Localisation of high dose rate ^{192}Ir source during brachytherapy using silicon detectors

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Brachytherapy

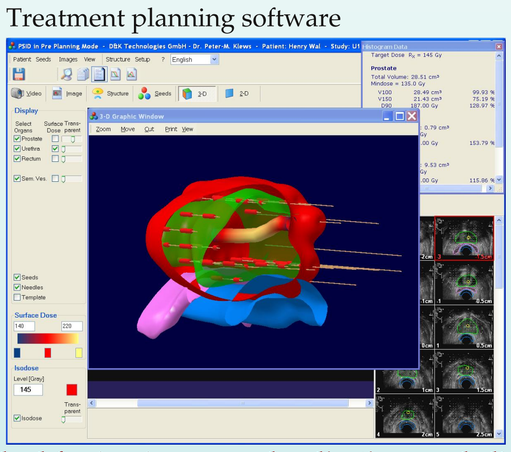
(from the Greek *brachios*, meaning "short"), also known as sealed source radiotherapy or endocurietherapy, is **a form of radiotherapy where a radioactive source is placed inside or next to the area requiring treatment**. Brachytherapy is commonly used to treat localized prostate cancer, cervical cancer and cancers of the head and neck.

Strong localisation of radiation dose (inverse square law)

Pulse Dose Rate (PDR) and High Dose Rate (HDR) brachytherapy:
- temporary implantation
- >12 Gray/hour (typically 100-300 Gray/hour)
- Iridium 192 source pellets, activity 1 Ci (PDR) to 10 Ci (HDR)
- dwell positions 3 - 5 mm apart
- dwell times ~1 s (up to couple of minutes for HDR)

Possible misadministrations
- cables connected to wrong needles
- not connected / disconnected cables
- malfunction of afterloading system
- source-wire detachment
- innaccuracy of treatment set-up
- ...

Treatment planning software

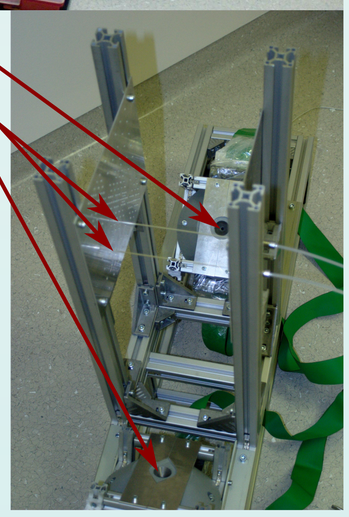


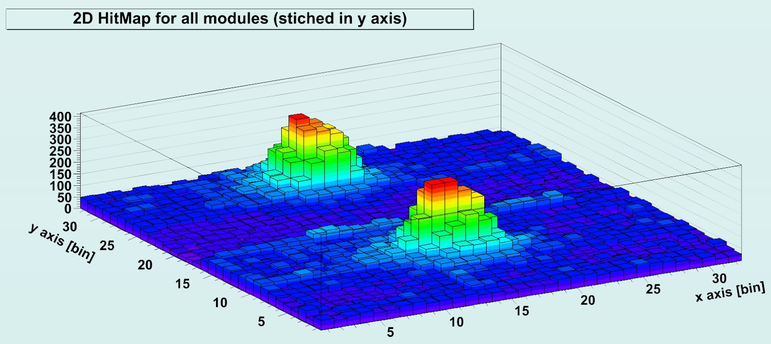
Independent method for *in-vivo* source localisation needed!

Measurements and simulations

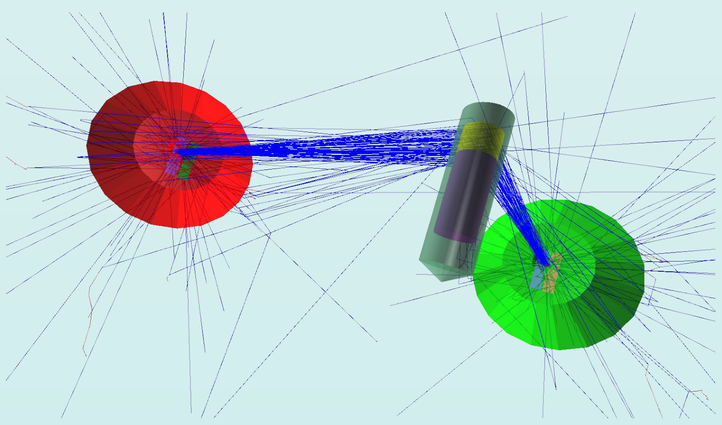
Measurements were done at Institute of Oncology, Ljubljana

Measurements info:
- Varian GammaMed Plus afterloader with ^{192}Ir 1 Ci source;
- measurements with and without 20×20×20 cm^3 plexi-glass phantom;
- distances between dwell positions varying from 25 mm down to <5 mm.

