Building Hadron Therapy Center in the Republic of Moonland

By group of experts:

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**The Republic of Moonland**

**Government type:** Social Democracy  
**Area:** 367 332 sq. km  
**Population:** 28 mln  
**GDP:** 373,4 billion $  
**No oncological patients a year:** 9000-10000  

**Public health infrastructure:** widely available private coverage and government subsidized care for low income residents  

**International Community:** MoU with CERN, MedAustron  

**Academic Infrastructure:** good educational tradition with low-cost post-secondary education, strong University system (with emphasis on natural Sciences). There is a significant governmental funding for research.  

**Political Climate:** considered stable
Oncological treatment capabilities

- People are getting cancer ... Why??

  - Longer life expectancy
  - Cancer risk increases with age
  - Higher cancer rate

- Several regional and one national oncological centers (electron accelerators, gamma-knives, brachytherapy, powerful imaging systems)

- No facilities for radioisotope production

- Governmental subsidies for treatment in Rimerland’s Proton Therapy Center (2500 km across the sea)

- The Ministry of Health has approved building the next Moonland’s Hardron Therapy Center

- Government is interested in:
  - New facility for hadrontherapy
  - Medical research
  - Establishing an accelerator community
  - Some industrial development
The Proposal

Highly Modular Research + Treatment Center

**Beam Parameters**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Proton Energy</td>
<td>[MeV]</td>
<td>1000</td>
</tr>
<tr>
<td>(Treatment)</td>
<td></td>
<td>{250}</td>
</tr>
<tr>
<td>Carbon Ions</td>
<td>[MeV/u]</td>
<td>400</td>
</tr>
<tr>
<td>Future ions</td>
<td>He…O</td>
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</table>

**Treatment Specifications**

<p>| | | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Fraction time</td>
<td>[mins]</td>
<td>20</td>
</tr>
<tr>
<td>Avg fractions x treatment</td>
<td>[-]</td>
<td>8</td>
</tr>
<tr>
<td>Max Dose</td>
<td>[Gy/ fraction]</td>
<td>8</td>
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</table>

Expected Number of Patients: 1350
Cost x Treatment: 16k$
Overview of hadron therapy facility

Isotope production

Stripping foil

250 MeV Proton
400 MeV Carbon

Research room

Therapy room p & C

Therapy room p & C

RF

D

Q

Beam measurement device

2.45 GHz ECR

14.5 GHz ECR

LEBT

RFQ 3 MeV

DTL 10 MeV

Q

Q

Q

Q
**Injector**

**Ion sources**

<table>
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<th>Parameters</th>
<th>$\text{H}_3^+$</th>
<th>$\text{C}^4+$</th>
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<td>Ion source type</td>
<td>2.45&amp;14.5 GHz ECR</td>
<td>14.5 GHz ECR</td>
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<tr>
<td>Current (uA)</td>
<td>500</td>
<td>200</td>
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<tr>
<td>Voltage (kV)</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td>0.5</td>
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<tr>
<td>Pulsed duration (s)</td>
<td>1</td>
<td></td>
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<tr>
<td>Possible ions</td>
<td>H, He.........O</td>
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*Comercial solution*
LEBT

- Extraction system
- Diagnostic:
  - slits
  - wirescanners
  - faraday cups
  - alisson scanner for emittance measurements

- Solenoid
- Steerers
RFQ
- Acceleration up to 3 MeV/u
- 350 MHz
- 4 vane RFQ solution for such RF frequencies
- Peak surface voltage → 1.8 kilpatrick limit (good vacuum)
- Contacts with companies (Bevatech) for RFQ design and fabrication
Injectors

- Higher effective impedance at low energies
- Focusing quads inside tubes
- Effective gradient 3.5 MV/m at 350 MHZ
- 2 m long
- Peak surface field up to 2*Kilpatrick field
RF system

Tetrode → optimum solution for 350 MHz
Linac 2 Synchr. Injection

Studies ongoing:

**Injection Chicane**
Beam Intensity Optimization (no intensity limits due machine aperture and septum geometry, as in phase space painting)

**Injection via Septum**

4m injection region, keeping 1T magnet limit

<4m injection region, ca 0.5T
Synchrotron

- Quadrupoles
- Sextupoles
- H/V correctors
- Vacuum pumps
- Beam diagnostics

<table>
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<th>Value</th>
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<tr>
<td>Circumference</td>
<td>80 m</td>
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<tr>
<td>Number of dipole</td>
<td>12</td>
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<tr>
<td>Magnet rigidity</td>
<td>6.8 T m</td>
</tr>
<tr>
<td>B</td>
<td>1.5 T</td>
</tr>
<tr>
<td>Effective length</td>
<td>2.1 m</td>
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Betatron core driven slow extraction

- Spill measurement
- Slow extraction allows precise control of the applied dose

Figure 2: Spill measurement. The time scale for curve one and two is 50 ms/division, for curve three 1 ms/division.
Open Source Control System

Connecting things together

What is TANGO Controls?
A free open source device-oriented controls toolkit for controlling any kind of hardware or software and building SCADA systems...

Why choose TANGO Controls?
Because it is easy to use, flexible, and highly scalable. It provides a complete set of features for controlling equipment and lots of services for managing systems.

How to use TANGO Controls?
Just download it and install it. Then reuse or write a device server, deploy and marvel at how it works!
Tumour localization and Treatment planning at site
Patient positioning

- CBTC for in room patient positioning
- Patient fixation in house
Patient positioning

- Position verification before each fraction
Beam Delivery
Quasi-Discrete Scanning

Beam velocity: 20 m/s
Typical Step: 1 mm
Spot size: 4 – 10 mm
Beam Delivery System

Scanning Magnets with $B = 0.4 \, T$
Field ramp $62 \, T/s$

20x20x cm$^2$ IC strip chambers
128 channel
But wait, no Gantry?
Extensive analysis campaign on different tumours (pediatric, head & neck..):

- 80% treatable with (3+1)x directions (0 & 180, 90, 135) and couch movement

V. Rizzeria, S. Bakegey, “Treatment Planning Efficiency for MoonLand Hadrontherapy Center: a comparison between multiple and four-fixed beam angles”
Treatment Verification

Beam Delivery System

PET
Treatment Verification

Beam Delivery System

PET
Patient safety

- On line super vision of Beam Spot size and Position
- On line super vision of Patient patient
- Interlock system to prevent patient harm
Day & Yearly Schedule

Running 24:7

20 Days: Integrated Shutdown
(Expected Uptime Efficiency = 90%)

5.00 → 8.00 : Q.A.

8.00 → 20.00 : Treatment

20.00 → 22.00 : Machine Dvlp & Maintenance

22.00 → 5.00 : Research & RI production
3 years for design (3.2M$/year):
Collaborations ongoing with other centers
15x Fully paid Scholarships
25x Staff
  - 2x Doctors
  - 20x Technical (Beam & RF, Magnets, Control...)
  - 2x Admin

4 years for construction/qualification & commissioning :)
(180M$ TOTAL):
80x Staff
- decreasing Design Engineering Staff,
- Increasing:
  - Management, Admin
  - Technicians & commissioning staff
  - Medical staff
From 3rd year, Isotope production (2M$)

Running Full Throttle:
29M$ Revenue (7% Isotopes, 13% Research, 80% Treatment)
19M$ Running Costs
Break even after 27 years
Thank you!