THE COBALT BOMB
HOW CANADA ADVANCED RADIATION THERAPY
TO THE MODERN MEGAVOLTAGE ERA

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Acknowledgements

- Jerry (J²) Battista, Jake VanDyk, and Cyril Danjoux; LRCP and Western University, London ON
Abstract

• The development of the Cobalt–60 radiation treatment unit in the 1950’s initiated a huge advance in radiation therapy by providing for the first time high energy gamma beams for cancer treatment. The Cobalt bomb, with its more penetrating radiation, enabled improved dose delivery to deep seated disease without some of the limitations and toxicities of previous radiation treatments.

• We will review the strong Canadian contribution to the development of Cobalt therapy, look at its decline in the 1980s and the Kingston role in establishing renewed interest in developing Cobalt–60 to enhance the availability of radiation therapy throughout the world.

The 2003 Nobel Prize and Then Some: The Influence of Physics on Medicine

L. John Schreiner, PhD, FCCPM

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Queen’s Depts of Oncology & Physics
Outline

• Look at the development of radiation therapy
  – soon after the discovery of x-rays and radioactivity
  – Into the first half of the 1900’s
• Put this into a Canadian context
  – development of the Cobalt Bomb
  – review the London/Saskatoon ‘rivalry’
• Very briefly look at the clinical rise and fall of Cobalt–60
• See if there is a future for Co–60 therapy
  – (a Kingston story)

Cancer and radiation therapy

• About 40% of folk in Canada will develop a cancer at some time in their lifetime
• About one half of these people will undergo radiation therapy at some time in their course of treatment
Role of Radiation Therapy: example Cervix Cancer

Discovery of Ionizing Radiations

- 1895, Wilhelm Röntgen discovered the existence of X-rays,
- 1896, Henri Becquerel discovered radioactivity when he noted that uranium salts emitted rays that resembled X-rays in their penetrating power.
Radiation ‘Research’

Late 1890’s to early 1900’s radiation studies become the cutting edge science

Clarence Madison Daily: Thomas Edison’s x-ray technician

Mr Pierre and Mrs Marie Curie, Radium, December 1904, Vanity Fair cartoon.

Early X–ray Therapy

First successful treatments of cancer:
Stockholm, 1899

Sweden Tor Stenbeck (a general practitioner) treated a 49 yo with basal cell carcinoma for total of 99 Tx

R.F. Mould
X-ray vs x-ray

- X-ray when used as noun or modifier
- x-ray when used as verb

Early X-ray Therapy

- Sweden Tage Sjögren (also a general practitioner) treated a with epithelioma showing response after 50 Tx
- He noted that: ‘the determination of the appropriate dosage of roentgen rays is at present difficult’

R.F. Mould
Early γ-ray Therapy with radium

- French patient with epithelioma of parotid region showing response after radium Tx
- The patient was not treatable by surgery

R.F. Mould

Early γ-ray Therapy with radium

Examples technique for surface treatments with radium plaques

1923: Institut Curie in Paris

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Further developments in γ-ray Therapy

Development of Brachytherapy:

1901: Pierre Curie suggested to Dr. Danlos at St. Louis Hospital in Paris that a small radium tube be inserted into a tumor to treat it.

The Birth of Brachytherapy: A Canadian connection

1903: Alexander Graham Bell independently made a similar suggestion.
I understand from you that Röntgen rays have a marked curative effect on external cancers…

but effects on deep seated tumours have not been satisfactory…

has occurred to me …the reason for the unsatisfactory results ….rays have to pass through healthy tissue to reach …

Radium sealed in a glass tube should be inserted into the heart of the cancer…
Technical Developments Radiation Therapy (1900–40s)

A German X-ray Department (Munich) in 1900–1904

R.F. Mould

X-ray cannons in the Radiotherapy Department of the Curie Institut, Paris (1920)

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Technical Developments Radiation Therapy (1900-40s)

- A Belgian radium bomb (Sluys and Kessler, 1925)
  - contained a total of 1.3 gm radium (could be increased to 5.2gm) with 13 fixed cylindrical applicators.
  - Designed for cancers of the brain, larynx, pharynx, oesophagus, bladder
  - Treatments were noted to demand ‘much delicate adjustment’
  - Daily treatments were usually 4-6 hrs duration to a total of 150-200 hrs.

