Medical isotopes research at KEK

KEK

Shin MICHIZONO

- *^{99}Mo and its application*
- *SRF linac (CW/pulse)*
- *Specification of SRF accelerator*
- *SRF components for ^{99}Mo*

Mo-99 and Tc-99m

<u>Stable supply of Mo-99/Tc-99m</u>

^{99}Mo is the raw material of the Tc-99m (widely used for the medical diagnostic).
100% imported and most of them are produced by using the nuclear reactors.
Due to the aging of the fusion reactor, stable supply of ^{99}Mo becomes important.

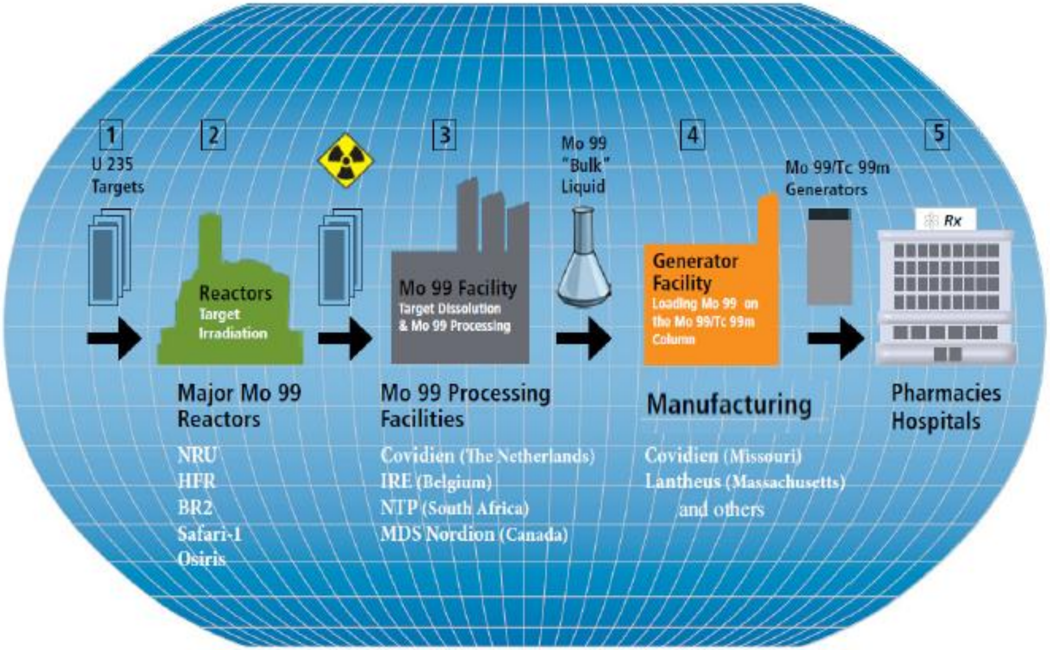
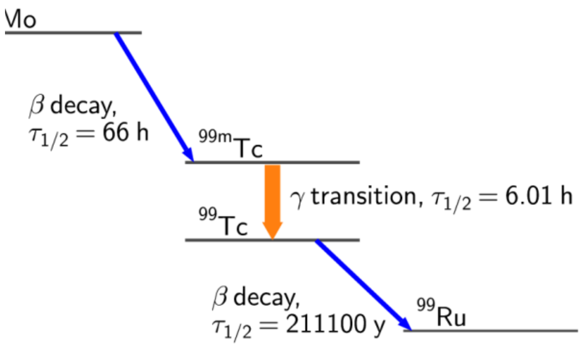


FIG. VII-1: Global supply chain of ^{99}Mo and subsequent utilization schematics. Source: www.covidien.com (October 2009)

