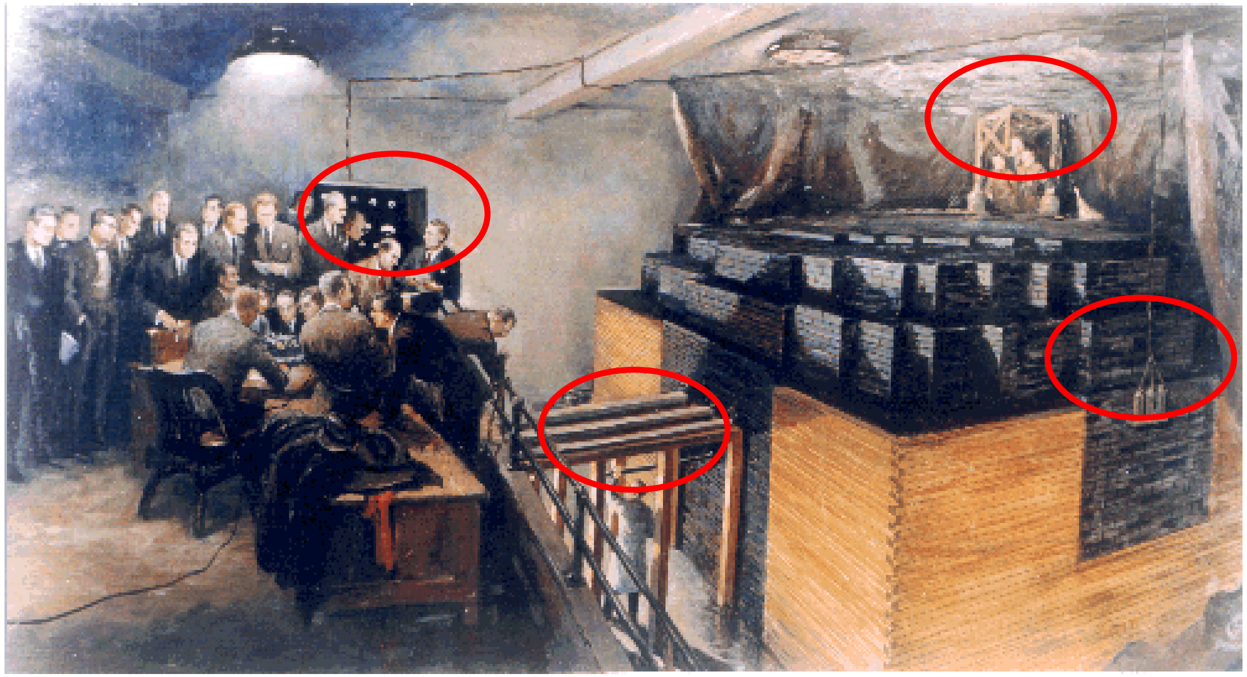
Une géométrie…



Structure du premier réacteur : la Pile de Fermi CP1



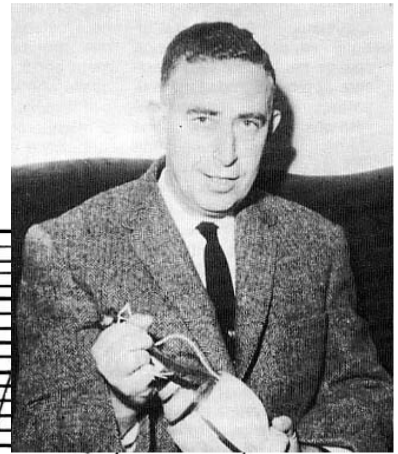
1942 : FERMI Première pile atomique (Chicago pile n°1)

