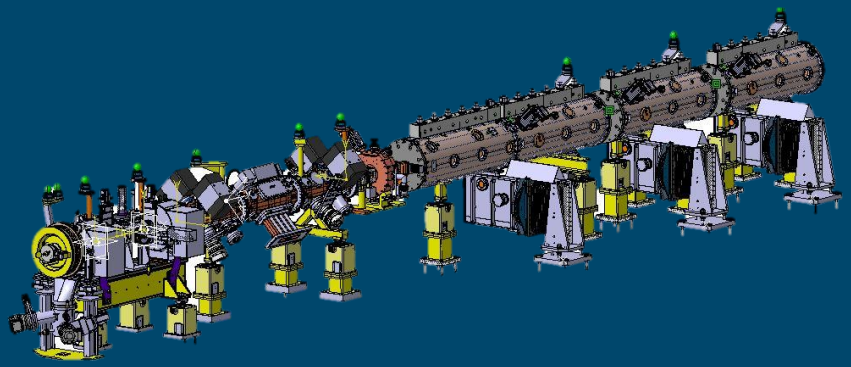
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Workshop on Research & Innovation in Poland



Radioisotopes & Applications

Dariusz Bocian
Lazar Nikitovic

Research Programme for Linear Accelerator

22 October 2026

Accelerators: the future or the past?

- ~ 6% of accelerators are used for scientific research

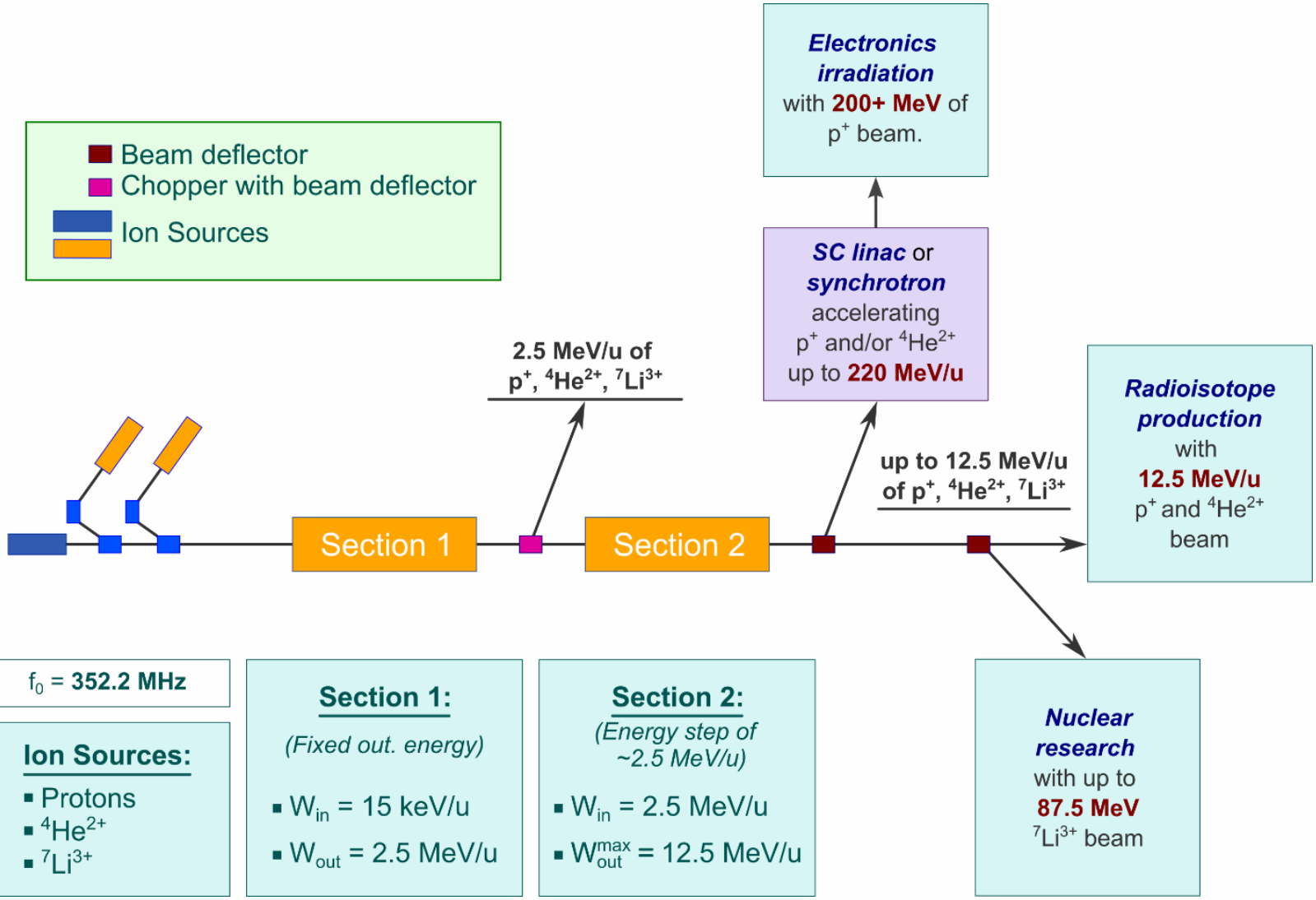
  (particle physics – 0.5%, nuclear physics, solid, materials – 0.5%, biology – 5%);

