## Part I-A: radio-isotopes for medical diagnosis

SPECT: Single Photon Emission Computed Tomography

PET: Positron Emission Tomography

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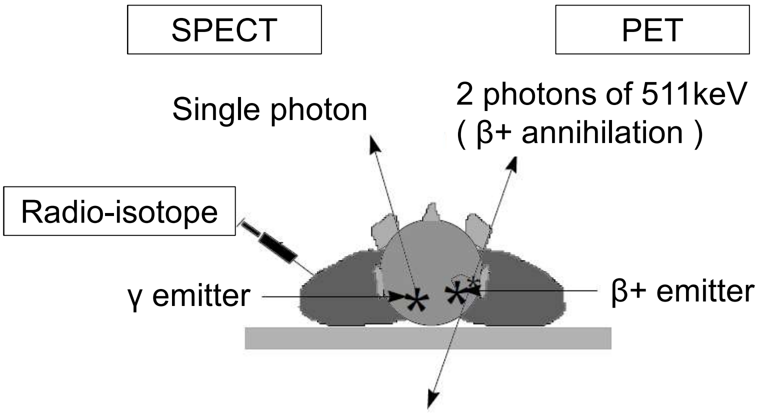
## How is imaging done with radio-tracers ?



SPECT

PET

Single photon

2 photons of 511keV
( β+ annihilation )

Radio-isotope

γ emitter

β+ emitter

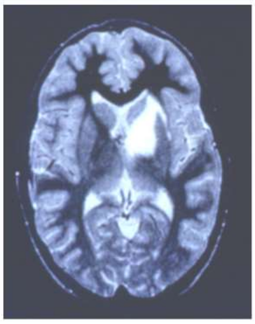
A camera (Gamma or PET) detects the photons emitted from the body and computes 3D distributions of the radio-activity

## The use of Radio Isotopes for medical imaging

- Radio tracers can be used to label a specific bio-chemical molecule.
- They allow to see metabolism
  - X-ray (CT-) scan or MRI are better to see the anatomy (structure)
- Nuclear medicine (imaging of metabolism using molecules labeled with an appropriate radioisotope) is therefore not in competition, but in complement of imaging techniques such as X-ray, X-ray CT-scan or MRI.

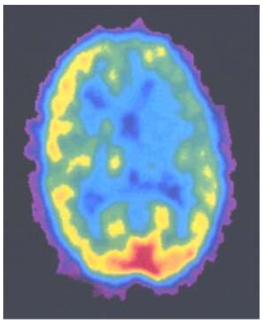
## Metabolic versus anatomic imaging

MRI



Anatomic View
(Tissue-structure)

PET



Metabolic imaging
(Biological-function)

## How is imaging done with radio-tracers ?

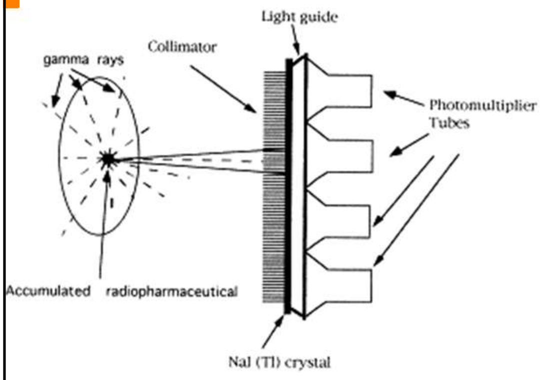
**Single photon isotopes (SPECT)**

- The imaging of single photons emitters requires:
  - a collimator (causes a loss of efficiency !).
  - a position-sensitive detector (with good detection efficiency): the Gamma (or Anger) camera.

- The image obtained is a projection.
- Multiple (perpendicular) projections can be mathematically correlated to produce a 3D representation.
- SPECT (Single Photon Emission Computed Tomography).

## The SPECT gamma camera (Anger camera)

**Anger camera** The collimator prevents photons that are not approximately perpendicular to the collimator holes from interacting with the detector.



The spatial resolution degrades as the distance to the object is increased.