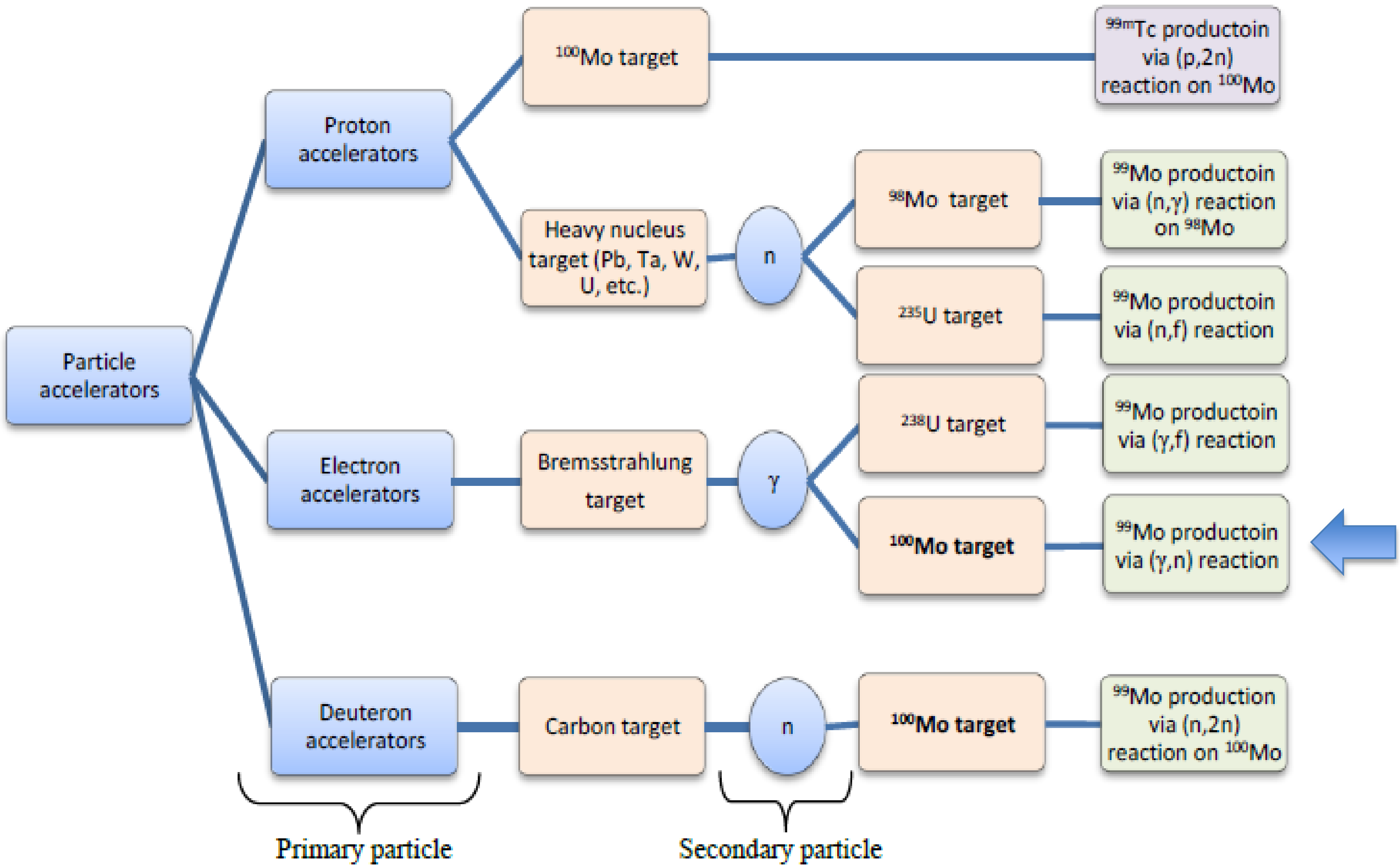


「Producing Medical Isotopes Using X-rays」 by M. S. de Jong @ IPAC2012

<u>Nuclear reactors</u>

- ^{235}U(n,f)^{99}Mo
- ^{98}Mo(n,γ)^{99}Mo

Accelerator driven ^{99}Mo production

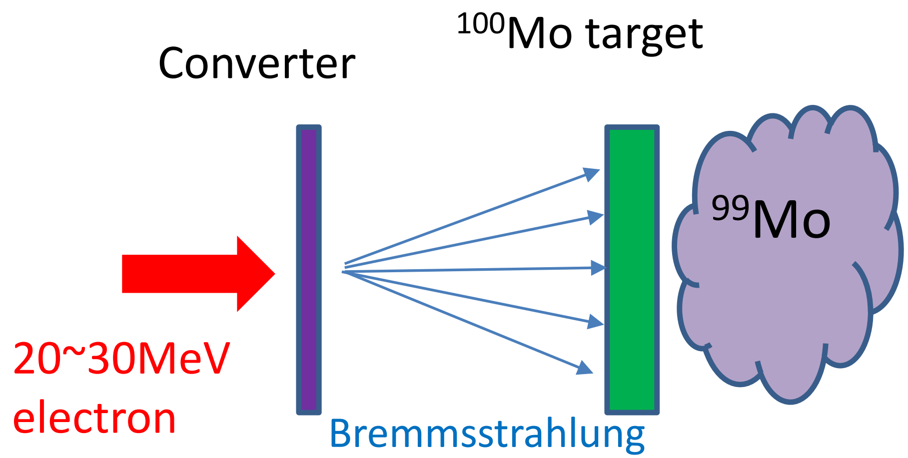


The Supply of Medical Radioisotopes - Nuclear Energy Agency

NUCLEAR ENERGY AGENCY ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT,2010