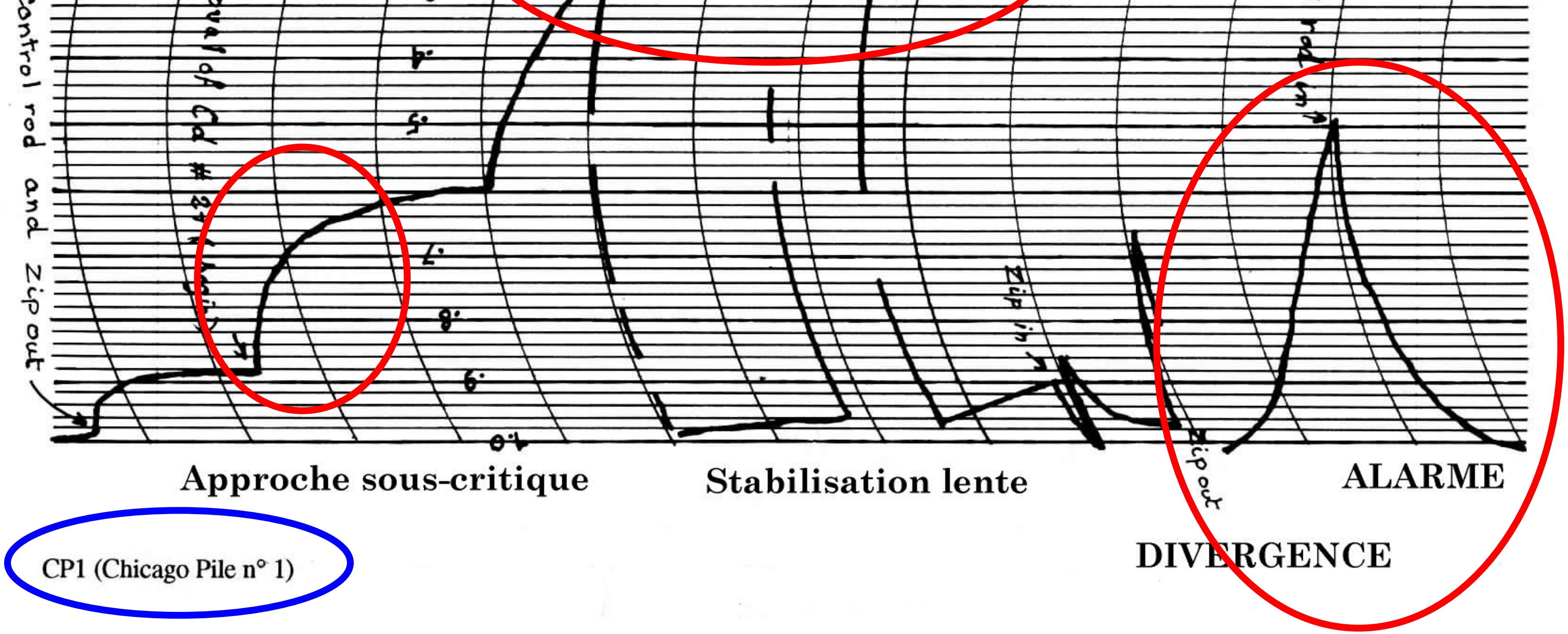


Empilement de graphite, d'UO2 et d'uranium naturel à peu près en forme de sphère avec des barres de contrôle en Cadmium