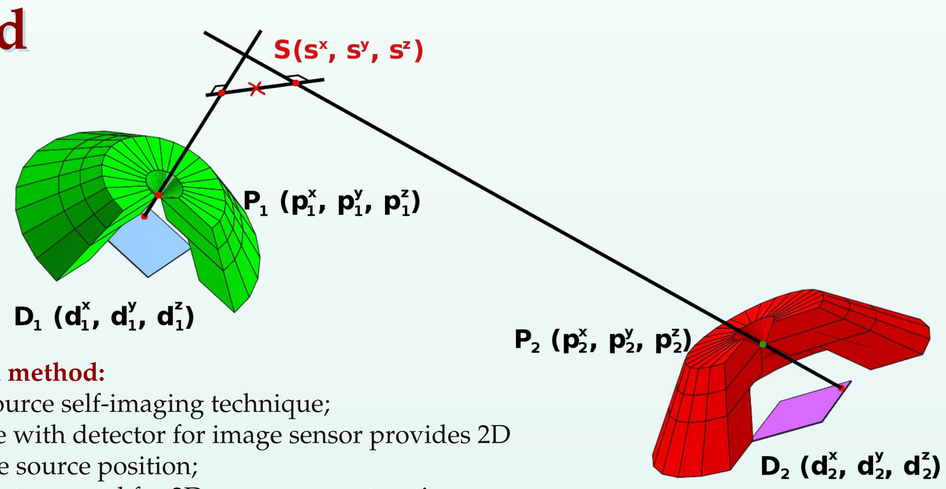




Simulation info:
- GEANT4 toolkit code;
- ROOT framework for data persistency and analysis;
- EVE for visualisation;
- long simulations (~88×10^9 gamma particles for simulation of 1 s of real source activity takes 4300 hours on 2.6 GHz machine);
- run on nordugrid.org grid infrastructure with custom runtime environment.

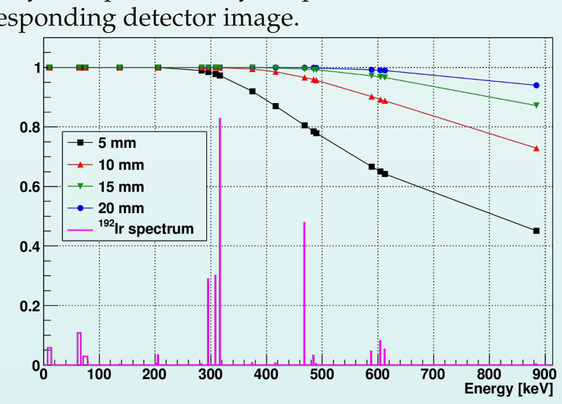


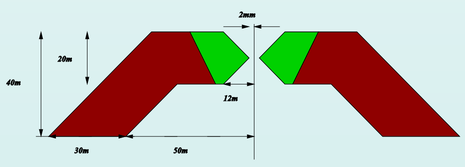
Method



Reconstruction method:
- radioactive source self-imaging technique;
- single pinhole with detector for image sensor provides 2D projection of the source position;
- two pinhole setups used for 3D source reconstruction;
- due to measurement error the source position may be represented by the point closest to two lines, each connecting pinhole position with corresponding detector image.

Pinhole geometry:
- large pinhole aperture due to high energy of gamma particles from ^{192}Ir spectrum (to compensate for low detector efficiency for high energy photons);
- 2 cm thick block of lead has sufficient stopping power for all gamma rays from ^{192}Ir spectrum;
- knife-edge angle was calculated to provide good source image within chosen field of view.

