BEST THERATRONICS LIMITED

An AECL Spin-Off Success Story

Nuclear Physics in Medical Diagnostics and Therapeutics

Ragnar Dworschak, Ph.D., P.Phys.
Director of Technical Services, BTL
CRB – CNS Evening Talk
29 June 2011
• Brief history of Best Theratronics Limited
• Product Lines
  o Self Contained Irradiators
  o External Beam Gamma Teletherapy
  o Cyclotrons
  o Particle Therapy
• **AECL Commercial Products Division**
  – The world’s 1st treatment of a patient using the new Co60: London, Ontario, on 27 October 1951.
  – 1965 Moved to present Kanata site

• **1985 AECL Medical and AECL Industrial Divisions**

• **1988 CDIC Federal Holding Company acquires both Divisions. Calls the Medical division Theratronics**

• **1991 MDS acquires Industrial division**

• **1998 MDS acquires Theratronics, eliminates name**

• **2008 Best Medical International acquires Theratronics Division, renames it **Best Theratronics Limited**.**
  – 71 representatives worldwide
  – 2000+ Self Contained Blood Irradiators installed worldwide (Cs-137 + X-ray source)
  – 2700+ Co-60 Gamma Teletherapy cancer treatment units installed.
Best Medical International

WW HQ (est. 1977)
BMI, Springfield, VA

Huestis Medical/ARI, MA & RI

Best Theratronics/Best Medical
Canada Ottawa, Canada

ARI
Chicago, IL

Best NOMOS,
Pittsburgh, PA

CNMC
Nashville, TN

INTERNATIONAL
Arplay Medical, France
Nomos China, Beijing, China
Best Medical Belgium, Fleurus, Belgium
Best Medical Italy, Padova, Italy
Best Medical Asia, India
Best Medical South America, Brazil

Novoste
Norcross, GA
Our Factory in Ottawa
Blood Irradiation

• To manage transfusion associated Graft Versus Host Disease (TA-GVHD)
• Filtration, washing, freezing, prolonged storage provide insufficient degree of leuko-reduction
• Irradiation is recognized by regulatory organizations as the most efficient and reliable method to inactivate lymphocytes
The following regulatory organizations recommend:

- **US (AABB/FDA)**
  - minimum 2500 cGy (2500 rad) targeted to the centre
  - minimum 1500 cGy (1500 rad or 15 Gy)
  - maximum 5000 cGy (5000 rad or 50 Gy)

- **Europe**
  - minimum 25 Gy, maximum 50 Gy

- **France and Germany**
  - minimum 25 Gy, maximum 45 Gy

- **Japan**
  - minimum 15 Gy, maximum 50 Gy
Raycell X-ray Blood Irradiator

Figure 1: Raycell X-ray Blood Irradiator
Irradiator Beam Geometry

Sample Chamber

X-ray Tubes

Canister

Beams

Shield

Boron nitride
New Raycell Mk2

• 3.5 L canister
• CDR = 4.4 Gy/min
• Dose uniformity
  – 20 Gy min, 25 Gy central, 36 Gy max
  – 25 Gy min – 45 Gy max
Gammacell 3000 Elan

Gammacell Blood Bank “work horse”

Gamma ray Blood Irradiation Cs137 source
<table>
<thead>
<tr>
<th>Unit type</th>
<th>Number of minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC 1000 A</td>
<td>7.14</td>
</tr>
<tr>
<td>GC 1000 I</td>
<td>2.94</td>
</tr>
<tr>
<td>GC 1000 II</td>
<td>1.56</td>
</tr>
<tr>
<td>Raycell (1.5L, 3.5L)</td>
<td>5.0 or 5.7</td>
</tr>
<tr>
<td>GC 3000 I</td>
<td>5.0</td>
</tr>
<tr>
<td>GC 3000 II</td>
<td>2.56</td>
</tr>
</tbody>
</table>
Gammacell 1000/3000 Turntable

CANISTER

MAGNETS

CANISTER LOCATING PIN

BEAKER SENSOR
Gammacell 1000/3000 Accessories
### Typical External Radiation Fields GC 1000 Elite

<table>
<thead>
<tr>
<th>READING LOCATION</th>
<th>mrem/h</th>
<th>μSv/h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Model A</td>
<td>Model I</td>
</tr>
<tr>
<td>TOP</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>LEFT SIDE</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>RIGHT SIDE</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>BACK</td>
<td>0.3</td>
<td>0.6</td>
</tr>
</tbody>
</table>

