project
INTRA-DOSE

IntraLine

electron accelerator for intraoperative radiation therapy

PROJECT INTRA-DOSE

Intraoperative electron-beam radiation therapy

In the European Union malignant tumours are the second most common cause of death after cardiovascular disease, currently they are diagnosed in several million people each year.

Methods of destroying tumour cells in patients include the use of various types of ionizing radiation, mainly photons and electrons, recently protons and heavy ions are being employed more frequently. Radiation breaks up the DNA strands of the cells and separates water into free radicals that oxygenate the chemical molecules that are essential for cells to maintain life processes.

Ionizing radiation kills both tumour and healthy cells. For this reason, irradiation has to be performed carefully, restricting its effect on healthy tissue to a minimum. What is of key importance here is the careful choice of the type of particles and their energy as well as forming a beam of radiation of precisely controlled dimensions and properties.

High energy photons (X-rays or gamma rays) penetrate through the body destroying cells throughout the path of the beam in the body. Protons are more accurate, as they begin to interact strongly with tissue only from a certain depth and to a specified depth of penetration. Electrons behave in yet another manner: they interact with cells right after penetration into the tissue (like photons), but only for a **limited distance** which depends on their energy (so they are similar to protons).

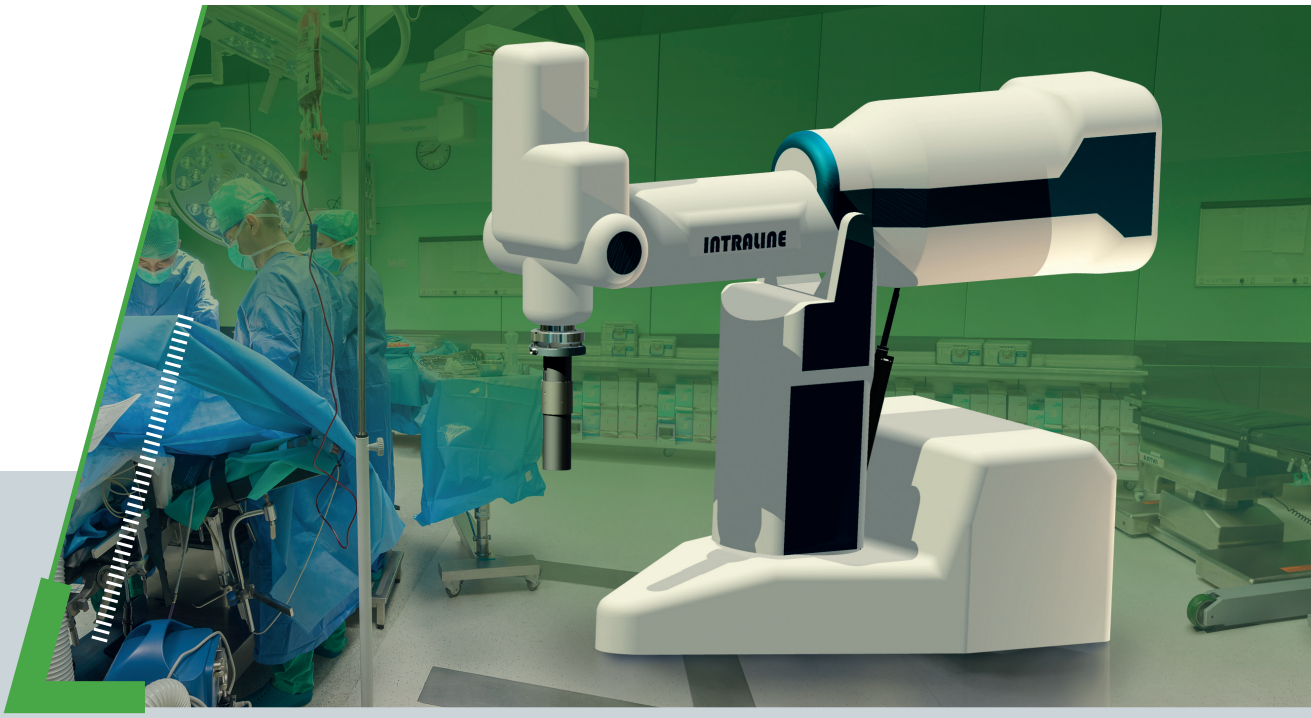
Intraoperative radiation therapy involves irradiation during surgery of the tumour bed following the resection of the tumour. Beam of particles is delivered directly onto the site at risk without the need to irradiate healthy tissues. Performed using **electrons**, this method gives results similar to those obtained using much more expensive procedures using protons or heavy ions.