^{99}Mo generation by electron accelerator

- Utilize the gamma ray generated by the electron beam irradiation to the converter.
- Typical energy of the gamma ray contributing to the reaction ^{100}Mo(γ,n)^{99}Mo is 10～20MeV
- Electron with the energy of 20～30MeV is required for this reaction.
- Beam quality (emittance) is not important as long as the electron is irradiated to the converter.



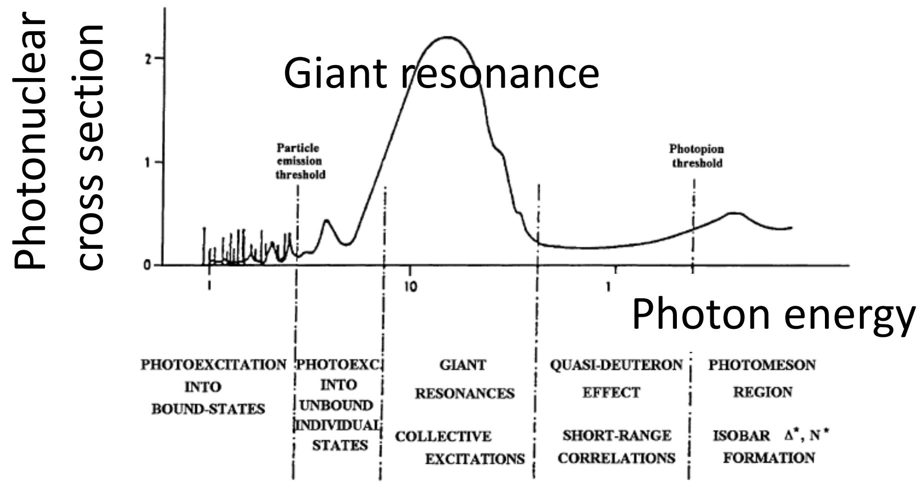
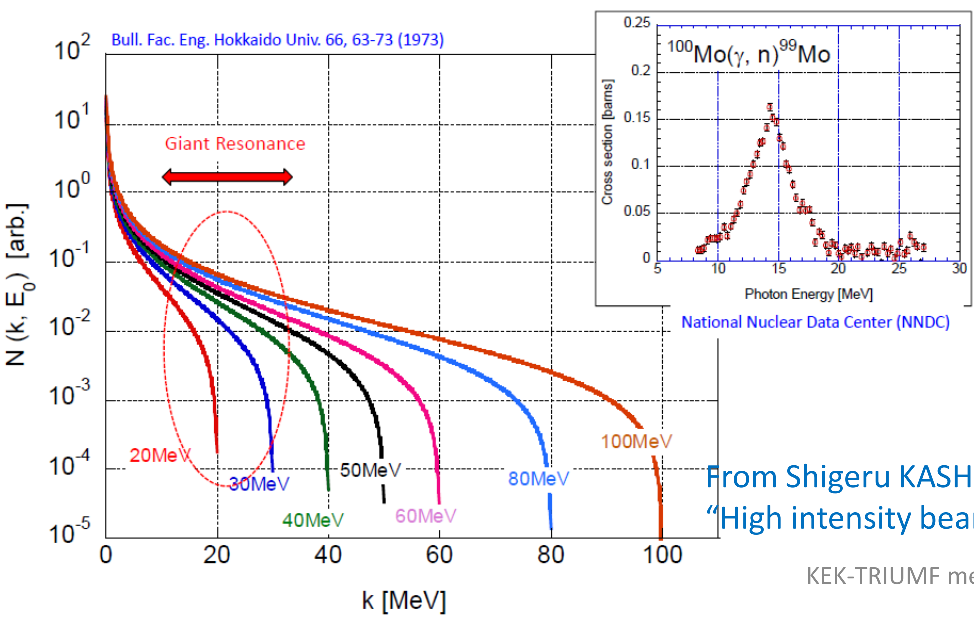


Fig. 1. Total photonuclear cross section as a function of the photon energy k [17].

Nucl Instr Meth B 155 (1999) 373



From Shigeru KASHIWAGI (U. Tohoku)
"High intensity beam and its application" (in Japanese)

Superconducting or normal conducting?