Production de 0,5 W…

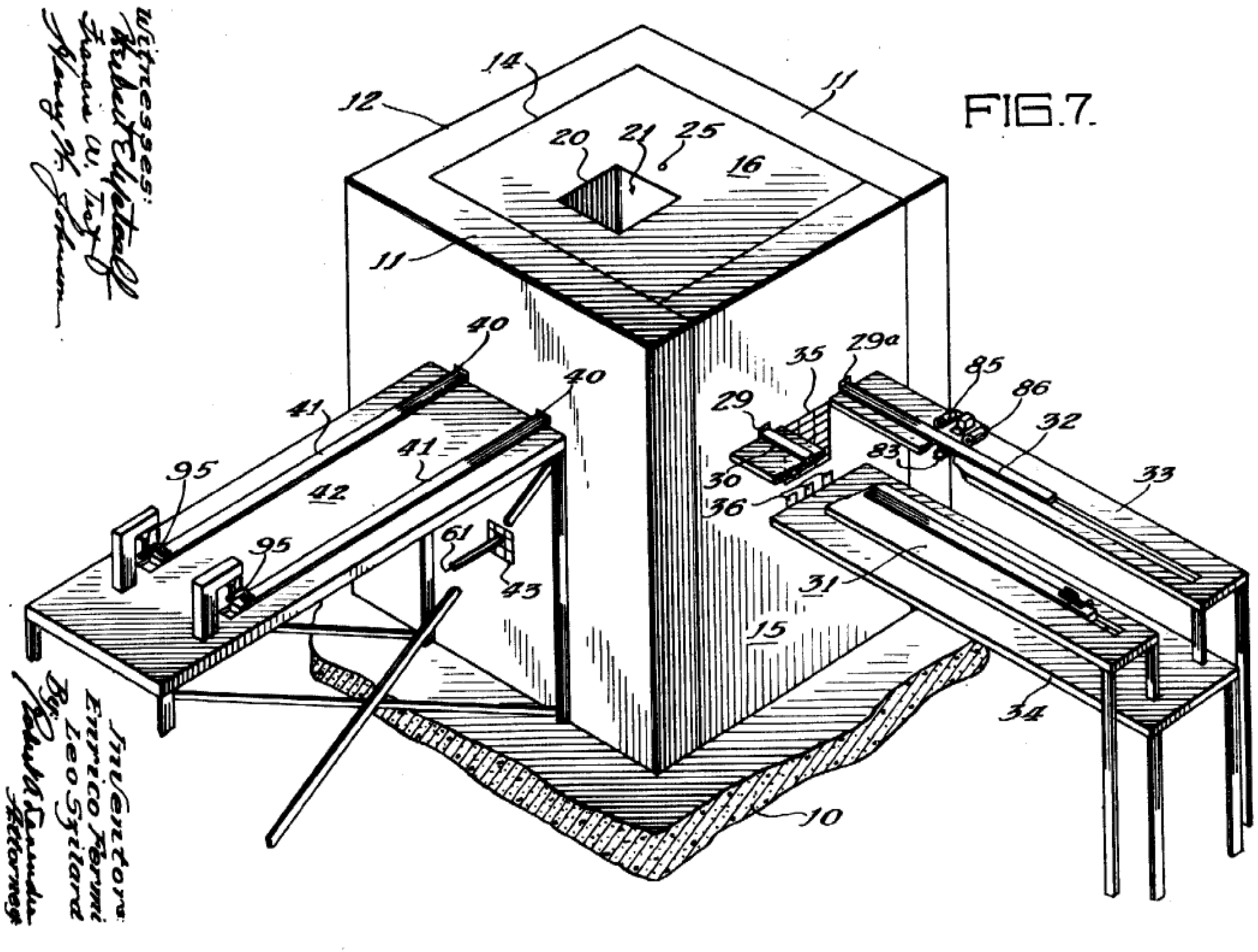
Enregistrement de la première divergence