  medical applications (~35%); industrial applications (almost 60%).
- *In the scientific community associated with accelerators, there is a belief that accelerators will be key actors in the fourth industrial revolution, enabling industry and medicine to use technologies based on access to and interaction with the atomic and subatomic levels.*
- In Poland we have ~80% of competences to build linear accelerator

→ A new era of nuclear medicine: radioisotopes for topical treatment of cancer (teragnostics).

→ "Light factories": lithography ⇒ innovative microprocessors

Accelerator design



More detailed layout

- Ion sources,
- Pre-acceleration and chopper line (Section 1),
- Main accelerating section (Section 2)
- Targets and experiments



Currently working on:

- Design of the main accelerating section
- Beam instrumentation – collaboration CERN, ESS, PSI
- ion sources – market survey
- power sources – discussion with Polish companies



Preliminary schedule

BUILDINGS – design and implementation

Accelerator (Source, DTL, RFQ)

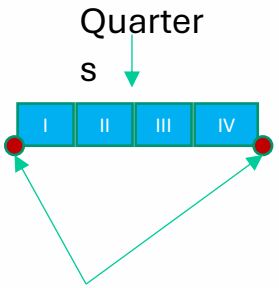
Procurement & Production & Delivery

INSTALLATION AND COMMISSIONING

LINIAC DESIGN production with tests

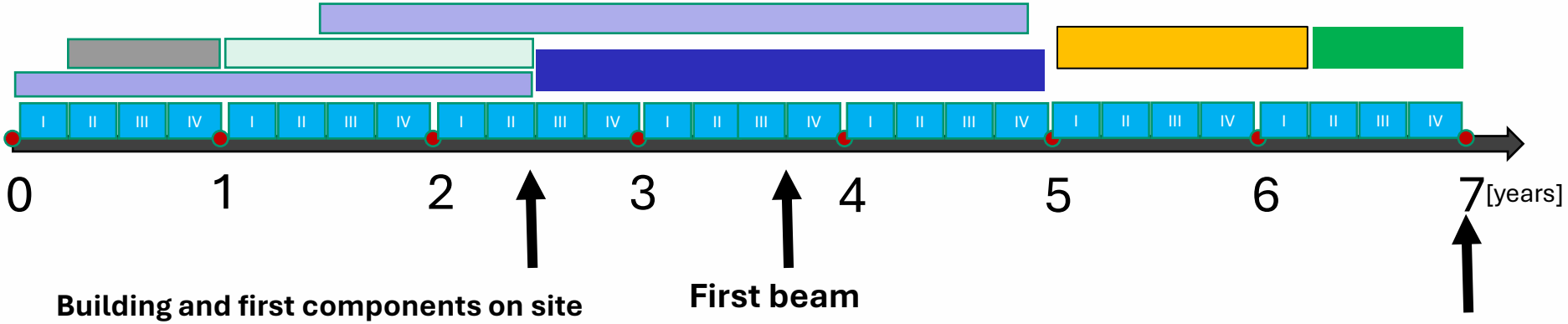
FINAL COMMISSIONING

Beam Testing and Operation



The beginning and end of the year.

MILESTONES



Building and first components on site

First beam

Possible project organization

- **WP1 – accelerator**
  - Linear accelerator design,
  - Beam diagnostics – agreed cooperation with an expert from CERN, PSI, ESS
  - Power distribution system,
- **WP2 – Basic scientific research (nuclear physics, solid state physics, medicine, archeology, etc.)**
  - Developing a basic research plan for a new linear accelerator.
- **WP3 – Target**
  - Create the teams to solve challenges
- **WP4 – Radioisotope extraction**
  - Working meetings
  - Report on radioisotope extraction methods.
- **WP5 – Innovative research on targeted therapy**
  - Report on ??? (the carrier platform for the radioisotope, encoded protein, etc.).
- **WP6 – Accompanying activities**
  - The radioactive isotope market in Poland and Europe,
  - Human resources and competence building,
  - User community