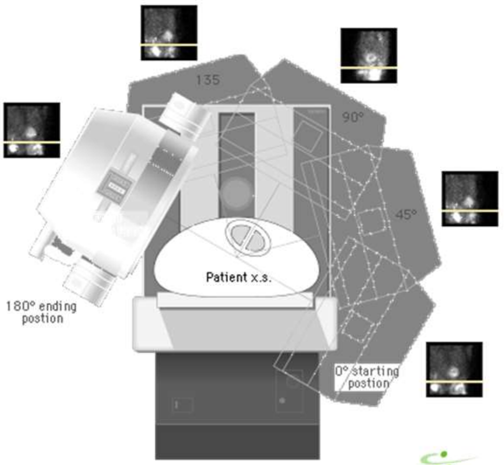
So the detector should be placed as close as possible to the patient.

Collimators are usually made of lead.

Typical dimensions: holes 3mm, walls 1mm, depth 40mm.

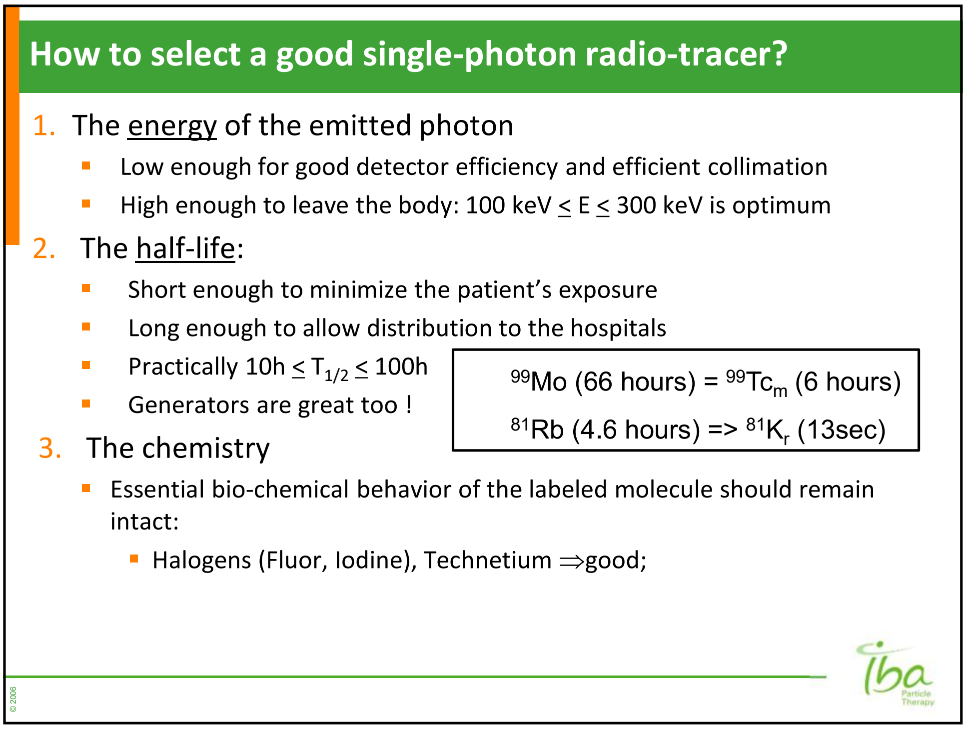
## The SPECT gamma camera

Projections from different angles are taken by rotating the camera around the patient



## “Traditional” nuclear medicine

- Technetium 99m, the most commonly used radio-isotopes in nuclear medicine is produced in reactors.
  - 90% of diagnostic studies in hospitals is done with $^{99m}$Tc !
- But a number of other, very important nuclear medicine radio-isotopes are produced with cyclotrons of higher energy.
  - $^{201}$Tl (Cardiac studies).
  - $^{123}$I (Thyroid, Various examinations).
- For these longer life isotopes, international distribution is possible.
- Large, very powerful cyclotrons are owned by radiopharmaceutical companies.