R.F. Mould

John Austin Society April 013

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Technical Developments Radiation Therapy (1900–40s)

1934: A radium bomb containing 1gm of radium used at the Royal Marsden (London)

Technical Developments Radiation Therapy (1950s)

1957: A telecaesium unit from the Royal Marsden with 1500Ci Cs–137 (was used for about 25 yrs) for mainly head and neck and head cancers, some
Technical Developments Radiation Therapy (~1940–50s)

- High energy x-ray units using linear accelerators, betatrons, or other means

1937: A 2MV Van de Graff generator unit (Boston)

1953: A 4MV linear accelerator unit (Philips Medical) Original installed in Newcastle, this unit was at Royal Marsden (London)

High Energy X-rays

The information is about technical developments in radiation therapy during the 1940s and 1950s, focusing on high energy x-ray units using linear accelerators, betatrons, or other means. Specific examples are provided, such as a 2MV Van de Graff generator unit installed in Boston in 1937 and a 4MV linear accelerator unit installed in Newcastle (originally Royal Marsden in London) in 1953. The text describes the advancement in technology, particularly in the use of linear accelerators and betatrons, which were crucial for modern radiation therapy. The illustrations show actual units, providing a visual representation of these technical developments.
Cs–137

The Evolution of Radiation Therapy Devices
The Classification of Teletherapy Devices

Table 18.1. Teletherapy treatment classifications in terms of X-ray generating voltage.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>Superficial therapy</td>
<td>10–150 kV</td>
</tr>
<tr>
<td>Deep (or orthovoltage) therapy</td>
<td>200–300 kV</td>
</tr>
<tr>
<td>Megavoltage (or supervoltage) therapy</td>
<td>Above 1 MV</td>
</tr>
</tbody>
</table>

Since gamma ray energies of cobalt-60 are 1.17 and 1.33 MeV, cobalt teletherapy machines are classified as megavoltage treatment units

The limits of early X-ray devices

- The practical limit of X-ray machines was reached at ~ 400 Kilovolts
  - Limited to superficial tumors
- To treat deep-seated cancer in the body
  - Other devices were needed
  - More powerful X-ray machines
  - Radioisotopes

Orthovoltage machine

Cyril Danjoux
The Megavoltage Advantage

250 kV x-rays  Cobalt-60

Beam Penetration

J.P. Battista, Ph.D.
Which brings us to COBALT

\[ \text{discovered in 1936} \]
\[ \text{(Phys Rev 50:382, 1936)} \]

Cobalt Activation

Fig. 1-4. Attainable specific activities for cobalt-60 as a function of time for various neutron fluxes (neutrons per square centimeter per second [1]).
Formation of $^{60}$Co

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Probability of formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{59}$Co $(n, \gamma) ^{60}$Co</td>
<td>100%</td>
</tr>
<tr>
<td>$^{59}$Co $(d,p) ^{60}$Co</td>
<td>100%</td>
</tr>
<tr>
<td>$^{63}$Cu $(n,\alpha) ^{60}$Co</td>
<td>$\sim$ 70%</td>
</tr>
</tbody>
</table>

discovered in 1936
(Phys Rev 50:382,1936)

The whole story spans much of Canada
Why Canada?