Normal conducting electron linac

- Easier construction and operation
- Pulsed operation (typical duty factor ~1%)
- Smaller average beam current (max. ~1mA)

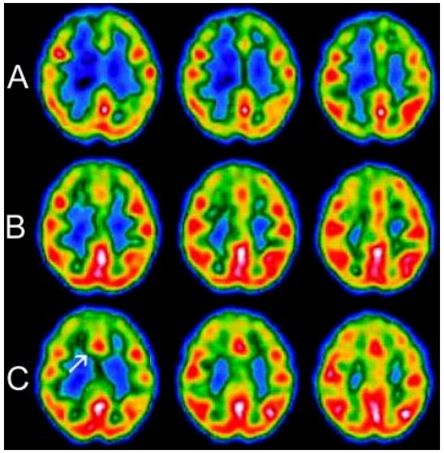
Superconducting electron linac

- Requires cryogenic system
- CW operation
- Higher beam current 10mA~100mA

If the higher current is preferred, superconducting electron linac will be better.

Demand of ^{99}Mo in Japan

- SPECT (Single photon emission computed tomography) are used at 1260 hospitals in Japan.



- This Nuclear medical inspection uses ^{99}Tc (for gamma ray imaging).
- One million inspections per year in Japan (~4,000/day)
- Suppose 10m Ci (370 MBq) ^{99}TC is used for each inspection, 1.5TBq/day should be supplied.
- Including the radioactive decay of 99Mo, 3~10TBq/day will be necessary.
- 3000Bq/mg/uA/h was reported by Prof. Kikunaga (U.Tohoku).

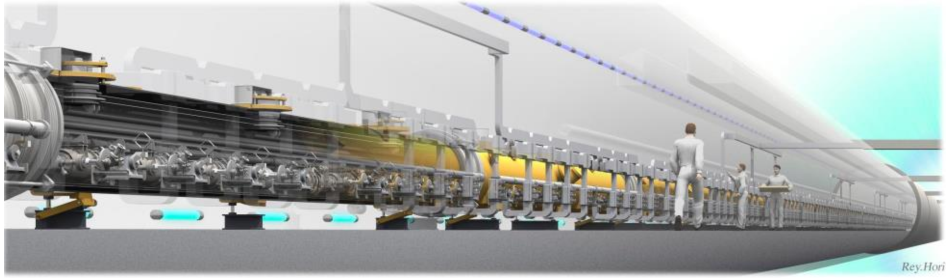
-> 10 mA electron beam linac might satisfy the most of demand of Japan.

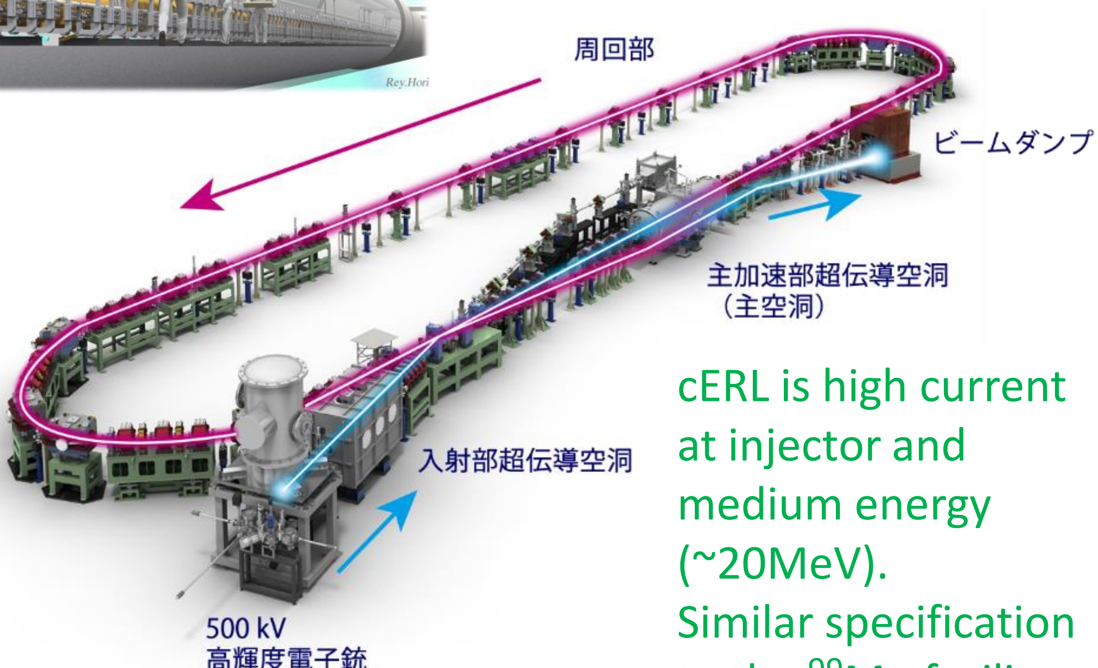
SRF linac with pulse/CW operation

XFEL

Pulse operation
EXFEL,ILC
High gradient (25~30 MV/m)
High bunch current (~3 nC)
Long pulse (~1ms)
low repetition (~5Hz)

