Industrial and Societal Applications – WP3

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HUD & CNRS

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Tasks

- Task 3.1. Coordination and Communication
  (Rob Edgecock - HUD)
- Task 3.2. Low energy electron beam applications: new technology development
  (Andrzej Chmielewski - INCT)
- Task 3.3. Low energy electron beam applications: new applications
  (Frank-Holm Roegner - FEP)
- Task 3.4. Medium energy electron beams
  (Angeles Faus-Golfe - CNRS)
- Task 3.5. Radioisotope production
  (Concepcion Oliver - CIEMAT)

Deliverables & Milestones

D3.1	Application of electron beams in the environmental area	INCT	M24	Done
D3.2	Evaluation of new technology for electron beam accelerators	INCT	M30	Done
D3.3	Comparison of different accelerator options for ^{99m}Tc and therapeutic isotope production	HUD	M36	Done
D3.4	Design of a compact 140 MeV electron linear accelerator	CNRS	M40	Done

MS13	Current applications of e-beam accelerators up to 10 MeV	INCT	M12	Done
MS14	New industrial applications of electron beams	FEP	M18	Done
MS15	Medical applications of high energy electrons beams	CNRS	M24	Done
MS16	Study of different options for PET isotope production	CIEMAT	M30	Done

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Main Achievements T3.2 and T3.3

Low-energy e-beam applications: new technology and applications

Many activities studying the use and development of e-beams

(300 Kev to 10 MeV):

- High-beam power for high-dose rate
- Basic process:

$$H_2O \rightarrow [2.7]\ OH\bullet + [2.6]\ e^-_{aq} + [0.6]\ H\bullet + [2.6]\ H_3O^+ + [0.45]\ H_2 + [0.7]\ H_2O_2$$

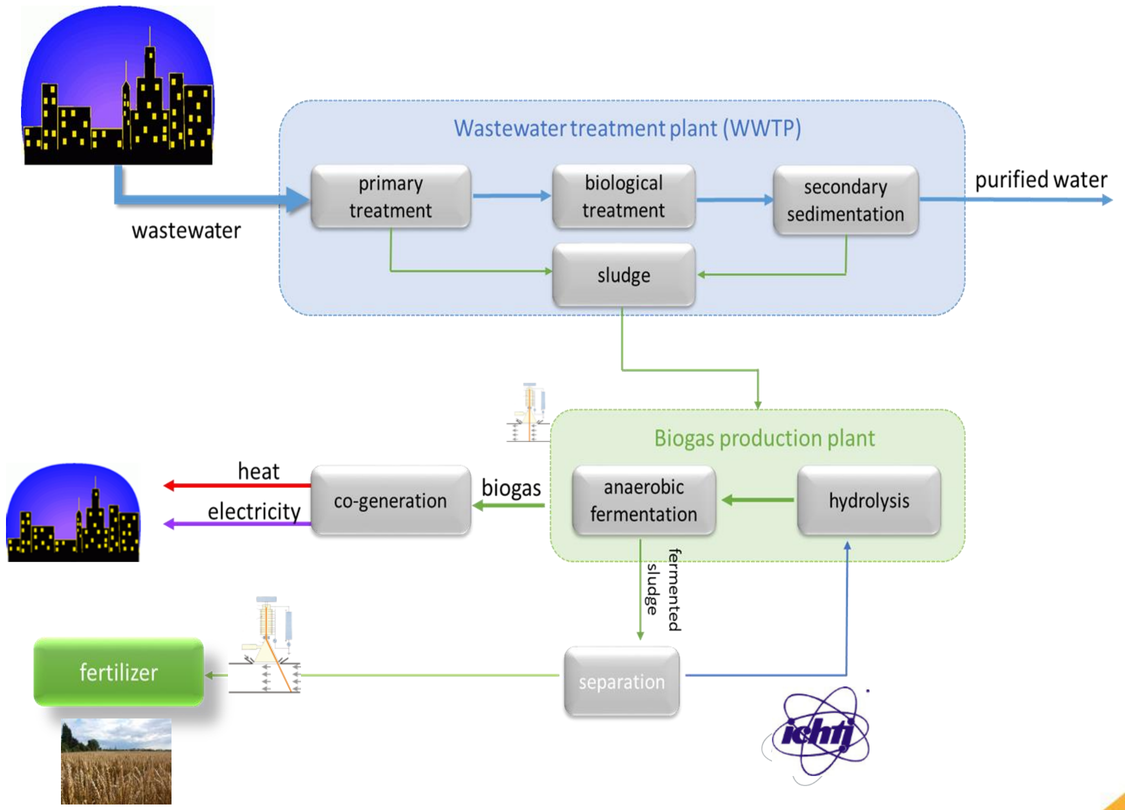
- G-value: molecules/100 eV
- radicals react with biological, organic and inorganic matter