Intraoperative electron-beam radiation therapy (IOERT) is one of the **most modern** methods of combating cancer.

Exceptional mobility

High quality of electron beam

Very low level of leakage irradiation



The **IntraLine** Accelerator

The IntraLine medical linear accelerator was built as part of the INTRA-DOSE project. The device, suitable for use in sterile conditions, serves to irradiate tissues and organs with a spatially homogeneous and time-stable beam of electrons of a high energy and intensity, administered directly to an open operating field. The task of the apparatus is to destroy – still at the stage of the surgical operation – those tumour cells that may remain in the patient's body despite the resection of the tumour.

The **exceptional mobility** of the IntraLine accelerator head makes it possible to deliver the therapeutic beam rapidly and comfortably directly to the area at risk. Since the radiation doesn't pass through health tissues and organs, its dose may be safely increased. This sort of irradiation is more effective, reducing the risk of complications and shortening the treatment period by even several weeks.

With the **integrally built-in** trolley the surgeon can move the IntraLine accelerator to a standard operating table for just the time of the irradiation.

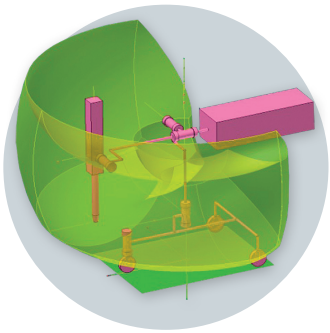
IntraLine
an exceptional accelerator

The innovative technical solutions of the electron accelerating systems, the beam formation and its positioning, developed at the National Centre for Nuclear Research (NCBJ) and covered by patent protection, guarantee the creation of a uniform and stable therapeutic beam of a high quality. The accelerating structure itself is short and lightweight. Range of available electron energies (4-12 MeV) makes it possible to carry out virtually any of the procedures of today's intraoperative radiation therapy. The profile of the beam, verified in dosimetric measurements, is flat in a range corresponding to international standards and guarantees the uniform irradiation of tissues within the volume of a cylinder of a height to 6 cm with a high radiation dose (5 or 15 Gy/min). At the same time the level of scattered X-ray radiation is even 500 times less than that required by the relevant standard.

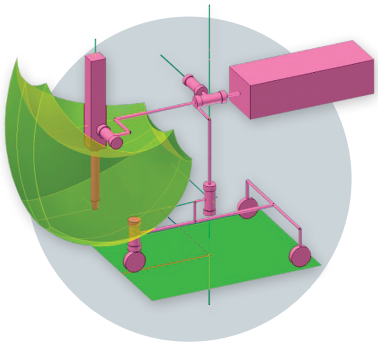
Extraordinary mobility

No other irradiation apparatus offers such configuration of features like IntraLine does. The unique set of parameters have permitted the construction of a device that is exceptionally mobile:

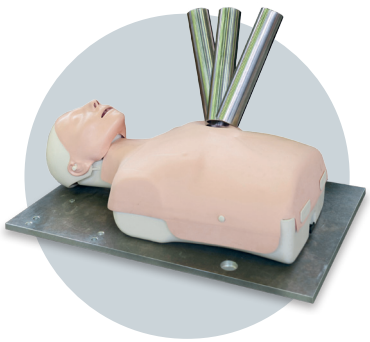
- ✓ The trolley (an integral part of the accelerator) can move forwards/backwards and to the left/right
- ✓ The head of the IntraLine accelerator inclines in the range ±60°
- ✓ The supporting column installed on the trolley rotates in the range ±90°
- ✓ The robotic arm assembly with the head inclines from +30° to -20° and turns ±45°



Working area of applicator head with immobilised trolley.