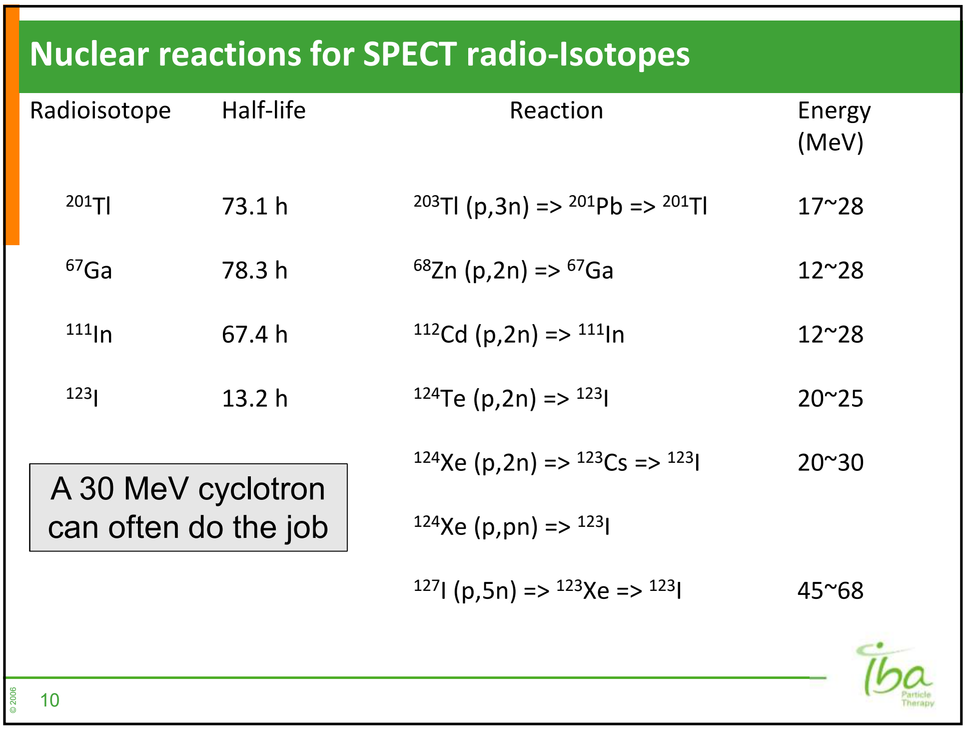


## How to select a good single-photon radio-tracer?

1. The energy of the emitted photon
   - Low enough for good detector efficiency and efficient collimation
   - High enough to leave the body: $100\ \text{keV} \le E \le 300\ \text{keV}$ is optimum
2. The half-life:
   - Short enough to minimize the patient's exposure
   - Long enough to allow distribution to the hospitals
   - Practically $10\text{h} \le T_{1/2} \le 100\text{h}$
   - Generators are great too !
3. The chemistry
   - Essential bio-chemical behavior of the labeled molecule should remain intact:
     - Halogens (Fluor, Iodine), Technetium ⇒good;

$^{99}$Mo (66 hours) = $^{99}$Tc$_m$ (6 hours)

$^{81}$Rb (4.6 hours) => $^{81}$K$_r$ (13sec)



## Nuclear reactions for SPECT radio-Isotopes

| Radioisotope | Half-life | Reaction | Energy (MeV) |
|---|---|---|---|
| $^{201}$Tl | 73.1 h | $^{203}$Tl (p,3n) => $^{201}$Pb => $^{201}$Tl | 17~28 |
| $^{67}$Ga | 78.3 h | $^{68}$Zn (p,2n) => $^{67}$Ga | 12~28 |
| $^{111}$In | 67.4 h | $^{112}$Cd (p,2n) => $^{111}$In | 12~28 |
| $^{123}$I | 13.2 h | $^{124}$Te (p,2n) => $^{123}$I | 20~25 |
| | | $^{124}$Xe (p,2n) => $^{123}$Cs => $^{123}$I | 20~30 |
| | | $^{124}$Xe (p,pn) => $^{123}$I | |
| | | $^{127}$I (p,5n) => $^{123}$Xe => $^{123}$I | 45~68 |

A 30 MeV cyclotron can often do the job

## Positron emitting radio-isotopes (PET)

- ☐ The emitted positron travels a few millimeters, then meets an electron and annihilates, emitting two anti-parallel photons of 511keV.
- ☐ These two photons can be detected in **coincidence** by a ring of detectors surrounding the region of interest.
- ☐ One knows then that the origin of the photons is on the line connecting the two detectors
- ☐ no collimator needed=> better resolution