Possible facility development

- Deuteron ($^2H^+$) acceleration

  → additional radioisotopes
  (same q/m as $^4He^{2+}$ - no linac changes);

- Facility upgrade via superconducting linac or synchrotron

  → accelerate H^+, $^4He^{2+}$ and $^7Li^{3+}$ ions to higher energies;

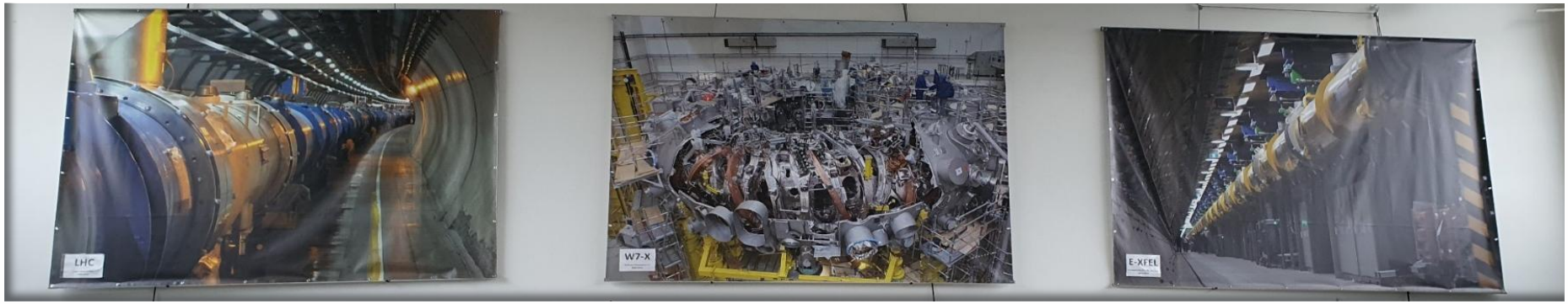
- Higher energies ⇒ broader research programs;
- Neutron production station (12.5 MeV protons on Be or Li target)

  → Boron Neutron Capture Therapy (BNCT) or neutron-diffraction oriented research.

A compact, multi-purpose light-ion linac
(delivering H^+, $^4He^{2+}$ and $^7Li^{3+}$ up to 12.5 MeV/u)
can be realized on the available site at IFJ PAN.;

pre-Conceptual Design Report is on-going

Thank you for attention



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Some possibilities

Purpose	Order	Short	Long	Reactions	Energies [MeV]	References
PET	1	^{64}Cu	Copper-64	^{64}Ni(p,n) ^{64}Cu	9 - 12	[1][2]
				^{64}Ni(p,n) ^{64}Cu	11	[3]
	2	^{18}F	Flourine-18	^{16}O(α, np) ^{18}F	40	[4]
	3	^{68}Ga	Gallium-68	^{68}Zn(p, 2n) ^{68}Ga	12.5	[5][6]
	4	^{124}I	Iodine-124	^{124}Te(p, n) ^{124}I	12.5	[1][7]
	5	^{89}Zr	Zirconium-89	^{89}Y(p, n) ^{89}Zr	12.5	[8]
SPECT	6	^{67}Ga	Gallium-67	^{65}Cu(α, 2n) ^{67}Ga	28	[9]
	7	^{111}In	Indium-111	^{109}Ag(α, 2n) ^{111}In	27, 30	[10][11]
	8	^{203}Pb	Lead-203	^{203}Tl(p, n) ^{203}Pb	12.5	[12]
THERAPEUTICS	9	^{211}At	Astatine-211	^{209}Bi(α, 2n) ^{211}At	28	[1]
	10	^{131}Cs	Cesium-131	^{nat}Xe(α, xn) ^{131}Ba → ^{131}Cs	50	[13]
	11	^{131}I	Iodine-131	^{121}Sb(α, 2n) ^{123}I	26	[14]
	12	^{192}Ir	Iridium-192	^{192}Os(p, n) ^{192}Ir	12.5	[15]
	13	^{212}Pb	Lead-212	^{228}Th → ^{212}Pb	12.5	[16]
	14	^{186}Re	Rhenium-186	^{186}W(p, n) ^{186g}Re	12	[17]
				^{186}W(α, x) ^{186g}Re	43	
	15	^{117m}Sn	Tin-117m	^{116}Cd (α, 3n) ^{117m}Sn	42	[18]