- New environmental applications:
  - Residual marine ballast water treatment
  - Sewage sludge treatment, biogas production, MPs, etc
  - Marine diesel exhaust treatment: PoC, Hertis
- Document preservation
- Food irradiation
- Virus inactivation

EB-system for Hybrid Biogas

Advantage of proposed solution:

- **Environmental friendly technology**
- Biogas production is **disposal of problematic wastes**
- Production of **renewable power through combined heat and power cogeneration**
- Production of microbiologically safe organic fertilizer **due to electron beam hygenization**
- Technology can be applied in any place with sufficient biomass resources while there is **no need for external electric energy supply**
- **Also shows potential for modern contaminants**: microplastics, PPCP, POPs, AMR, etc



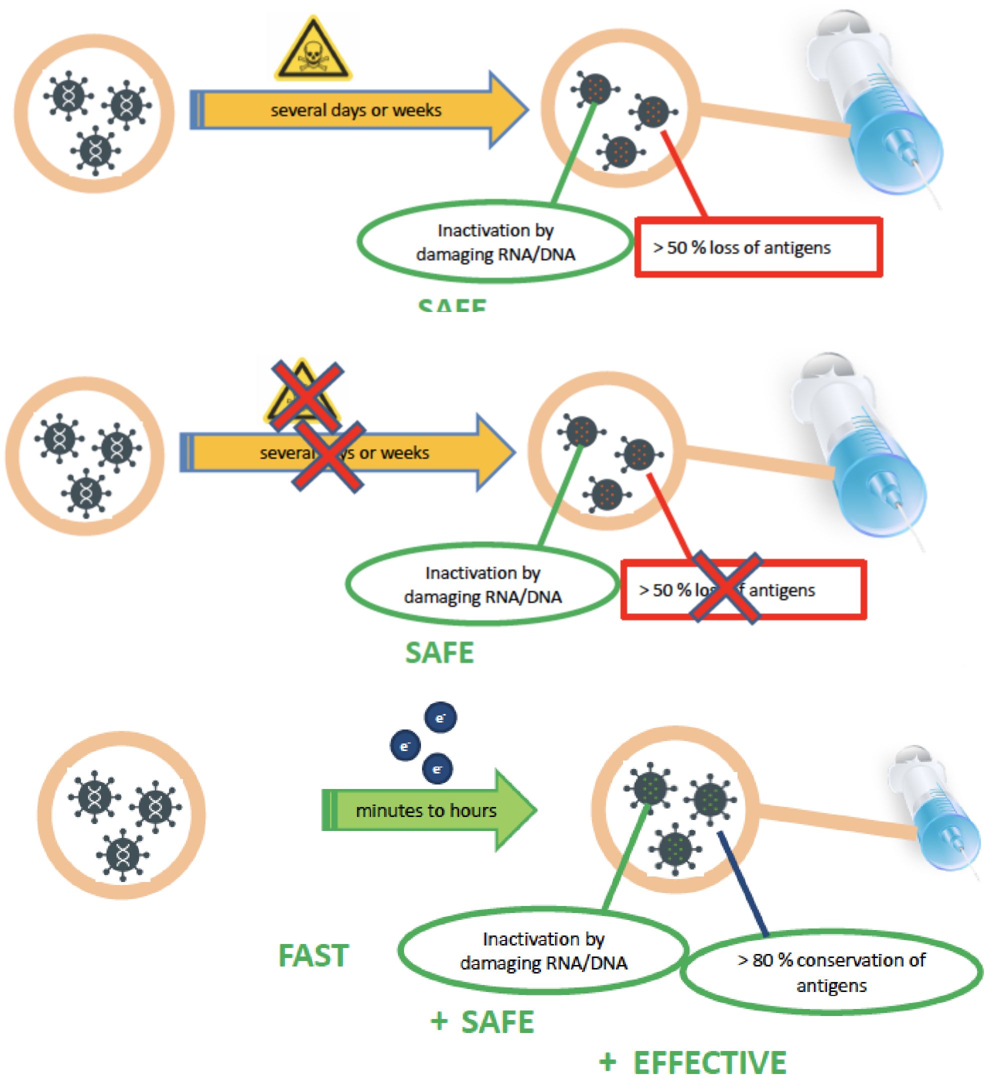
EB-technology against biohazards

- **Inactivation of viruses for vaccine production**