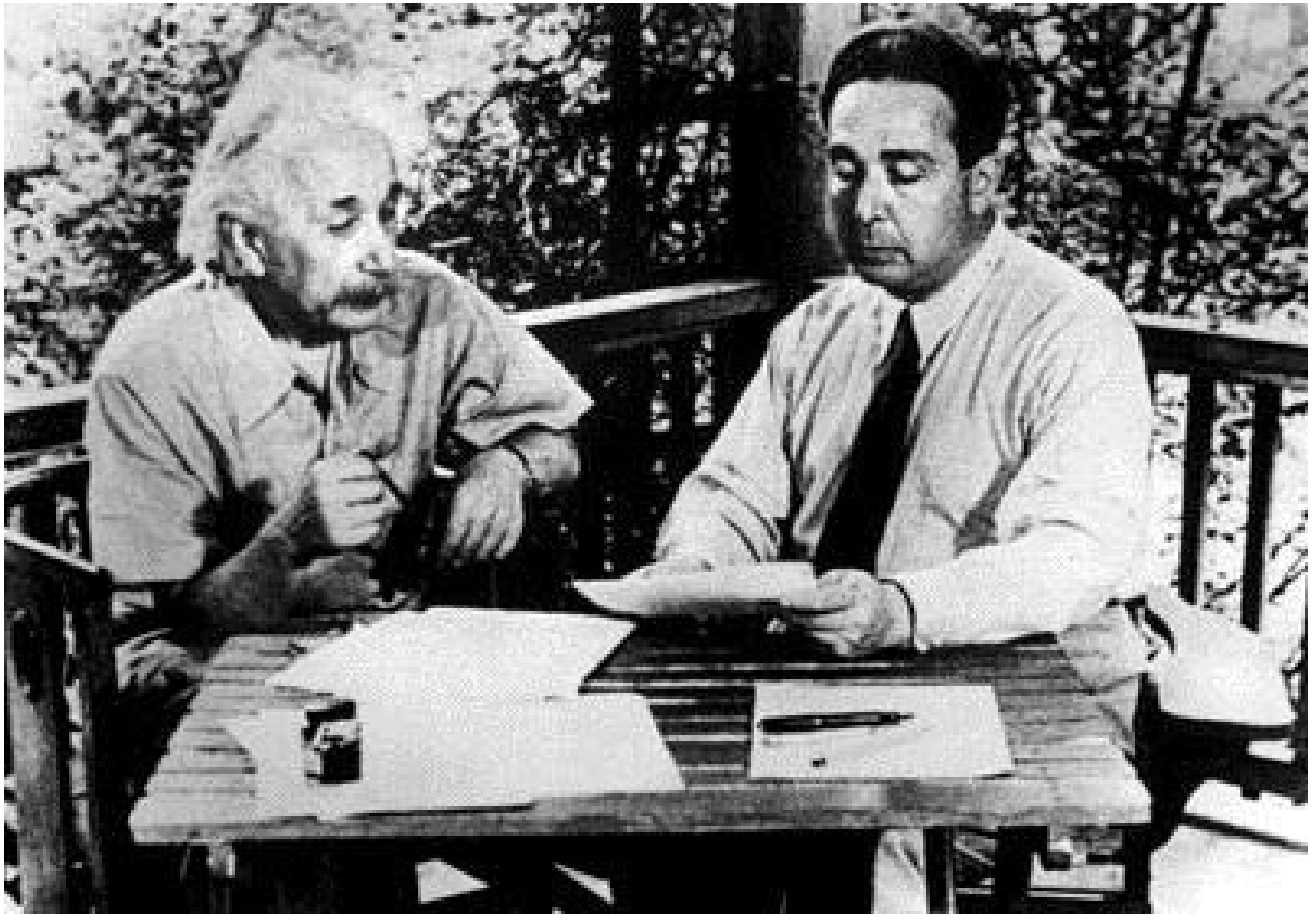


L'équipe de la première divergence

Les nombreux PATENT de Fermi et Szilard



Lettre d'Einstein au président Roosevelt : 2 août 1939



Albert Einstein
Old Grove Rd.
Nassau Point
Peconic, Long Island

August 2nd, 1939

F.D. Roosevelt,
President of the United States,
White House
Washington, D.C.

Sir:

Some recent work by E.Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendations:

In the course of the last four months it has been made probable - through the work of Joliot in France as well as Fermi and Szilard in America - that it may become possible to set up a nuclear chain reaction in a large mass of uranium,by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.

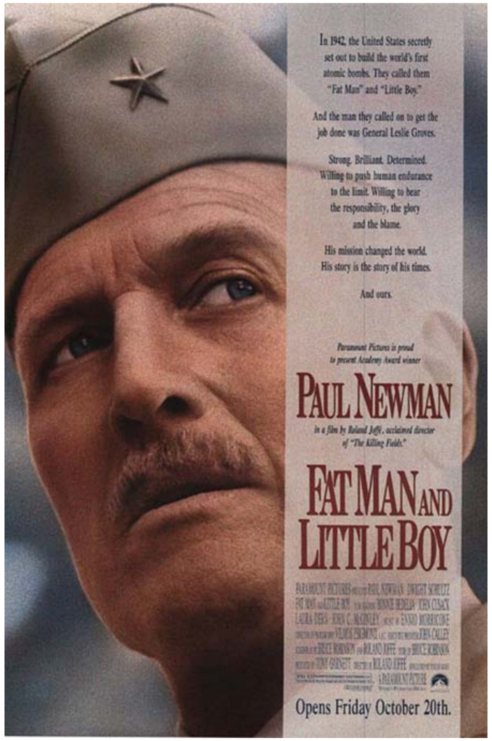
This new phenomenon would also lead to the construction of bombs, and it is conceivable - though much less certain - that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.