- In 1942: Cambridge group moved to Montreal Canada
  - Could not join the group in Chicago because of military and industrial security
  - "Canada was a workable alternative" as it was close to the USA
  - The NRC had an established research program in fission under GC Laurence and BW Sargent from Queen’s.
  - Close to Eldorado Uranium
  - Near heavy water plant recently established in Trail B.C

Montreal

- They designed a pilot heavy water reactor the NRX (National Research Council Experimental) whose construction started in Chalk river in 1945 - isotope production

- The first chain reaction outside the USA took place in Canada in the NRX "little brother" the "ZEEP" Zero Energy Experimental Pile with Heavy water produced by the Cominco plant in Trail, BC
NRX and Radioisotopes

- Radioisotopes were high priority for NRX once it fired up (1947).
  - first shipment of radioisotopes (cerium-144) was to University of Saskatchewan Oct. 31, 1947, three months after startup.

- By 1949, routine shipments were being made
  - iodine-131 to pharmaceutical companies,
  - along with phosphorous-32 and sulfur-35 to university labs.
  - "moderate" strength activities of cobalt-60 (500–1500 mCi) to research institutes.

- A total of sixty different isotopes were in production at Chalk River,

www.Canadian Nuclear FAQ
Roy Errington

1946 Roy Errington manager of Eldorado Mining and refining
- market and sell radium as a by-product of their uranium mines
- decided to explore selling radioactive Co 60 as a replacement for radium
- concern about the commercial future of radium because of its cost and the limited hospital budget

Why Cobalt 60?

In 1944 Mitchell advisor to the Biological and Medical branch of the Atomic Energy Project in Canada and the UK

His report on the production of radioactive isotopes and their merits for medical applications concluded that:
- Co 60 was the most promising substitute for radium and that the
- "Canadian pile could easily produce several hundred curies of radiocobalt every six months"

(Br J Radiol 19:481,1941)
Cobalt-60 vs Radium

Table 19.1. Advantages of cobalt-60 over radium as seen in 1948.

1. Much softer beta radiation: easily filtered out.
2. Homogeneous gamma radiation: 1.1 MeV and 1.3 MeV.
4. Breakage almost impossible.
5. Suitable alloys of cobalt are chemically inert.
7. Magnetic: makes handling easier and safer.
8. Strength determinable before irradiation in the atomic pile.
9. Residual activity can be "warmed up" in a nuclear reactor.
10. Suitable alloys containing cobalt are inexpensive.
11. Cobalt-60 can be generated in any desired quantities.
12. It is available at moderate cost.

Radioactive Cobalt

- Maynord and Cipriani suggested its therapeutic use in a variety of sources (Can J Res 25:303, 1947)

- Problem of source protection and transfer not solved until 1946
Harold E. Johns

- In the summer of 1946 at the invitation of Dr. Gordon Richards, Professor Mayneord delivered a course of lectures at Toronto General Hospital on the Physics of Radiotherapy.

- Harold Johns attended the course. His notes became the first draft of his textbook of “The Physics of Radiology.”

- Interest in Cobalt 60 and betatron.

Ontario Institute of Radiotherapy in London

- On his way to discuss Co-60 unit with Dr. Hummon in Chicago, he stopped at the Ontario Institute of Radiotherapy in London.
  - The Institute was the 2nd largest treatment facility in the province.

- Dr. Ivan Smith, the head of the cancer centre was enthusiastic.
  - Back in Ottawa, Errington obtained $7,000 from Eldorado, to start the development division which ultimately designed the Eldorado A Co60 unit.
MD Anderson

- Gilbert Fletcher from the MD Anderson Hospital in Houston was also interested in Co-60 as a result of visit in London, Manchester and Stockholm to gain further training in radiotherapy.

Requests

- Three independent requests for kilocurie Cobalt 60 sources were made to Cipriani in Aug 1949 by:
  - H E Johns & T. A Watson - Saskatoon
  - DT Green & R Errington of Eldorado Commercial products with Ivan Smith of the London Cancer clinic
  - G Fletcher and LG Grimmett of the MD Anderson Hospital
H E Johns request for high activity source

The reply from the NRC was:
‘sure, but...’