Current method: Chemical inactivation

Aim: Elimination of drawbacks

Novel method: low energy e-beam irradiation



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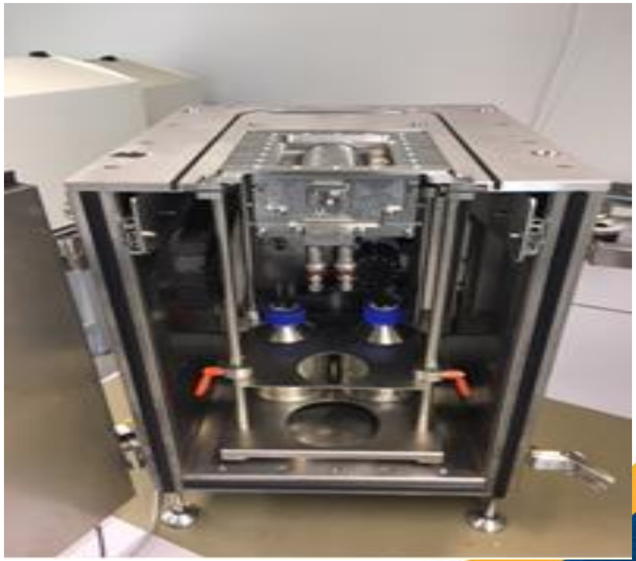
EB-technology against biohazards

- **Inactivation of viruses for vaccine production**
    - First prototype machine, developed by Fraunhofer-consortium (FEP, IZI, IPA) works well and produces inactivated suspensions in the range of some liters per hour
    - Evaluated results for a lot of real types of vaccines
    - **First positive results on Corona-virus as well!**
    - High dose rate enables high preservation of important antigens
    - 300 keV accelerator for compact design
    - **First industrial licensing acquired!**



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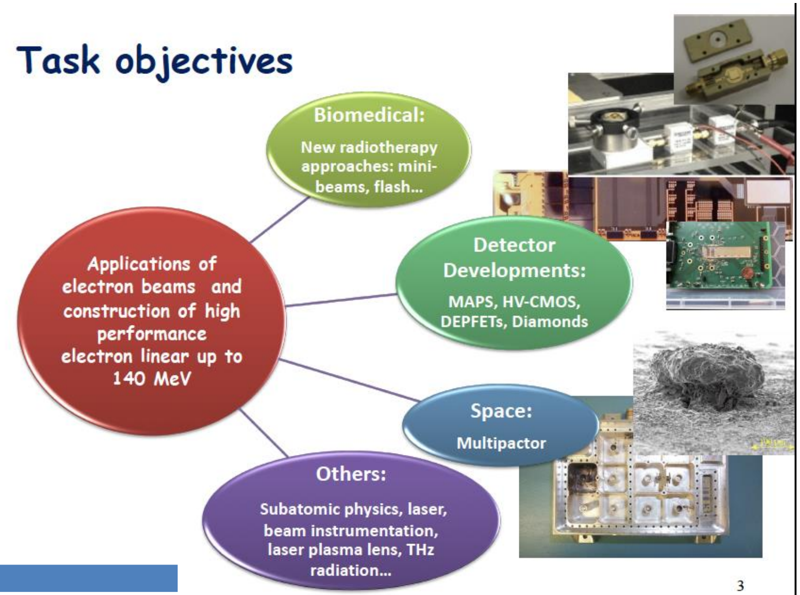
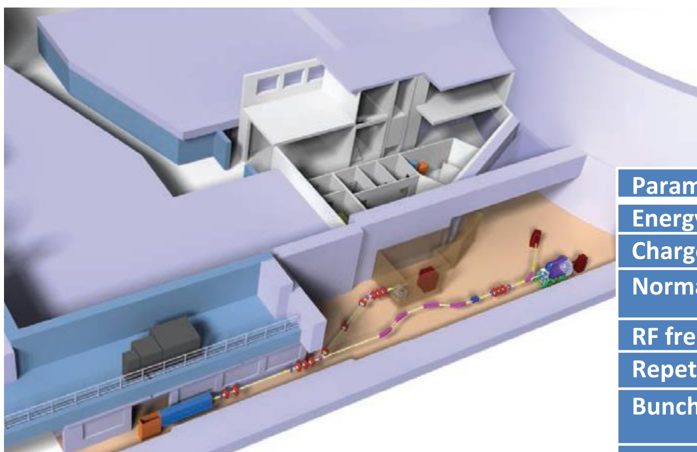
Main Achievements T3.4

