75 Years of Fission

Jeremy Whitlock
1896-1898 … Radioactivity

Discovery of radioactivity

Nobel Prize in Physics, 1903 (Curies + Becquerel)

Marie and Pierre Curie
(1867 - 1934)  

Henri Becquerel
(1852 - 1908)

Birth of nuclear medicine
(starting with Radium)
1898-1907 ... The Nucleus

McGill University
Describes radioactivity, half-life
Coins “alpha”, “beta”, “gamma”
Nobel Prize in Chemistry, 1908

1910 ...
Nuclear structure of atoms

1919 ...
First artificial transmutation:
$^{14}\text{N} + \alpha \rightarrow ^{17}\text{O} + \text{p}$

Ernest Rutherford (1871 - 1937)

Otto Hahn, 26 yrs. old (Nobel Prize in Chemistry, 1944)
Ernest Rutherford

McGill University, 1905
“If it were ever possible to control at will the rate of disintegration of the radio-elements, an enormous amount of energy could be obtained from a small amount of matter”

Ernest Rutherford, 1904
1905 ...

\[ E = mc^2 \]
1930 … Uranium

Gilbert LaBine
(1890 - 1977)

Discovery of uranium at Great Bear Lake

Port Hope refinery, 1933
1932 ... The atom is split!

(April)

John Cockcroft
(1897 - 1967)

Ernest Walton
(1903 - 1995)

First to “split the atom”:
\[ ^7\text{Li} + p \rightarrow ^4\text{He} + ^4\text{He} \]

Verification of Einstein’s E=mc\(^2\)

Nobel Prize in Physics: 1951

Cockcroft first head of Chalk River (Nuclear) Laboratories: 1944-46

John Cockcroft, Ernest Rutherford, Ernest Walton

Cockcroft and Walton's 1932 accelerator (800 kV)
1932 ... (May) The Neutron

James Chadwick
(1891 - 1974)

Discovers the neutron, 1932
Nobel Prize in Physics, 1935
Start of the Neutron Transmutation Bandwagon...
  England (Rutherford)
  France (Joliot-Curie)
  Italy (Fermi)
  Germany (Meitner, Hahn)

1934: the new frontier (Fermi)
“[It’s] a very poor and inefficient way of producing energy ... anyone who looked for a source of power in the transformation of the atoms is talking moonshine”

Sir Ernest Rutherford, 1933  
(1871 - 1937)
1934 ... Artificial Radioactivity

Irène & Frédéric Joliot-Curie
(1897 - 1956) (1900 - 1958)

First artificial radioactivity
Nobel Prize in Chemistry, 1935
Boost to nuclear medicine development

Example: $^{27}\text{Al} + \alpha \rightarrow ^{30}\text{P} + n$
($^{30}\text{P}$ half-life 2.5 minutes)
“Moderated” neutrons have much larger probability of reaction

Nobel Prize in Physics, 1938 for “transuranic elements”

Causes nuclear fission in uranium, but doesn't realize it

1934 ...

Slow Neutrons Do It Better

Enrico Fermi
(1901 - 1954)

Ida Noddack → First proposes fission
(1896 - 1978) → Totally ignored...
1934 ... Neutron Chain Reaction Patented

Leó Szilárd
(1898 - 1964)
1935 ...

“Liquid Drop Model” of Nucleus
1938 ...

Questions about Fermi’s 1934 Nobel Prize-winning results...

- Irène Joliot-Curie and Pavle Savić: “interpretational difficulties” when repeating Fermi’s experiment ...

- Lise Meitner (exiled in Stockholm): urges colleague Otto Hahn and Fritz Strassman to take another look ...

- Dec 17, 1938 – Hahn, Strassman: Hm, chemical proof of Barium...
December 1938 …

Hahn’s desperate plea to Lise Meitner

“Perhaps you can come up with some sort of fantastic explanation. We knew ourselves that [uranium] can’t actually burst apart into [barium].”
Christmas Day 1938, Sweden ...

... a snowy walk leads to...
December 1938 ...
Why?

The Valley of Stability!

Uranium-235

H
He
Li
B
C
O
Mg
Ca
Fe
Zn
Kr
Mo
Te
Sm
Lu
Hg

MORE STABLE

LESS STABLE

“POTENTIAL” ENERGY

ATOMIC WEIGHT

0 50 100 150 200

Why?
January 1939 ... 
Experimental proof  
(Frisch) 

February 1939 ... 
Letter in *Nature*: “Disintegration of Uranium by Neutrons: a New Type of Nuclear Reaction” (Meitner, Frisch)
March 1939 ...