a64a01

La bombe allemande : Haigerloch

Le projet MANHATTAN : 3 objectifs

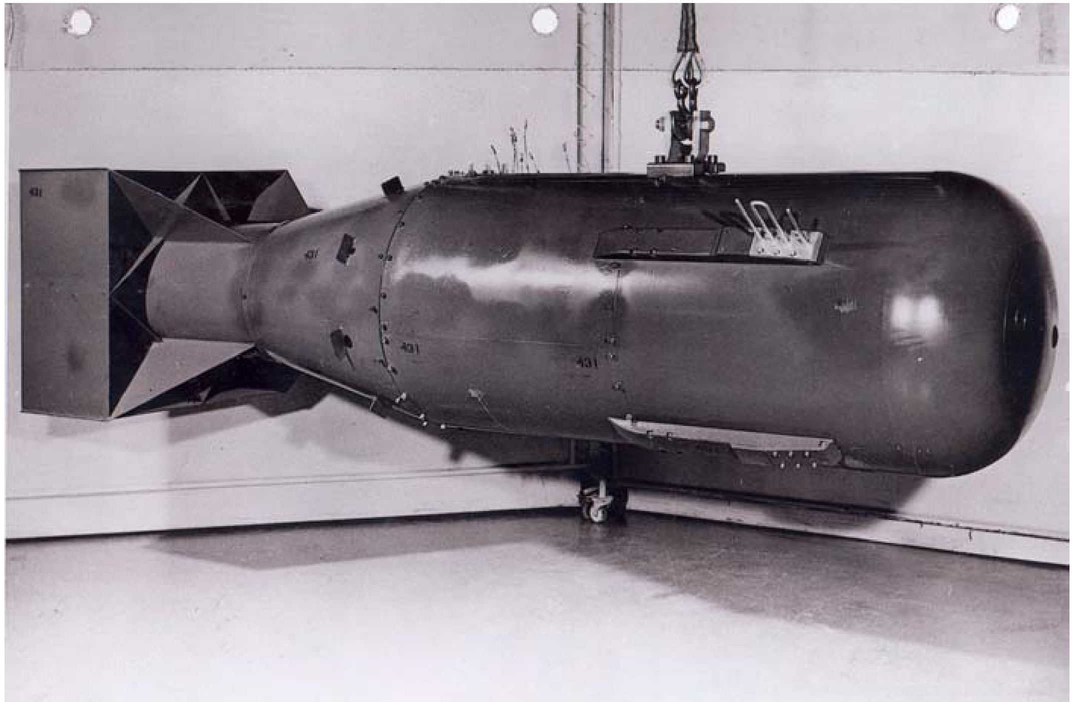
Les organisateurs : Oppenheimer et le G^{al} Groves