Medium energy e-beam: new Radiotherapy applications

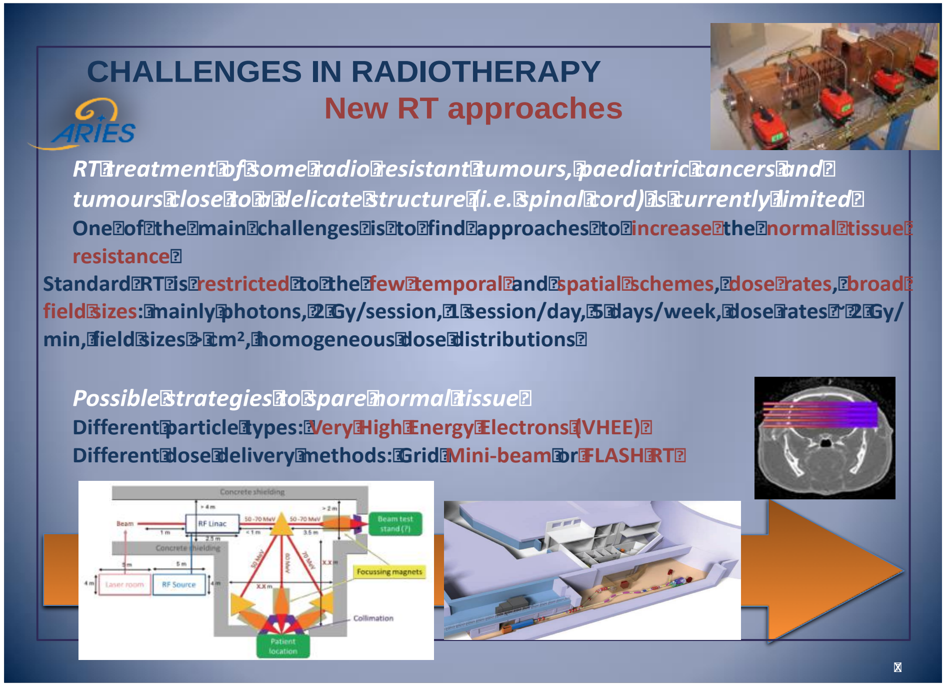
- Study of the applications of e-beams up to 140 MeV in the medical and other areas
- Study of the construction of high performance electron linear accelerator up to 140 MeV