#### FRONT CHAMBER
- LOAD POSITION: 0.25 0.5 1.0 2.5 5.0 10.0
- MOVING: 0.25 0.5 1.0 2.5 5.0 10.0
- IRRADIATE POSITION: 0.25 0.5 1.0 2.5 5.0 10.0
- INSIDE STORAGE: 0.25 0.5 1.0 2.5 5.0 10.0

ICRP MAXIMUM ALLOWABLE RATE 20 mrem/h

**RECOMMENDATIONS OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION**

**PUBLICATION-#15, 21 & 33**

(1 mrem/h = 10 μSv/h)

**NOTE:** The radiation meter is reading the value approximately 5 cm from the surface of the unit.
External Beam Gamma Teletherapy
Product Line

Theratron® Phoenix

Theratron® Equinox

Avanza™
Manual Collimator 4x4 cm to 35x35 cm

Motorized Gantry Rotation

Mechanical Scales

Manual Head Rotation

Full line of Beam Modifiers

THERATRON PHOENIX
Clinical and Workflow Benefits

- Reliable performance, 24 hours/day, 7 days/week [even during power outages]
- Simple and intuitive to use
- Maximizes patient treatment capacity
- Minimal service support needs and low maintenance
- Advantages of Co-60 gamma source
Asymmetrical Jaws
Automatic Jaws Closure
Motorized Wedge
Midline Overtravel
Equinox MLC Development

**Highlights:**
- Conformal RT (replacement of shielding blocks)
- “Sliding Window” Intensity Modulated Radiation Therapy (IMRT)
- Easily removable for standard Equinox operation.

**Specs:**
- 60 leaves (2 x 30).
- Max field size: 30 x 30 cm
- 15 x 30 cm IMRT window (50% overtravel)
Equinox MLC Option

Physics measurements ongoing.
Serial Tomotherapy Option

- Binary operation, leaves are either open or closed
- Pneumatically operated (no motors), fast leaf speed: 50 cm/s
- 2 x 20 individual leaves
- Leakage and through leaf transmission (<1%)
- Each row is a slice but deliver two slices at a time
- Dynamic arc delivery, not static step and shoot, delivering
  a new field every 5 degrees (54 fields/270 deg arc)
Clinical and Workflow Benefits

- Greater treatment flexibility – from the routine to the complex treatment modalities
  - MLC for 3DCRT or IMRT
  - Serial tomotherapy for IMRT
- Treat more patients per day
- Accurate and reproducible treatment set-ups
- 80 & 100cm units: dose rate, patient clearance.
COMPLEXITY:
LINAC VS COBALT TELETHErapy

Linear accelerator

Cobalt teletherapy
• In collaboration with Carleton University (Ottawa) Department of Physics and Mechanical Engineering, Kingston General Hospital and Queen’s University (Kingston)
  – A Co-60 specific MLC to take advantage of the gamma energy from Co-60 and to improve the treatment efficacy of IMRT treatment plans
  – Robotic deployment of IGRT hardware: keV and MeV imaging panels, tubes, etc.
  – Optimize Co-60 design to minimize penumbra and maximize high SA Co-60 utilization
  – Design, modeling a new flood source for gamma cameras.
• Cobalt-60 cancer treatment units have been in use for 50+ years
• Reliable: mechanical and QA/QC
• Physics: penumbra vs scatter, dose depth, no neutrons, predictable dose rate
• New advances – MLC, IMRT, IGRT
• Co-60 vs 6 MeV IMRT treatment plan DVH identical but cheaper and more reliable.
Nuclear Medicine

Diagnostics  ↔  Therapeutics

Medical Isotopes

- Reactor Produced
  - Fission, Bombardment
- Cyclotron Produced
  - Bombardment
Solid Target Assembly
Diagnostics  ↔  Therapeutics

Medical Isotopes

- Reactor Produced
  - Fission, Bombardment
- Cyclotron Produced
  - Bombardment
Diagnostics

SPECT
Single Photon Emission Computed Tomography

PET
Positron Emission Computed Tomography
Nuclear Medicine

Images from SPECT/PET Scans
14, 25, 35 and a 70 MeV cyclotron systems provides a comprehensive selection of PET & SPECT medical isotopes, given appropriate targetry and radiochemistry.
Cyclotrons

Radioisotope Production Facility Design: BEST 35, BEST 70

• Site design, shielding
• Custom designed beam lines
• Targets, consumables

Radioisotope Production Facility Design
BEST 14 (turn key system)
Excitation functions for $^{97}\text{Tc}$, $^{98}\text{Tc}$ and $^{99}\text{Tc}$ for proton irradiation of $^{100}\text{Mo}$. 
Excitation Function for the $^{18}$O(p,n)$^{18}$F Reaction
## PET Isotopes from Best 14p