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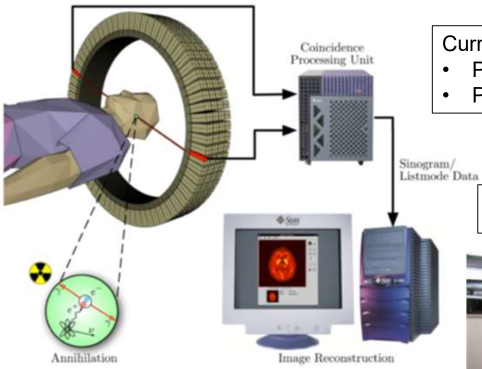
## The PET scanner



Currently available are
- PET scanners integrated with CT: PET-CT
- PET scanners integrated with MRI: PET-MRI

PET scanner in a hospital

- Coincidents events are grouped into projected images (sinograms) and sorted by the angle of view
- 3D image re-construction is similar to that of CT scanners

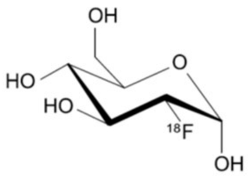
## Common positron emitting radioisotopes for PET

| Radioisotope | Half-life (min) | Positron energy (MeV) | Reaction | Energy (MeV) |
|---|---|---|---|---|
| $^{11}C$ | 20.4 | 1.0 | $^{14}N$ (p,α)=> $^{11}C$ | 5=>16 |
| $^{13}N$ | 9.96 | 1.2 | $^{16}O$ (p,α)=> $^{13}N$ | 8=>16 |
| | | | $^{12}C$ (d,n)=> $^{13}N$ | 3=>8 |
| $^{15}O$ | 2.07 | 1.7 | $^{15}N$ (p,n)=> $^{15}O$ | 5=>14 |
| | | | $^{14}N$ (d,n)=> $^{15}O$ | 3=>8 |
| $^{18}F$ | 109.8 | 0.6 | $^{18}O$ (p,n)=> $^{18}F$ | 5=>14 |