Cyril Danjoux
Co-60 early designs

Eldorado A

Courtesy of Canadian Medical Hall of Fame

J.Battista, Ph.D.
The Saskatchewan Team

H.E. Johns

“Sandy” Watson

London Chronology

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1946</td>
<td>R.F. Errington hired by Eldorado Mining and Refining (1944) Ltd.</td>
</tr>
<tr>
<td>1949</td>
<td>R.F. Errington and T.D. Green embark on car trip to promote the idea of a Cobalt-60 teletherapy</td>
</tr>
<tr>
<td>15 March 1950</td>
<td>OCTRF approves purchase of Cobalt-60 unit for the Ontario Institute of Radiotherapy, London</td>
</tr>
<tr>
<td>11 May 1950</td>
<td>Purchase order placed by OCTRF for Cobalt-60 unit</td>
</tr>
<tr>
<td>June 1950</td>
<td>Source for London unit placed in NRX reactor at Chalk River</td>
</tr>
<tr>
<td>Aug. 1951</td>
<td>Measurements of the isodose distributions from the London Cobalt-60 unit made at NRC by Cy Garret, John MacDonald, Bill Dixon, A. Fish, and A. Morrison</td>
</tr>
<tr>
<td>6 Oct. 1951</td>
<td>Cobalt-60 unit arrived in London, Ont.</td>
</tr>
<tr>
<td>27 Oct. 1951</td>
<td>First patient treated using the new unit</td>
</tr>
<tr>
<td>12 Nov. 1951</td>
<td>Official opening of the new treatment unit</td>
</tr>
<tr>
<td>April 1951</td>
<td>First patient treated by the new Cobalt-60 unit dies</td>
</tr>
<tr>
<td>20 May 1952</td>
<td>Toronto Telegram reports the treatment of Eva Peron in London</td>
</tr>
<tr>
<td>July, 1955</td>
<td>Coronet – a popular magazine – publishes an article entitled “The C-bomb Halts Cancer”</td>
</tr>
<tr>
<td>Oct. 1955</td>
<td>The first source change occurs for the London Cobalt-60 unit</td>
</tr>
<tr>
<td>27 April 1962</td>
<td>Dr. Ivan Smith dies suddenly at his home following a scientific conference</td>
</tr>
<tr>
<td>Aug. 1963</td>
<td>The first London Cobalt-60 unit is decommissioned</td>
</tr>
</tbody>
</table>
Saskatoon Co-60 Commissioning

Saskatoon Co–60 inauguration

Co–60 Eldorado

- Rotation on the stationary Eldorado
London Co–60 inauguration

- Official opening 12th Nov 1951
- Officially known as Model A Eldorado Co-60
- “Cobalt bomb” or “Peacetime bomb” by popular press

The birth of Co–60 Radiotherapy

- These three sources were used clinically on:
  - Oct 27th 1951 (London),
  - Nov 9th 1951 (Saskatoon) and
  - Feb 1954 (MD Anderson)

- This ushered in the Megavoltage era of radiation therapy
Kingston Co–60 inauguration

1957

Picture sent to CCSEO by family of a patient

October 1952

The greatest, most beneficial dividend from the A bomb may be this newest weapon in the war on cancer

Cobalt 60—
"Poor Man's Radium"

By Lois Matson Miller and James Monahan

Over the lunchroom table the man from Oak Ridge spread trinkets that might have come from the pockets of some small boys: metal rings, hooks, blunt needles, and a piece of nylon string that resembled larly those that cannot be removed surgically. Thin tubes of flexible nylon, loaded with bits of Co-60, are being sewed into cancerous tissues, to be withdrawn when the radiation treatment is complete.
Technical Developments Co–60 units (1950s–70s)

X–ray cannons in the Radiotherapy Department of the Curie Institut, Paris (1920)