<table>
<thead>
<tr>
<th>Product</th>
<th>Radionuclide</th>
<th>Reaction</th>
<th>t1/2</th>
<th>Application</th>
<th>Activity for Single Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>Carbon - 11</td>
<td>$^{14}$N (p, a) $^{11}$C</td>
<td>20.4 m</td>
<td>Broad Substitution</td>
<td>CO₂ 1500 mCi&lt;br&gt;CH₃I 800 mCi</td>
</tr>
<tr>
<td>CH₃I</td>
<td>Nitrogen - 13</td>
<td>$^{16}$O (p,a) $^{13}$N</td>
<td>10 m</td>
<td>Ammonia: blood flow</td>
<td>NH₃ 500 mCi</td>
</tr>
<tr>
<td>O₂</td>
<td>Oxygen-15</td>
<td>$^{15}$N(p,n)$^{15}$O</td>
<td>122 s</td>
<td>O₂, CO₂, H₂O: blood flow, volume, oxygen utilization</td>
<td>O₂ 1000 mCi&lt;br&gt;H₂O 750 mCi&lt;br&gt;CO₂ 800 mCi&lt;br&gt;H₂O 750 mCi</td>
</tr>
<tr>
<td>H₂O</td>
<td>Fluorine - 18&lt;br&gt;aqueous</td>
<td>$^{18}$O(p,n)$^{18}$F Liquid Target</td>
<td>109.8 m</td>
<td>FDG mainly, many others</td>
<td>$^{18}$F⁻ &gt; 8000 mCi&lt;br&gt;FDG &gt; 4 Ci&lt;br&gt;240 mCi/μA</td>
</tr>
<tr>
<td>CO</td>
<td>Fluorine - 18&lt;br&gt;gas</td>
<td>$^{18}$O (p,n) $^{18}$F Gas Target</td>
<td>109.8 m</td>
<td>Radiolabeling from gas phase</td>
<td>$^{18}$F₂ &gt; 1000 mCi</td>
</tr>
<tr>
<td>CO₂</td>
<td>Copper - 64&lt;br&gt;64Ni (p,n) 64Cu</td>
<td>12.7 hr</td>
<td>Integration through chelation chemistry</td>
<td>550 MBq/μAhr</td>
<td></td>
</tr>
<tr>
<td>I⁻¹²⁴</td>
<td>Iodine - 124&lt;br&gt;¹²⁴Te (p,n) ¹²⁴I</td>
<td>4.2 d</td>
<td>Monoclonal antibodies</td>
<td>28 MBq/μAhr</td>
<td></td>
</tr>
</tbody>
</table>
## SPECT

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>$t_{1/2}$</th>
<th>Reaction</th>
<th>Application</th>
<th>Activity for Single Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indium - 111</td>
<td>2.83 d</td>
<td>$^{111}$Cd (p,n) $^{111}$In</td>
<td>Blood cell labeling</td>
<td>63.4 MBq/μAhr</td>
</tr>
<tr>
<td>Ga - 67</td>
<td>78 hrs</td>
<td>$^{68}$Zn (p,2n) $^{67}$Ga</td>
<td>Fe analog, inflammatory lesions</td>
<td>78.4 MBq/μAhr</td>
</tr>
<tr>
<td>Iodine - 123</td>
<td>13 hrs</td>
<td>$^{123}$Te (p,n) $^{123}$I</td>
<td>low rad dose I imaging agent, replacing I131</td>
<td>5.6 MBq/μAhr</td>
</tr>
<tr>
<td>Technetium - 99m</td>
<td>6 hrs</td>
<td>$^{100}$Mo (p,2n) $^{99m}$Tc</td>
<td>many</td>
<td>2 MBq/μAhr</td>
</tr>
</tbody>
</table>

## Therapeutic

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>$t_{1/2}$</th>
<th>Reaction</th>
<th>Application</th>
<th>Activity for Single Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palladium - 103</td>
<td>17 d</td>
<td>$^{103}$Rh (p,n) $^{103}$Pd</td>
<td>Interstitial implants - brachtherapy</td>
<td>8 MBq/μAhr</td>
</tr>
<tr>
<td>Copper - 67</td>
<td>62 hrs</td>
<td>$^{70}$Zn (p,a) $^{67}$Cu</td>
<td>monoclonal antibodies: accumulation in tumor tissue</td>
<td>26 MBq/μAhr</td>
</tr>
</tbody>
</table>
Particle Therapy

Radiotherapy Modalities:
- X rays
- Gamma rays
- Neutrons
- Protons
- Heavy ions (C)

Deliver radiation to tumour volume

Depth Dose Distribution
Thank You!