ILC





CW operation
ERL, CW-FEL
Medium gradient (~10MV/m)
Medium bunch charge
High current (~10mA)

cERL is high current at injector and medium energy (~20MeV). Similar specification to the ^{99}Mo facility.

Requirements of the accelerator for ^{99}Mo production

～10mA(CW) electron beam
20～30MV acceleration

Essential accelerator components

- ☐ High current DC electron gun
- ☐ High power RF input coupler (for high beam loading)
- ☐ Superconducing cavity operated at 10～15MV/m

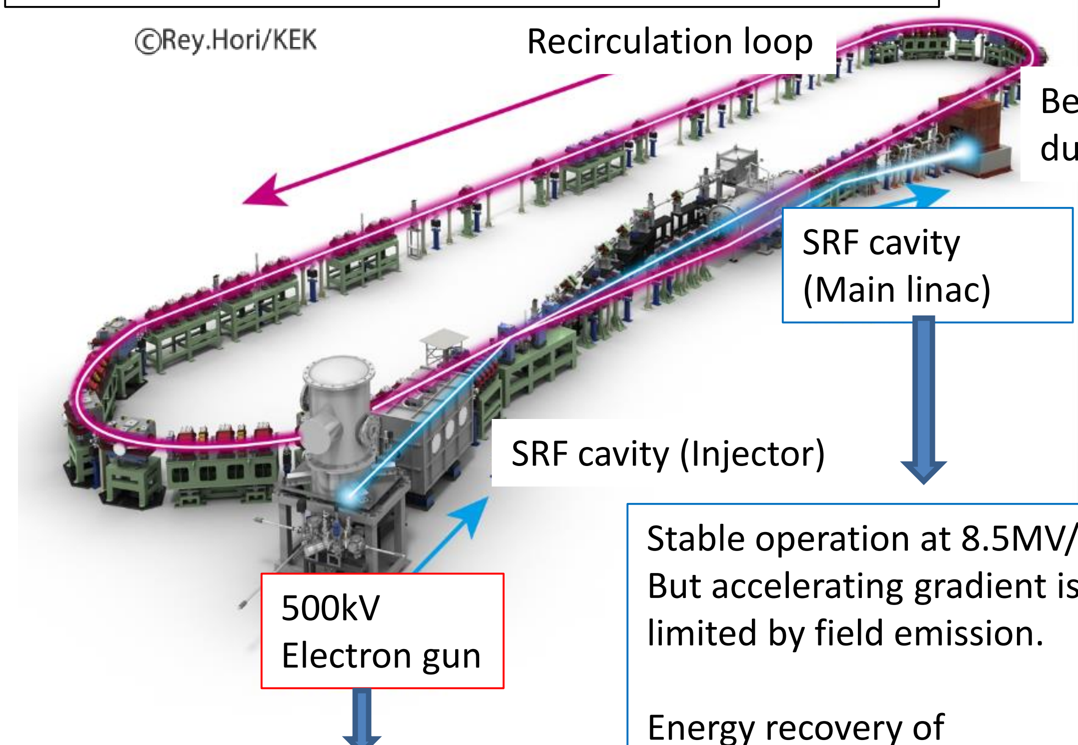
Key points for the accelerator

- Beam loading (beam current x accelerating voltage)
  - Max. rf power for CW input coupler is ~ a few 10 kW
  - Number of cavities, cavity gradients are limited by the input coupler.
- Cyrogenics
  - High Q cavity leads to low cryogenic load
  - Higher gradient operation results in the higher cryogenic load (load is proportional to (voltage)^2)

Compact ERL

Demonstration machine of energy recovery linac

Start beam operation from 2014/Jan. Energy recovery successful. 20MeV, ~1mA at present