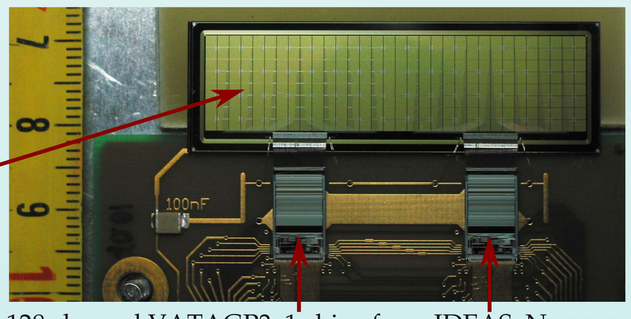




Detectors, read-out electronics:

Silicon pad detector
256 pads (1.4 × 1.4 mm^2 pad size)
1 mm thickness

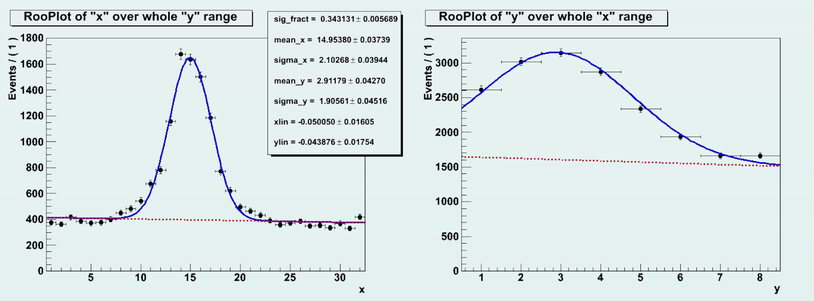
- two detectors per pinhole
- read-out via VMEbus and Optolink to Linux PC



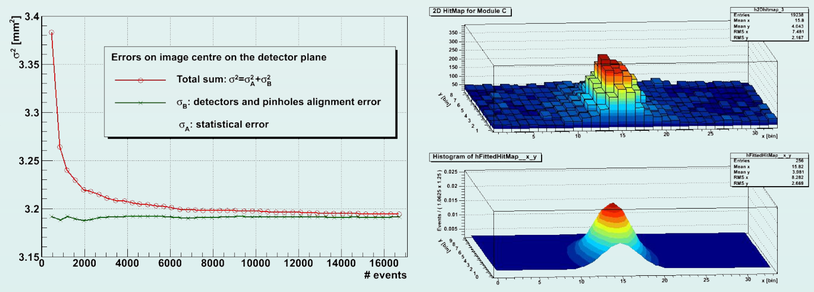
128 channel VATAGP3_1 chips from IDEAS, Norway.

Results

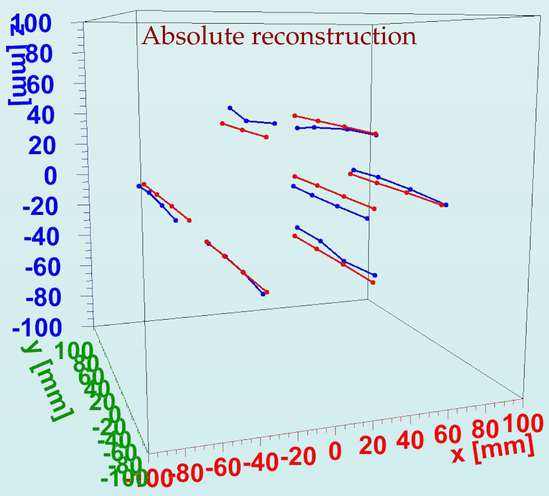
Peak finding algorithm:
- fitting of 2D Gaussian function if peak inside one detector;
- "centre of gravity" is used if peak is spread over both detectors;

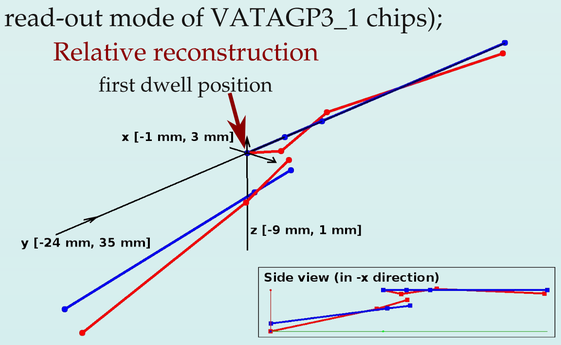


Reconstruction accuracy:
- large systematic errors for absolute reconstruction due to uncertainties of detector and pinhole positions;
- relative reconstruction is preferable (source locations are determined relative to first dwell position);



- 4000 hits suffice (sub second data taking in fast read-out mode of VATAGP3_1 chips);





Residuals for reconstructed source positions:
Absolute reconstruction **10 mm** (rms 3 mm)
Relative reconstruction **1.5 mm** (rms 0.6 mm)

Similar results with plexi-glass phantom.