Technical Developments Co–60 units (1950s–70s)

Argonne Cancer Research Hospital
Co-60 External beam unit

Last 30 years or so

Industrial Outcome: Kanata, ON

AECL ⇔ Theratronics ⇔ MDS Nordion

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Modern Radiation Therapy:

*Is there a role for Co-60??*

Linear Accelerators

IMRT enables us to carve the dose to conform to the target
Cobalt–60 vs. 6 MV: spectra

Photon Spectra @ 10 cm Depth in Water at Nominal SAD

Cobalt–60
Cobalt-60

1970's

today

Technology Trends in Radiation Therapy

[Graph showing the number of units (USA) and worldwide from 1975 to 1998]
Technology Trends in Radiation Therapy

**Linear Accelerators**
Mainstay of modern RT techniques e.g. IMRT, IGRT, IGAR
Tomotherapy.

**Cobalt–60**
Widely used for conventional RT in most of the world.
But...
Has lacked the required technical R & D (even MLCs...until recently) to facilitate IMRT/IGRT.

Cancer is a burden throughout the world
A dramatic rise in cancer across the developing world is stretching already limited resources and equipment. Shortages of qualified staff and equipment are growing constraints to treating cancer effectively. Some 5,000 radiotherapy machines are presently needed to help patients fight cancer. But the entire developing world has only about 2,200 such machines. Experts predict a long-term crisis in managing cancer, with an estimated five million new patients requiring radiation therapy every year.”

Mohamed El-Baradei
Director General
IAEA, Vienna (2003)

Perceived Problem: Nature of $^{60}$Co beam

<table>
<thead>
<tr>
<th>Single field</th>
<th>Four Fields</th>
</tr>
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<tbody>
<tr>
<td>Cobalt-60</td>
<td></td>
</tr>
<tr>
<td>390 %</td>
<td></td>
</tr>
<tr>
<td>280 %</td>
<td></td>
</tr>
<tr>
<td>6 MV X-Rays</td>
<td></td>
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</table>

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Reminder: Good Things About Cobalt

- $^{60}$Co source gives a stable output.
- The $^{60}$Co unit has been a robust workhorse in the clinic.
- A $^{60}$Co unit is technically less complex than a linac.
- Potential dose delivery benefits in some situations
Cobalt in the world

Basic Co-60 units
No additions likely fully manual

IGART ready Co-60 units with MLCs, IMRT, advanced imaging

Conformal Co-60 units with MLC, no IMRT, basic imaging

High Tech Co-60 Radiation Therapy

Machine: Elekta Gamma Knife 4C

Andrei Z. Damyanovich, Ph.D.
Princess Margaret Hospital University Health Network

Gamma Knife: Principles

Protective shielding
Spherical collimator helmet
Leksell Stereotactic System®
Isocenter Target in the Brain
Automatic Positioning System™
201 sources of radiation

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Can one be adventurous with Co–60

Magnetic resonance imaging for adaptive cobalt tomotherapy: A proposal

The ViewRay, Inc.

The Renaissance™ System 1000

James F. Dempsey, Ph.D.
Best Theratronics
Theratron 780C
with
Nomos MIMIC MLC

Dose Delivery Studies (Head and Neck Tx)

Figure 3: Co-60 tomotherapy and 6 MV based broad beam segmental IMRT dose distributions for two H&N cancer sites. Full 3D comparison between Co-60 and 6 MV IMRT is presented by transverse, sagittal, and coronal views.
Dose Delivery Studies 2 (prostate Tx)

Sandeep Dhanesar et al., subm MedPhys

Cobalt in the world

Basic Co–60 units
No additions likely fully manual

IGART ready Co-60 units with MLCs, IMRT, advanced imaging

Conformal Co–60 units with MLC, no IMRT, basic imaging
Recent developments at Best Theratronics

Cobalt-60
“The Sustainable Man’s Linac”
A Canadian Legacy