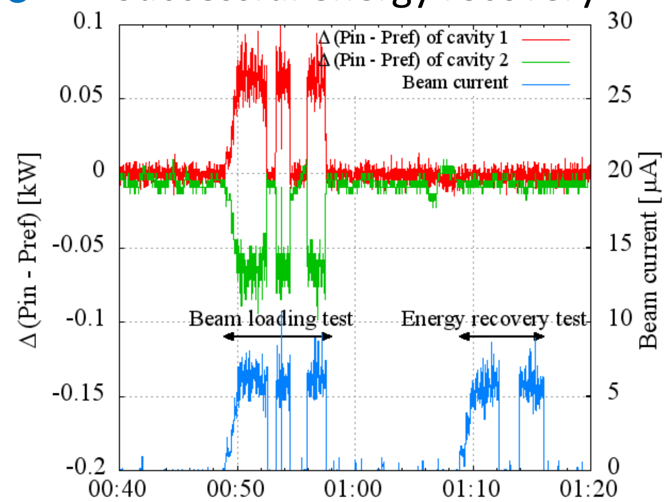


Stable operation at 8.5MV/m. But accelerating gradient is limited by field emission.

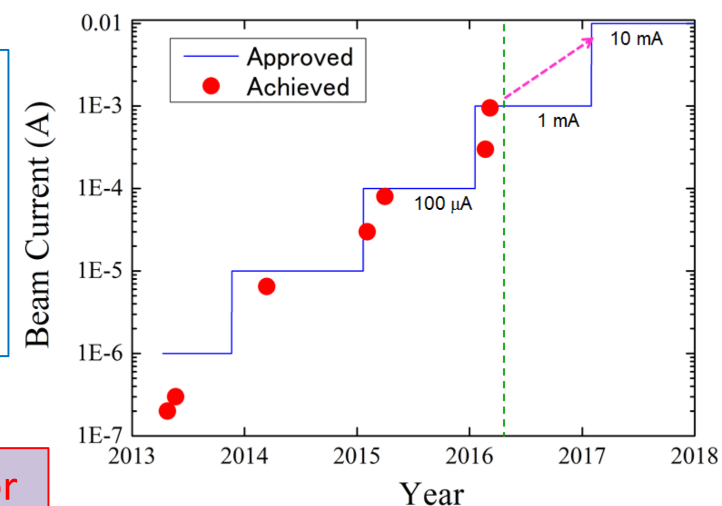
Energy recovery of E_beam(MeV)xI_beam(mA)

Very stable operation at 390kV. At present 1mA operation.

Successful energy recovery



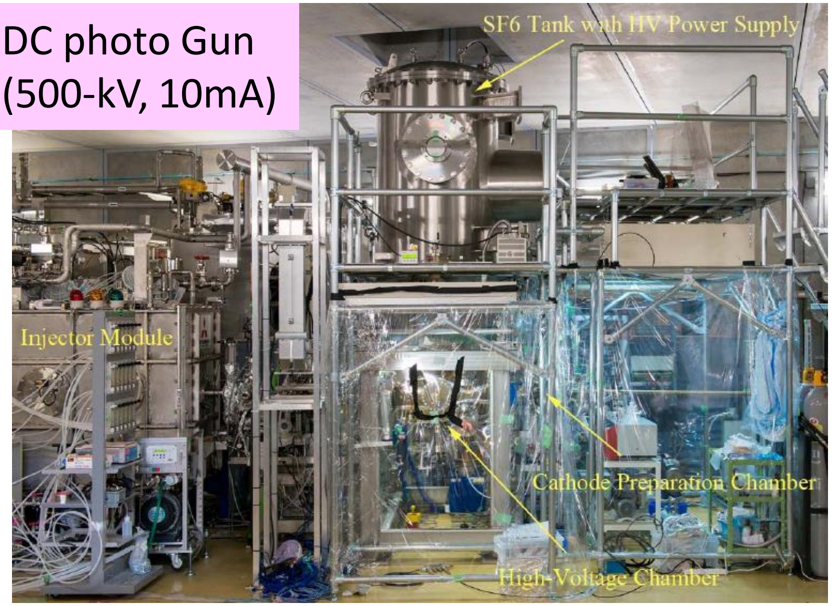
Upgrade of beam current (S. Sakanaka)