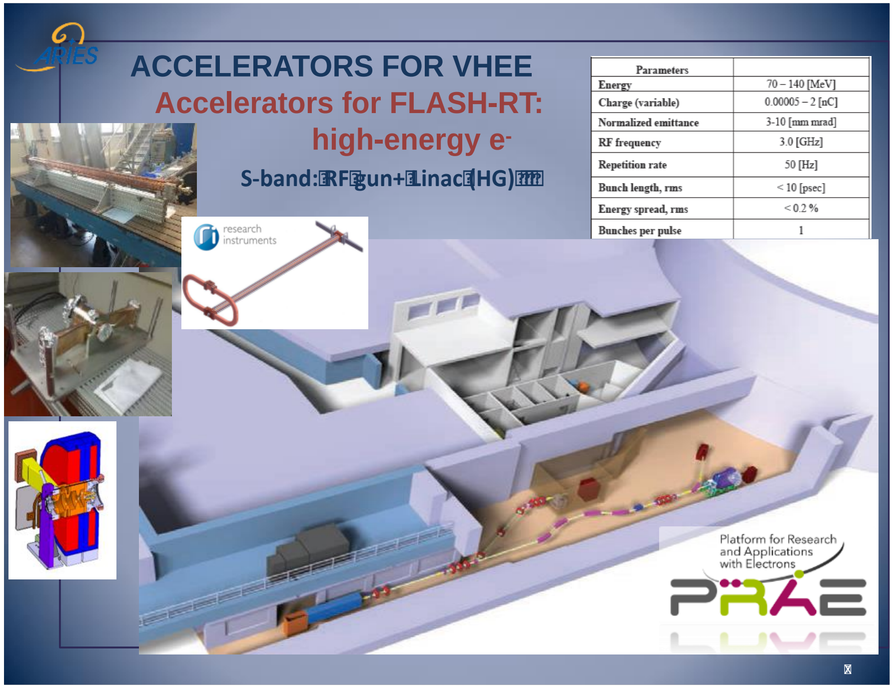




Parameters	
Energy	70 – 140 [MeV]
Charge (variable)	0.00005 – 2 [nC]
Normalized emittance	3-10 [mm mrad]
RF frequency	3.0 [GHz]
Repetition rate	50 [Hz]
Bunch length, rms	< 10 [psec]
Energy spread, rms	< 0.2 %
Bunches per pulse	1

New e- linac therapies and accelerator designs



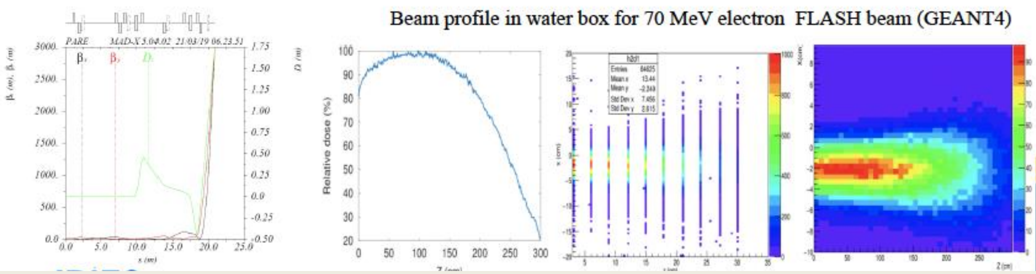


Very High Energy Electrons (VHEE) RT accelerator design, in particular for **Grid mini-beam** and **FLASH ultra-high dose rate** delivery modes:

- **Dose rates:** 2 Gy/min - 100 Gy/sec
- **Beam sizes**: 0.5 mm - 10 cm
- **Homogeneous beam**: +/- 2-3%

for single or multiple beams and single or multiple fractions in biological and preclinical applications.

- FLASH



PhD: B. Bai, Injector linac optimizations for FCCee and applications for PRAE, University: Paris-Saclay / University Chinese Academy of Sciences, 2021.

Very High Energy Electrons RT: VHEE’20 workshop

https://indico.cern.ch/event/939012/

Accelerators for VHEE RT

- **Normal Conducting RF linacs:**

eRT6-Oriatron at **CHUV, ElectronFlash** at **IC, CLEAR at CERN, CLARA at Daresbury and AWA at ANL**

- **Super Conducting RF linacs:**

ELBE Center of High Power Radiation Sources at **HZDR and PITZ** at DESY in Zeuthen

- **Laser Plasma Facilities:**

DRACO at **ELBE LOA** at **IPP**

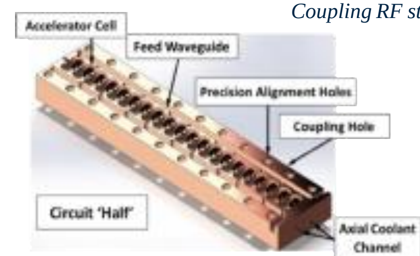
Accelerator technologies for VHEE RT

High-gradient RF structures where more than 100 MeV/m are now achievable.