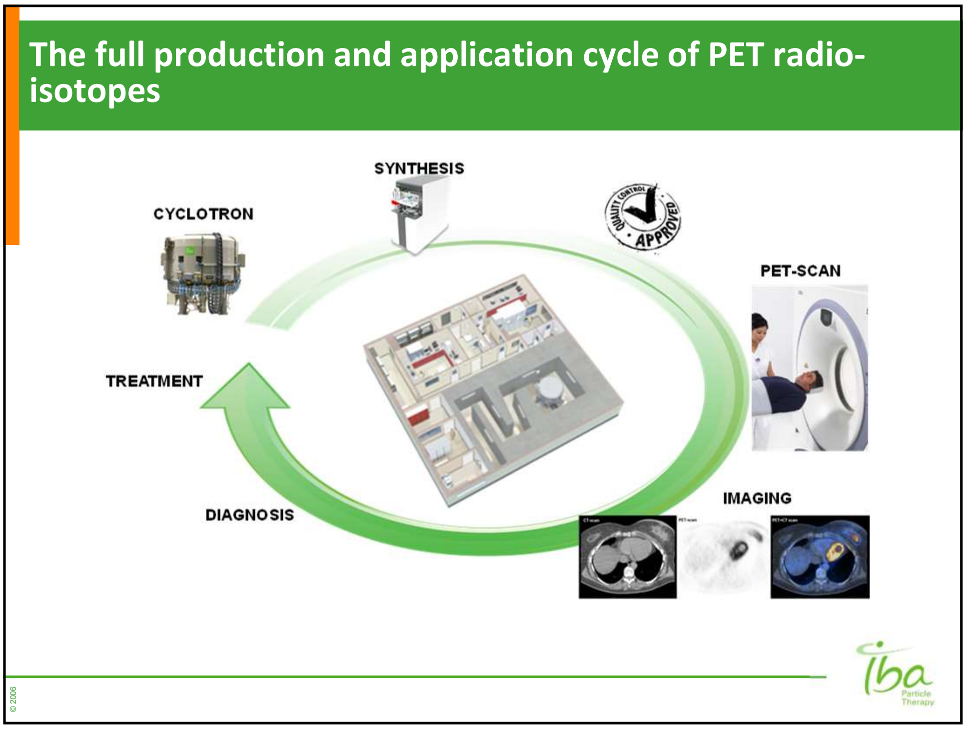
Cyclotrons 10-18 MeV

## FDG = Fluoro-Deoxy-Glucose

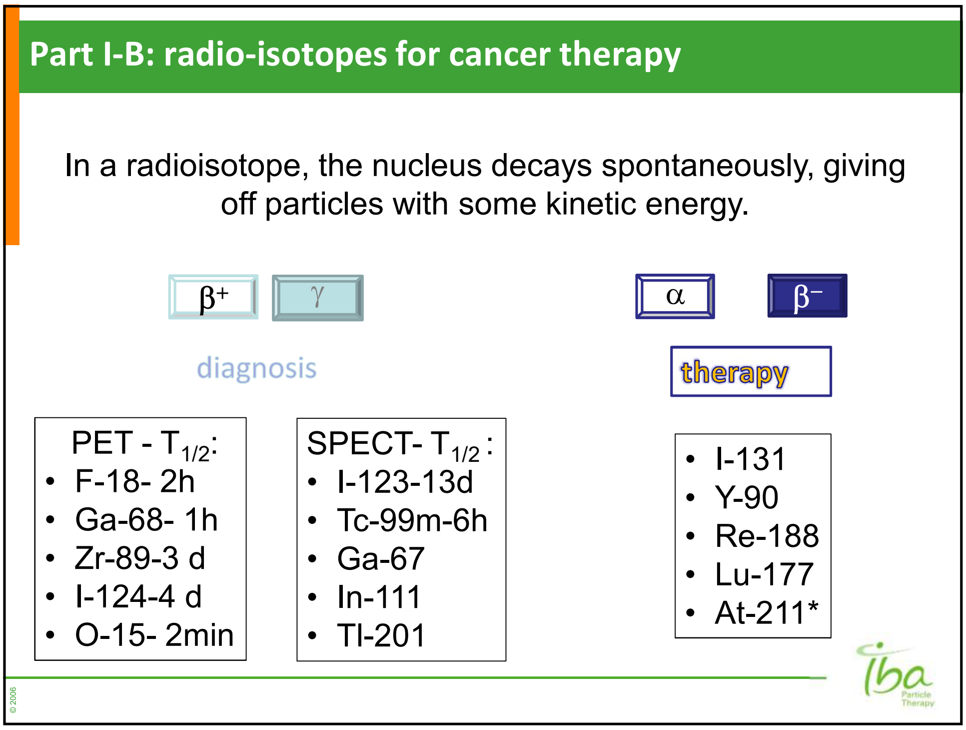
- Most commonly made PET scan (90% of cases) is done with 18F-FDG (Fluoro-Deoxy-Glucose)
- Metabolic activity by virtue of glucose uptake in tissue
- This tracer is mainly used to explore the possibility of cancer metastasis and the response to treatment



- In glucose one OH-group is replaced by a 18-F atom
- Both atoms have about the same size =>
- Bio-chemical behaviour almost not altered



## The full production and application cycle of PET radio-isotopes



## Part I-B: radio-isotopes for cancer therapy

In a radioisotope, the nucleus decays spontaneously, giving off particles with some kinetic energy.

$\beta^+$ $\gamma$

diagnosis

$\alpha$ $\beta^-$

therapy

PET - $T_{1/2}$:
- F-18- 2h
- Ga-68- 1h
- Zr-89-3 d
- I-124-4 d
- O-15- 2min

SPECT- $T_{1/2}$ :
- I-123-13d
- Tc-99m-6h
- Ga-67
- In-111
- Tl-201

- I-131
- Y-90
- Re-188
- Lu-177
- At-211*

## Brachy therapy

- Dose is delivered by placing the radiation source directly inside the area requiring treatment
- Commonly used for cervical (uterus), prostate, breast and skin cancer
- Irradiation affects only a very localized area => healthy tissues are spared
- Much higher doses can be delivered. For comparison:
  - Proton therapy: about 40 Gray
  - Prostate brachytherapy: about 100 to 150 Gray
- Brachytherapy can often be completed in less time
  - Reduce the possibility of recovery of cancer cells between treatment intervals