Working area of applicator head with immobilised trolley and column.

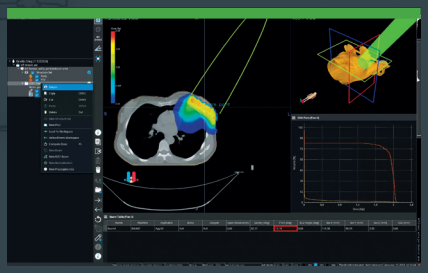


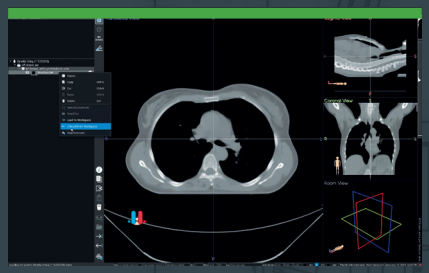
Positioning of a steel applicator by the patient's body.

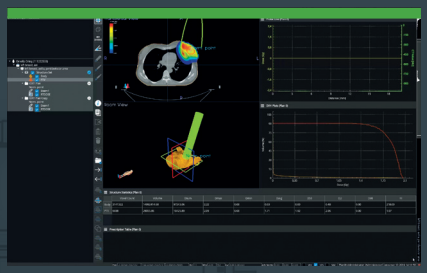
The high mobility of the IntraLine accelerator facilitates the surgeon's work, increases the precision of procedures and shortens the time required for their performance. It also enables the irradiation of places that are inaccessible to other accelerators.

The software

The software to plan the course of perioperative irradiation was developed by UJP Hilton Systems S.A. The system uses computer tomography images and apart from the typical functions of optimising the beam position and parameters and an analysis of the results of the irradiation, it allows for a correction of the original settings during the operation, appropriate to the true course of the tumour resection.







Surgical operation

After resection of the tumour, the surgeon mounts a short, relatively light and easy-to-position steel applicator by the patient's body. This covers the entire field to be irradiated (applicators with diameters ranging from 3 to 12 cm are available) and is oriented along the planned direction of the electron beam. The next step is to move the IntraLine accelerator towards the operating table. At this stage docking takes place, which involves the co-axial arrangement of the head with the applicator. The exceptional mobility of the accelerator facilitates the positioning of the head and reduces the time taken for this phase of preparation to just 2-5 minutes.* During irradiation a mechanical blocking system ensures the tightness of the connection between the applicator and the head.

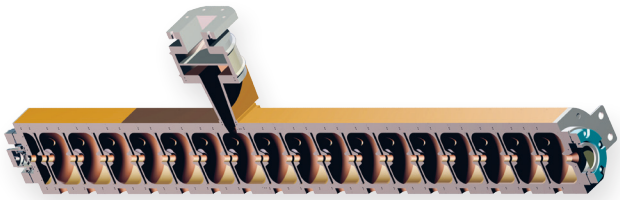
Radiation power

The high radiation energy means that typical irradiation using the IntraLine accelerator lasts no longer than two minutes. For safety reasons most of the medical personnel should leave the operating theatre for the duration of the irradiation. The operation of the beam is then controlled from a neighbouring room with the aid of a precise remote control system. A dedicated audio-visual system assures doctors continuous visual observation of the patient and guarantees continued audio contact with the persons remaining in the operating theatre.

* Under the INTRA-DOSE project a prototype laser system to aid docking has also been developed.