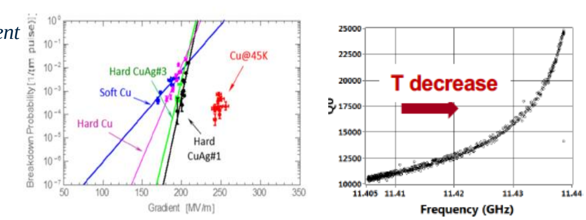
Some promising R&D are:

- **distributed coupling accelerator**
- use of **cryogenic copper**
- **higher frequencies millimetric waves** (~100 GHz) and **higher repetition rates** using THz sources

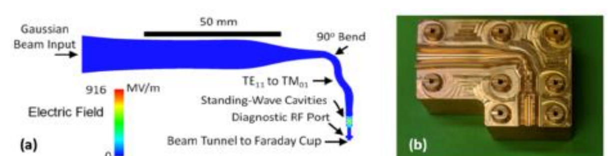
X-band π-mode Distributed Coupling RF structures



Left: Breakdown probability measurement in a single cell cryogenic test. Right: Quality factor for cryogenic copper accelerator structures



Built and tested structures to 230 MeV.



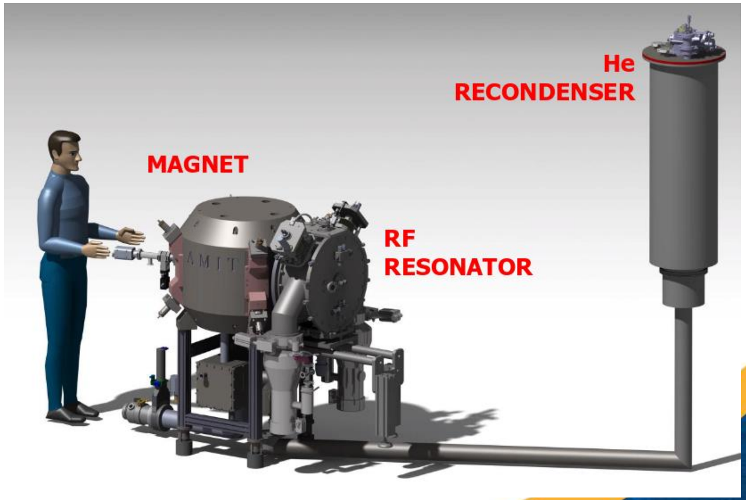
Main Achievements T3.5

Radioisotope production: AMIT cyclotron

- Advance Molecular Imaging Technology (AMIT) Cyclotron
- Development of a **compact mini-cyclotron for ^{11}C and ^{18}F single doses production**
- Cyclotron to be installed in (or near) the hospitals
  - Compactness requirement → high magnetic field
  - Low maintenance and power consumption

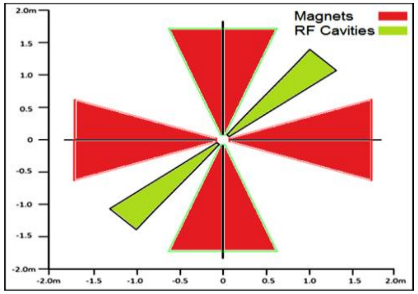
Optimization of AMIT cyclotron:

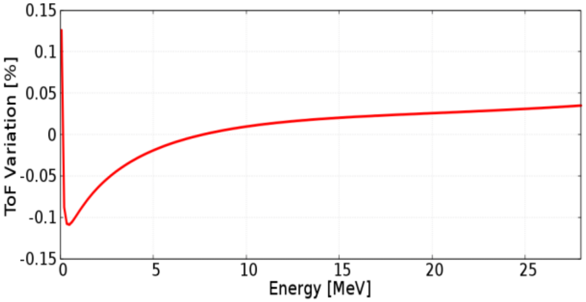
- Ion Source Validation and characterization
- Beam Dynamics
- Optimization of the autonomous Cooling Supply system



FFAG optics design - HUD

- 75 keV to 28 MeV
- Protons and alphas
- High current: 4mA protons, 800µA alphas
- ^{99m}Tc production with internal target looks feasible





PhD: David Bruton - UoH

Rhodotron for ^{99m}Tc production - IBA

- Photo-production of ^{99}Mo via ^{100}Mo(γ,n)^{99}Mo
- Direct replacement of reactor produced ^{99}Mo
- Uses new version of Rhodatron: TT300-HE
- 125kW of electrons at 40 MeV
- North Star Medical (US) buying 8, first 2 operational 2021

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Conclusions

- WP3 has done all
  - Milestones
  - Deliverables
  - Objectives
- A lot has been achieved
- It has had significant impacts in health, industry and the environment
- Collaborations have been created with new partners
- Funding proposals have been submitted to other sources