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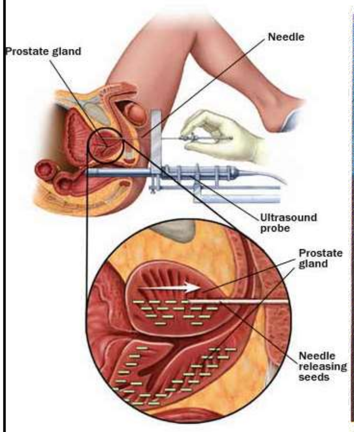
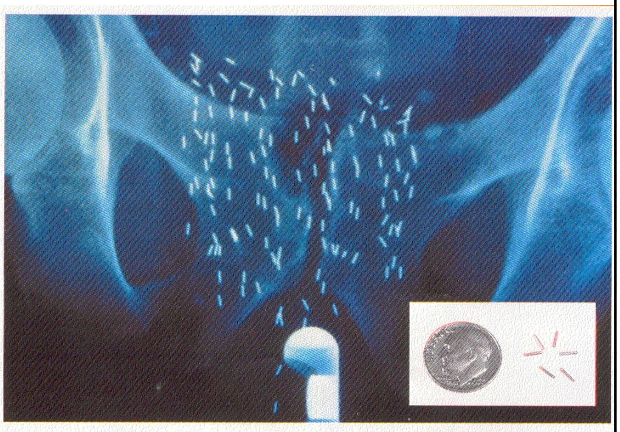
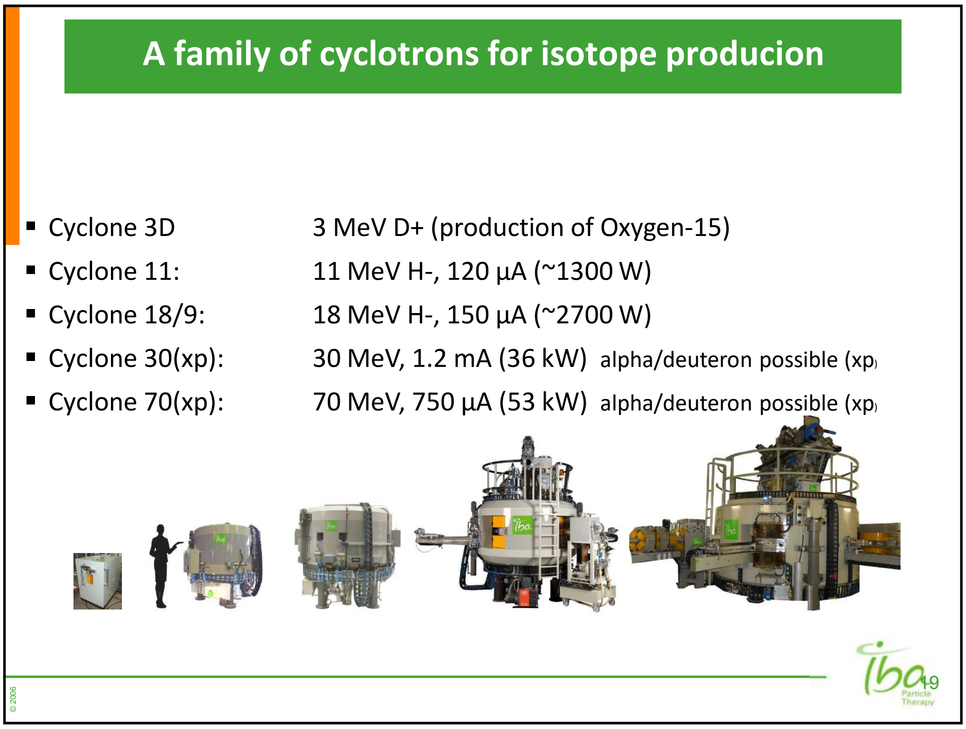
## Prostate brachytherapy with Pd-103 or I-125

Seeds placed with 3D precission verified with ultrasound probe
Seeds are not harmfull and can stay in place after treatment







## A family of cyclotrons for isotope producion

| | | |
|---|---|---|
| Cyclone 3D | 3 MeV D+ (production of Oxygen-15) | |
| Cyclone 11: | 11 MeV H-, 120 µA (~1300 W) | |
| Cyclone 18/9: | 18 MeV H-, 150 µA (~2700 W) | |
| Cyclone 30(xp): | 30 MeV, 1.2 mA (36 kW) | alpha/deuteron possible (xp) |
| Cyclone 70(xp): | 70 MeV, 750 µA (53 kW) | alpha/deuteron possible (xp) |