Stably operated at 1mA. Can be operated at 10mA at the injector

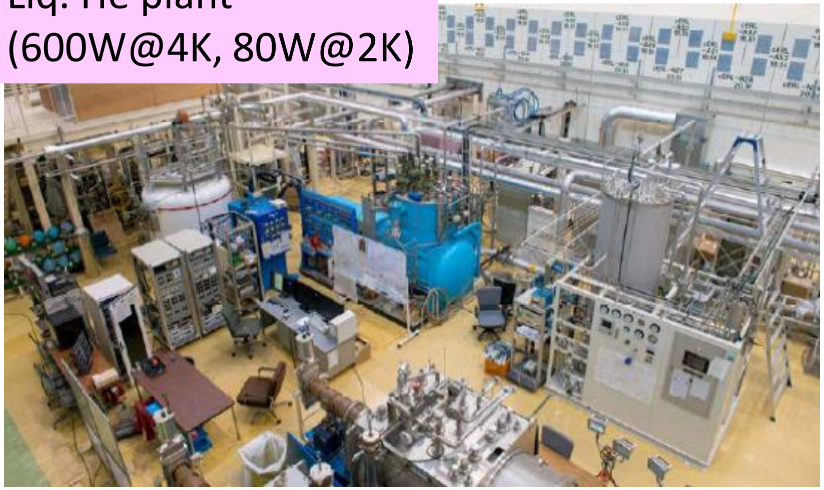
Major Components for the cERL

DC photo Gun
(500-kV, 10mA)

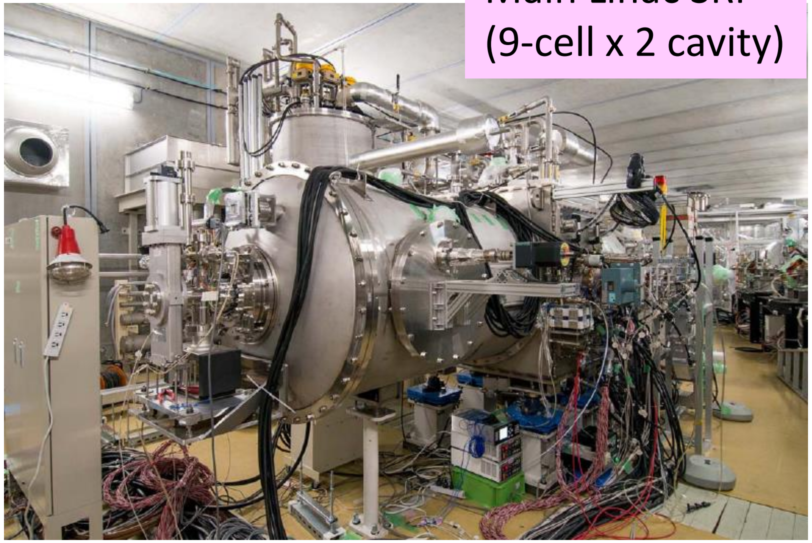


Injector SRF
(2-cell x 3 cavity)

Liq. He plant
(600W@4K, 80W@2K)



Main Linac SRF
(9-cell x 2 cavity)