More than one neutron emitted
(Joliot-Curie, Halban, Kowarski - France)
(Fermi, Szilard – USA)
May 1939 …

Three French patents:
1. “Device for energy production”,
2. “Method for stabilizing a device for energy production”,
3. “Method for perfecting explosive charges”

Pierre Joliot-Curie
Hans von Halban
Lew Kowarski
June 1939 ...

Most useful Part of Uranium is also the Scarcest

U-235: 0.7%
August 1939 ...

Einstein–Szilárd letter to President Roosevelt, urging nuclear program

Albert Einstein

Leó Szilárd
September 1939 ...

WAR!
1940 ...

Have heavy water, will travel

Lew Kowarski

Hans von Halban

Frédéric Joliot-Curie

D$_2$O

1940 ...
1941-42 ...

George Laurence
(1905 - 1987)

World's first large-scale fission experiments in graphite
(National Research Council)

100 Sussex Drive, Ottawa
Aug. 17, 1942 …

“Okay, let’s go!”

C.D. Howe
Cdn. Wartime Minister of Munitions & Supply

C.D. Howe
(1886 – 1960)

G.C. Laurence, C.D. Howe, C.J. Mackenzie, J.D. Cockcroft

Aug., 1945
Dec. 2, 1942 ...

Enrico Fermi
(1901 - 1954)

First self-sustaining nuclear fission chain reaction

Nobel Prize in Physics: 1938

Chicago: December 2, 1942
1943 ...

“Montreal Group”

(NRC, at U. of Montreal)

George Laurence

John Cockcroft
1944 ... Chalk River Laboratories
August 1945 ...

Hiroshima: August 6, 1945
64 kg U-235 $\rightarrow$ 15,000 kg (equiv) TNT
150,000 killed or wounded

Nagasaki: August 9, 1945
6.4 kg Pu-239 $\rightarrow$ 21,000 kg (equiv.) TNT
80,000 killed or wounded
September 1945 ...

Canada: second country to control nuclear fission

NRX (under construction)

ZEEP reactor
Chalk River: September 5, 1945

Lew Kowarski
Canada in 1945:

- Second largest nuclear infrastructure on the planet
- Atomic bomb knowledge
- World experts on heavy-water reactor
- Uranium supplies
- World’s most powerful research reactor (NRX) under construction

... WHERE DO WE GO FROM HERE...?
Canada’s Choice:
Peaceful Applications of Nuclear Energy

NRX (1947)

NRU (1957)

A Mecca for nuclear research
1951 ...

"The Atom Bomb That Saves Lives"
Maclean’s Magazine, 1952

University of Western Ontario
FIRST PATIENT: 27 Oct, 1951

University of Saskatchewan
FIRST PATIENT: 8 Nov, 1951
1952 ...

Atomic Energy of Canada Ltd.
1950’s …

Bertram Brockhouse
Nobel Prize in Physics, 1994

Ted Litherland, Allan Bromley, Harry Gove

Triple Axis Spectrometer, 1958

Tandem Accelerator, 1959
1957 ...

International Atomic Energy Agency (IAEA)

Follows Eisenhower’s 1953 “Atoms for Peace” speech

Canada instrumental in establishing IAEA
Nuclear Power Demonstration
Rolphston, Ontario: June 4, 1962

Atomic Energy of Canada Ltd.
Ontario Hydro-Electric Power Commission
Canadian General Electric
CANDU around the world

- Wolsong, South Korea (1982, 1997-99)
- Embalse, Argentina (1984)
- Qinshan, China (2002-03)
- Cernavoda, Romania (1996, 2007, ...?)
- Kanupp, Pakistan (1972)
- Rajasthan, India (1973, 1982)
A Canadian Gift to the World: Cancer Therapy and Nuclear Medicine

**Iodine-131**
Thyroid imaging and therapy

**Technetium-99m**
Cancer and heart disease diagnosis

**Xenon-133**
Lung imaging

**Did you know?**
More than 50,000 nuclear medicine procedures are carried out daily around the world.
NRU Research Reactor
(Chalk River Laboratories)
It’s still about good people

NPD design team (CAPD), Peterborough, 1955

doing good work