[1] *Cyclotron ProducedRadionuclides: PhysicalCharacteristics andProduction Methods*
[2] *Production and Quality control of Cyclotron produced Copper-64: A Validation study for the use of 64CuCl2 as a radiochemical precursor for radiolabeling of ligands*
[3] *Production of copper-64 using a hospital cyclotron: targetry, purification and quality analysis*
[4] *Production and Quality Control of Fluorine-18 Labelled Radiopharmaceuticals*
[5] *Gallium-68 Cyclotron Production*
[6] *Very high specific activity 66/68Ga from zinc targets for PET*
[7] *Iodine-124: A Promising Positron Emitter for Organic PET Chemistry*
[8] *Evaluation of nuclear reaction cross sections for optimization of production of the important non-standard positron emitting radionuclide 89Zr using proton and deuteron induced reactions on 89Y target*
[9] *Nuclear model analysis and optimization of production data of the medically interesting 66,67,68 Ga via alpha induced reactions on 63,65 Cu targets*
[10] *Interaction between In impurity atoms and impurity atoms of Mn and Co dissolved in silver*
[11] *Determination of Excitation Function for Production of InIsotopes by natAg (α , xn) Reaction*
[12] *Optimized production, purification, and radiolabeling of the 203Pb/212Pb theranostic pair for nuclear medicine*
[13] *Investigation of excitation functions of alpha induced reactions on natXe: Production of the therapeutic radioisotope 131Cs*
[14] *Overview and evaluation of different nuclear level density models for the 123I radionuclide production*
[15] *Low energy cyclotron production and cyclometalation chemistry of iridium-192*
[16] *Production, purification, and radiolabeling of the 203Pb/212Pb theranostic pair*
[17] *Cyclotron production of no carrier added 186gRe radionuclide for theranostic applications*
[18] *Investigations of proton and deuteron induced nuclear reactions on natural and enriched Titanium, Calcium and Vanadium targets, with special reference to the production of 47Sc*

- High-intensity H^+ and $^4He^{2+}$ beams - left table;
- $^2H^+$ source in the future - marked in red (table below);

Purpose	Order	Short	Long	Reactions	Energies [MeV]	References
PET	1	^{64}Cu	Copper-64	^{64}Ni(d, x) ^{64}Cu ^{nat}Zn(d, x) ^{64}Cu ^{64}Zn(d, 2p) ^{64}Cu	19 <20 20	[1]
SPECT	2	^{67}Ga	Gallium-67	^{67}Zn(d, 2n) ^{67}Ga	14	[2]
	3	^{123}I	Iodine-123	^{122}Te(d, n) ^{123}I	14	[3][4]
THERAPEUTICS	4	^{225}Ac	Actinium-225	^{226}Ra(d, 3n) ^{225}Ac	19	[5]
	5	^{67}Cu	Copper-67	^{70}Zn(d, x) ^{67}Cu	25	[6]
	6	^{177}Lu	Lutetium-177	^{176}Yb(d, n) ^{177}Lu	21	[7]
				^{176}Yb(d, x) ^{177}Lu	25	[8]
	7	^{103}Pd	Palladium-103	^{103}Rh(d,2n) ^{103}Pd	13.3	[9]
	8	^{186}Re	Rhenium-186	^{186}W(d, 2n) ^{186g}Re	15	[10]
	9	^{47}Sc	Scandium-47	^{50}Ti(d, αn) ^{47}Sc	25	[11]

[1] *Copper-64 Radiopharmaceuticals: Production, Quality Control and Clinical Applications*
[2] *Production of 67Ga by Deuteron Irradiation of Zinc*
[3] Cyclotron ProducedRadionuclides: PhysicalCharacteristics andProduction Methods
[4] *Excitation functions of deuteron induced nuclear reactions on natural tellurium and enriched 122Te: Production of 123I via the 122Te(d,n)123I-process*
[5] *Method for producing actinium-225*
[6] *Is 70Zn(d,x)67Cu the Best Way to Produce 67Cu for Medical Applications?*
[7] *Optimization of Deuteron Irradiation of 176Yb for Producing 177Lu of High Specific Activity Exceeding 3000 GBq/mg*
[8] *Estimated Isotopic Compositions of Yb in Enriched 176Yb for Producing 177Lu with High Radionuclide Purity by 176Yb(d,x) 177Lu*
[9] *Excitation function and yield for the 103Rh(d,2n)103Pd nuclear reaction: Optimization of the production of palladium-103*
[10] *Cyclotron production of no carrier added 186gRe radionuclide for theranostic applications*
[11] *Investigations of proton and deuteron induced nuclear reactions on natural and enriched Titanium, Calcium and Vanadium targets, with special reference to the production of 47Sc*

Accelerator location

