Medical isotope production at TRIUMF - from imaging to treatment

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Beamlines and Production Sites at TRIUMF

- ARIEL
- ISAC
- TR30 cyclotron
- TR13 PET cyclotron
Routine production of $^{11}$C and $^{18}$F
New: radiometals Sc-44, Ga-68, Y-86, Zr-89
SPECT Isotope: Tc-99m

ARIEL

ISAC

TR30 cyclotron

TR13 PET cyclotron
**Project Status**
- 4.7 Ci (GE), 15 Ci (TR19), 32 Ci (TR30)
- Clinical Trials Underway
  - Bone/thyroid (36/60 patients scanned)

**Commercialization**
- Sole license issued to ARTMS Products Inc.
- Pursuing venture funding - ~$1.6M in stated interest to date
α emitters

ARIEL

ISAC

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Ionizing Radiation

Charged particles interact strongly and ionize directly.

Neutral particles interact less, ionize indirectly and penetrate farther.
DNA break

- DNA (Deoxyribonucleic acid): genetic instructions for development and functioning
- Cell needs information from DNA for survival

- Single helix break easy to repair
- Double helix break more difficult to repair
- Cell can not survive

- Radiotherapy: as many double helix breaks in cancer cells as possible with as few double breaks as possible in healthy cells
LET – Linear Energy Transfer

High LET – ions, neutrons, protons, direct damage

Low LET – photons, electrons, protons, indirect damage via free radical formation

Linear Energy Transfer (LET): Energy transferred (ionization, secondary electrons) per unit distance
Example of successful clinical application

Remarkable responses to Bi-213-DOTATOC observed in tumors resistant to previous therapy with Y-90/Lu-177-DOTATOC.

Case I: Shrinkage of liver lesions and bone metastases after i.a. therapy with 11 GBq Bi-213-DOTATOC.

Case II: Response of multiple liver lesions after i.a. therapy with 14 GBq Bi-213-DOTATOC.

Targeted alpha therapy (TAT) showed very high potential!


SNM 2012 Image of the Year (A. Morgenstern, JRC, Germany)

Slide: Valery Radchenko
Isotope production using TRIUMF’s 500 MeV infrastructure

1) ISAC – ISOL (Research, Feasibility)
   Low activity (kBq to MBq), high purity

2) 500 MeV – IPF (BL1A)
   Intermediate activity (MBq), spallation
   • Routine, independent production

3) ARIEL/H+
   High activity (GBq), spallation
   • Enable radiopharmaceutical development and clinical trials

Experiments underway
Spallation Reaction on $^{232}$Th with 500 MeV Protons

- Hundreds of co-produced isotopes including:
  - $^{225}$Ra, $^{225}$Ac, $^{224}$Ra, $^{223}$Ra, $^{213}$Bi, $^{212}$Pb, $^{212}$Bi, $^{209/211}$At
Isotope Separation On-Line

Sample holder (with current monitor)
collimator (with current monitor)
incoming ion beam

target

$p^+$
480 MeV
10 μA

ionization & extraction
to yield station
to implantation station

heterogeneous ion beam

mass separator magnet

$^{225}\text{Ra}$ & $^{225}\text{Ac}$, ion beam
A Focus on Radium

\[ {^{225}\text{Ra}} \xrightarrow{100\% \beta^-} {^{225}\text{Ac}} \xrightarrow{100\% \alpha} {^{221}\text{Fr}} \xrightarrow{100\% \alpha} {^{217}\text{At}} \xrightarrow{99.99\% \alpha} {^{213}\text{Bi}} \xrightarrow{97.8\% \beta^-} {^{2.2\%}} \alpha \]

\[ {^{224}\text{Ra}} \xrightarrow{100\% \alpha} {^{220}\text{Rn}} \xrightarrow{100\% \alpha} {^{216}\text{Po}} \xrightarrow{100\% \alpha} {^{212}\text{Pb}} \xrightarrow{100\% \beta^-} {^{212}\text{Bi}} \xrightarrow{64.1\% \beta^-} {^{35.9\%}} \alpha \]
Implantation and Isolation $^{225}$Ra/$^{225}$Ac

Dilute acid extraction

> 99% of all implanted $^{225}$Ra/$^{225}$Ac activity* recovered

*quantified using HPGe gamma spectroscopy

Clean sample of $^{225}$Ra and $^{225}$Ac

<1 mCi $^{225}$Ac per implantation

4 runs so far
Distinguishing $^{221}$Fr from $^{213}$Bi

$^{225}$Ac Decay Chain Energy Spectrum

Relative count rate vs. energy [keV]
First $^{225}$Ac scan

Robertson

High Energy Collimator

High Sensitivity Collimator

rod diameters [mm]

- $^{221}$Fr - 218 keV
- $^{213}$Bi - 440 keV

- $^{221}$Fr - 218 keV
- $^{213}$Bi - 440 keV

5 mm

MBq/mL
α emitters

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• Feasibility chemistry, radiolabeling

2) 500 MeV – IPF (BL1A)
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3) ARIEL/H¹
High activity (GBq), spallation
• Enable radiopharmaceutical development and clinical trials
0.4 g/cm² ThO₂ target

FLUKA Parameters

- beam time: 12.5 h
- current: 90 µA
- FWHM x: 1.35 cm
- FWHM y: 1.38 cm
α emitters

ARIEL

ISAC

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Isotope production using TRIUMF’s 500 MeV infrastructure

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   Low activity (kBq to MBq), high purity
   • Actinide targets
   • Feasibility chemistry, radiolabeling

2) 500 MeV – IPF (BL1A)
   Intermediate activity (MBq), spallation
   • Routine, independent production

3) ARIEL/H⁺
   High activity (GBq), spallation
   • Enable radiopharmaceutical development and clinical trials
Summary

- ISAC
- ARIEL
- TR13 PET cyclotron
- $^{225}\text{Ra}/^{225}\text{Ac}$, $^{213}\text{Bi}$, ..... 
- $^{209/211}\text{At}$, $^{225}\text{Ra}/^{225}\text{Ac}$
- $^{99m}\text{Tc}$
- $^{68}\text{Ga}$, $^{89}\text{Zr}$, $^{44}\text{Sc}$, $^{86}\text{Y}$
- $^{225}\text{Ra}/^{225}\text{Ac}$
Alpha Research Team
   Jason Crawford, Keith Ladouceur, Andrew Robertson, John D'Auria, Caterina Ramogida, Peter Kunz, Paul Schaffer, Tom Ruth, Vesna Sossi, Francois Benard, Chris Orivg, Scott Wilbur

ARIEL Parasitic Target Station
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RIB Target Group
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Radiation Protection Group
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Thank you!
Merci!

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