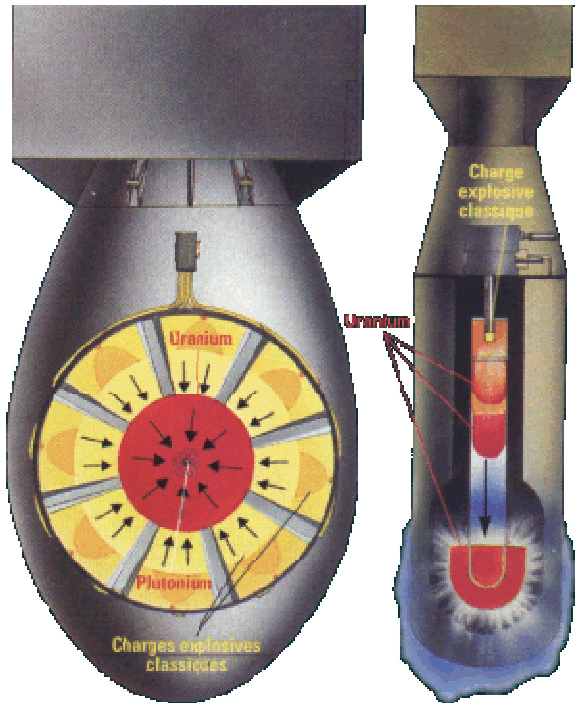


Et tous les chercheurs disponibles…

Enrichir en U235, produire du Pu239 et conditionner le tout

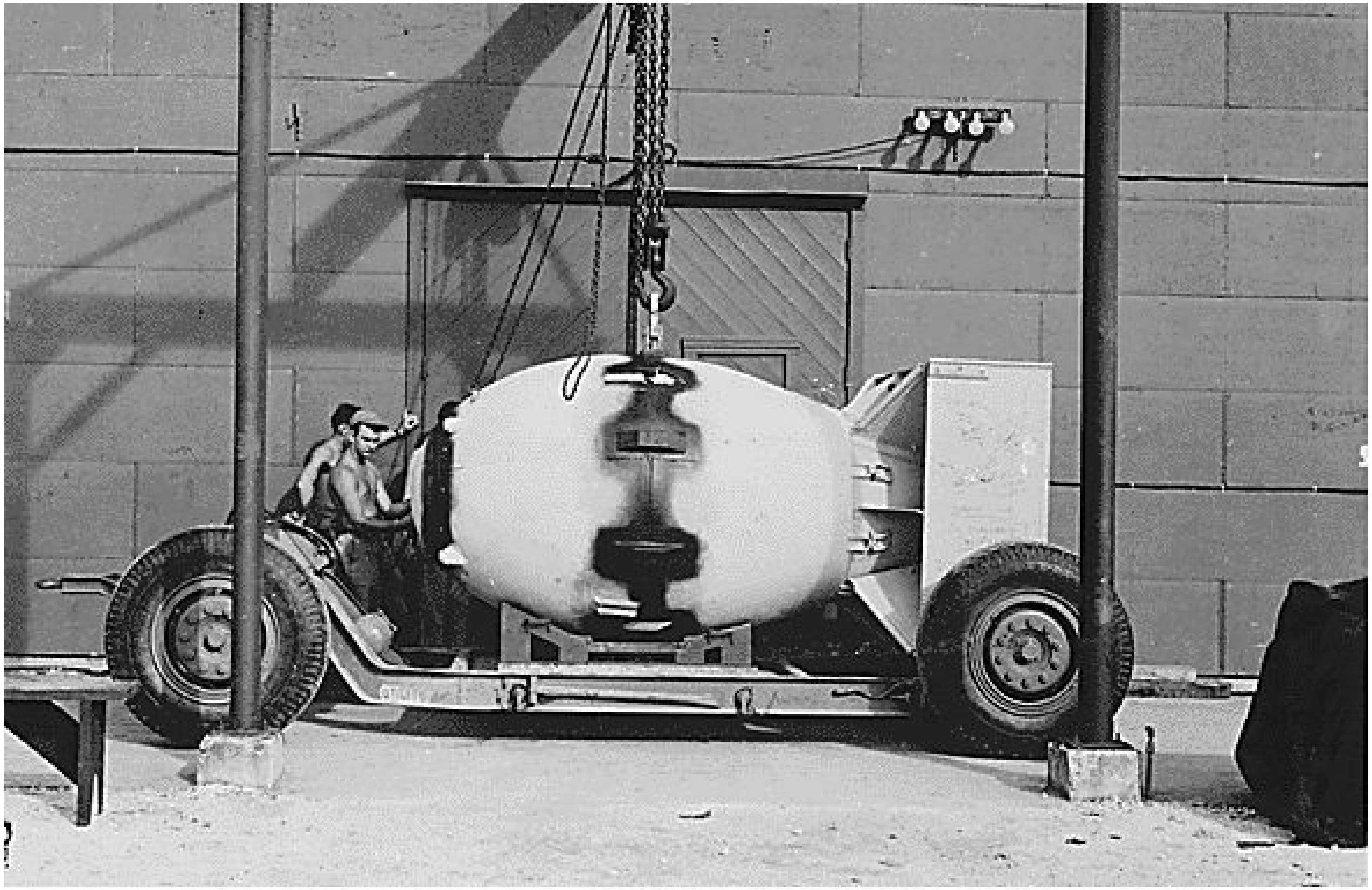
Deux principes de fonctionnement…



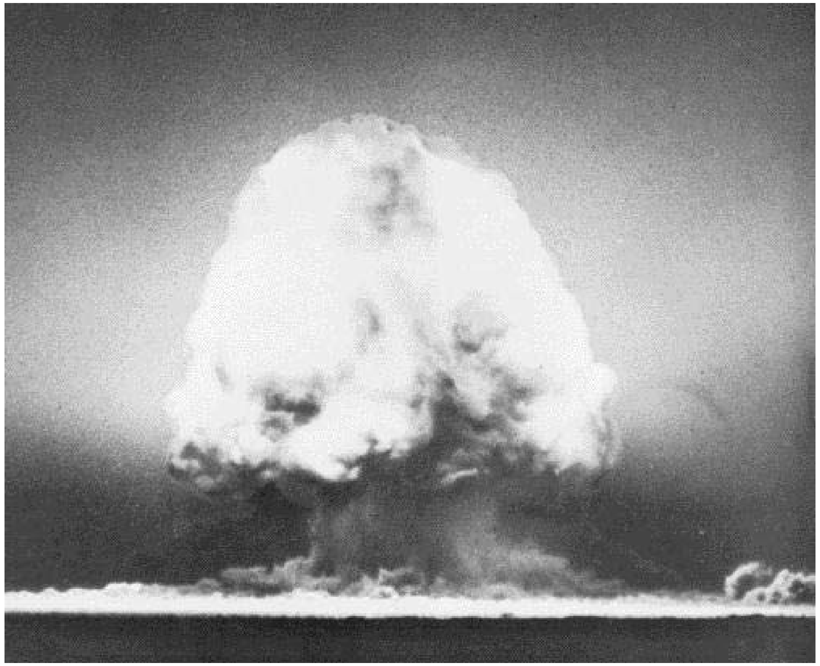


Deux types de matière fissile…

Fat Man (Alamogordo et Nagasaki)



Un premier essai... TRINITY : The Gadget !



Et deux bombardements...