From heating to irradiation

The source of electrons in the IntraLine accelerator is a heating element (a heated cathode in a triode system). The electrons emitted by it are grouped and directed towards the interior of an accelerating structure composed of 18 resonant cavities, creating a waveguide filled with a high frequency electric field. Portions of electrons are injected into the waveguide at appropriate moments, so that by moving with the electromagnetic wave they are continually accelerated.



A section through the accelerating structure.

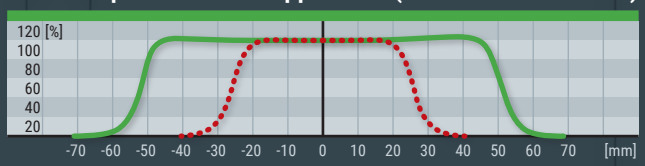
The intensity of the therapeutic beam is measured with the aid of two independent systems of ionisation chambers. They generate a reference signal, used to stabilize the doses of radiation emitted by the accelerator.

Beam shape

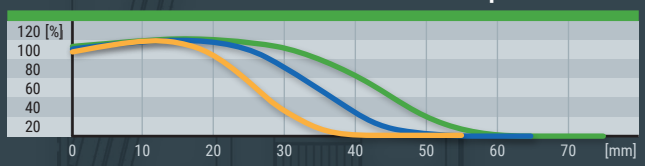
The shape of the beam of electrons leaving the accelerating structure resembles a bell. This type of beam is not suitable for therapeutic purposes. A special system of scattering and filtering foils is responsible for flattening the profile and forming a therapeutic beam. This is an original solution, entirely developed by researchers at the National Centre for Nuclear Research in Świerk.

Energy 6 MeV
Energy 8 MeV
Energy 10 MeV
Energy 12 MeV

Beam shape for different applicators (diameters 5 and 10 cm)



Radiation dose as a function of depth



Scientific research

The first research and design work on the intraoperative accelerator for irradiation with a high quality beam of electrons, including modelling the dynamics of the electron beam, Monte Carlo simulations , designing the control electronics and building the mechanical systems, was started at the NCBJ in 2008 in the Accelerators and Detectors (A and D) project. The project's conclusion in 2014 resulted in a demonstration version of the accelerator.

Specifications

PHYSICAL PARAMETERS standard IEC 60977	
energy	4-12 MeV
pulse current of electron beam	≤5 mA
applicator diameter	3-12 cm
symmetry for all fields	≤102%
flatness	≤10 mm
radiation dose	5 or 10 Gy/min (applicator Ø = 10 cm)
SSD distance	60 cm
proportionality	±3%

MECHANICAL PARAMETERS	
motions	**data**
column rotation	±90°
head inclination from/to the column	45° / 30°
lateral tilt of the head	±45°
max. height of the accelerator (operating/idle)	3 m / 2 m
max. width	1.15 m
dimensions (idle)	1.15 x 2 x 2.2 m
weight	<900 kg (distributed over 1.5 m²)
max. velocity of trolley in the operating room	≤10 cm/s; ≤7°/s
operating table	does not require any dedicated table

ELECTRO-ELECTRONICAL PARAMETERS	
electron gun	triode
length of radiation impulse	≤4 µs
repetition rate	≤30 Hz
emergency switches	3
motion control	control box
device control	control cabinet with a panel, PLC-based control system

Our team

A team of over 50 physicists, engineers and oncologists was involved in the creation of the IntraLine accelerator. Four inventions patented by the NCBJ were used in the project, as well as a range of innovative technical solutions.

INTRA-DOSE

The IntraLine intraoperative accelerator was built under the INTRA-DOSE project, implemented by a consortium composed of the National Centre for Nuclear Research in Świerk, the Greater Poland Cancer Centre in Poznań and industrial partners: UJP Hitec Systems S.A. and the Jarosław Kołcun company. The project was co-financed by the National Centre for Research and Development government agency under the Programme for Applied Research in Path B.

IntraLine

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