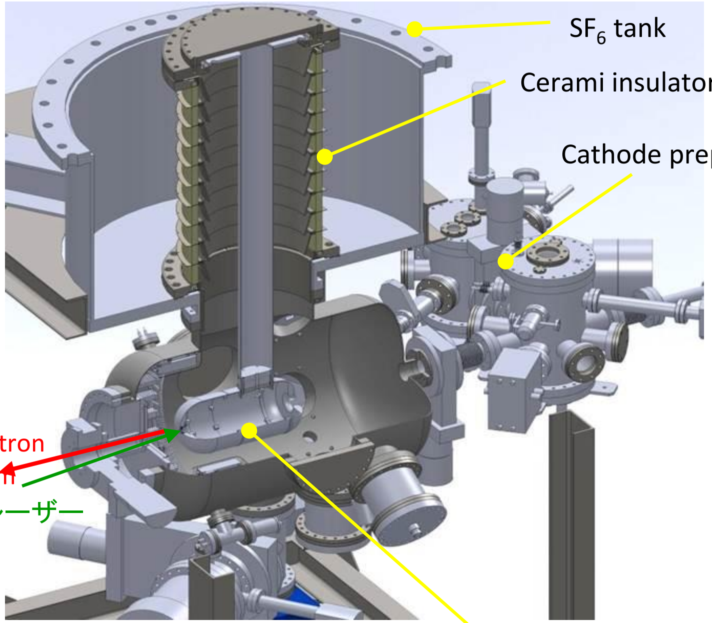


RF components developed at cERL

DC photo cathode electron gun

CW electron beam generator

- Low emittance (< 1 mm·mrad)
- High current（ ≥ 10 mA）



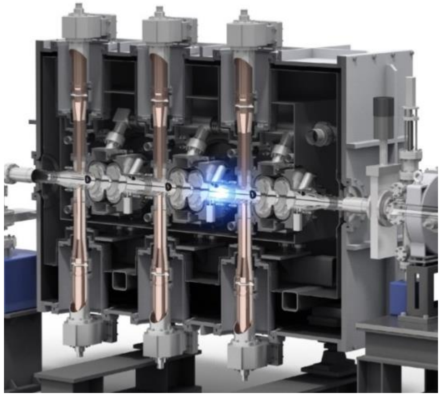
Input coupler & Superconducting cavity

Input coupler

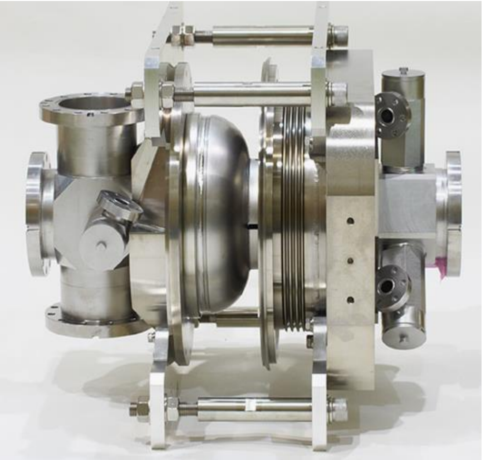
rf input coupler

~10kW each

Two cuplers/cavity



Injector cryomodule
(three 2-cell cavities)



Injector cavity

2-cell cavity

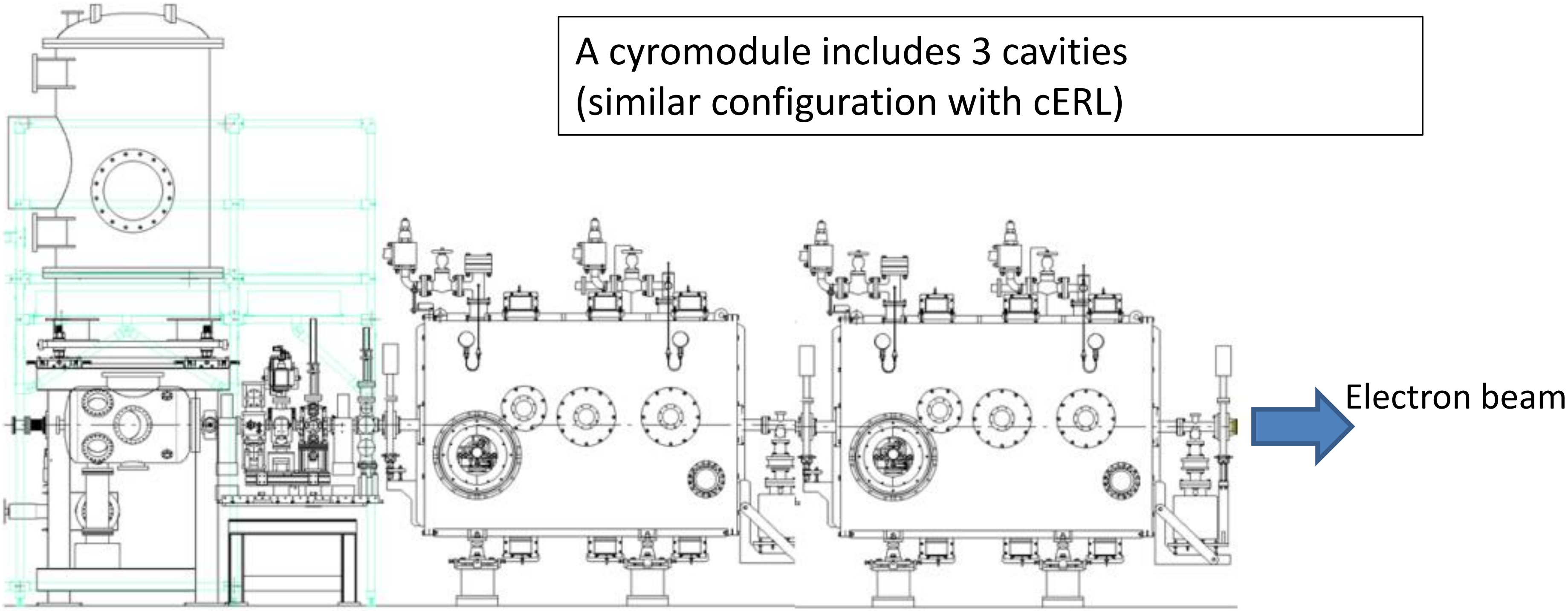
$E_{acc} \leq$ 7 MV/m

(operational gradient)

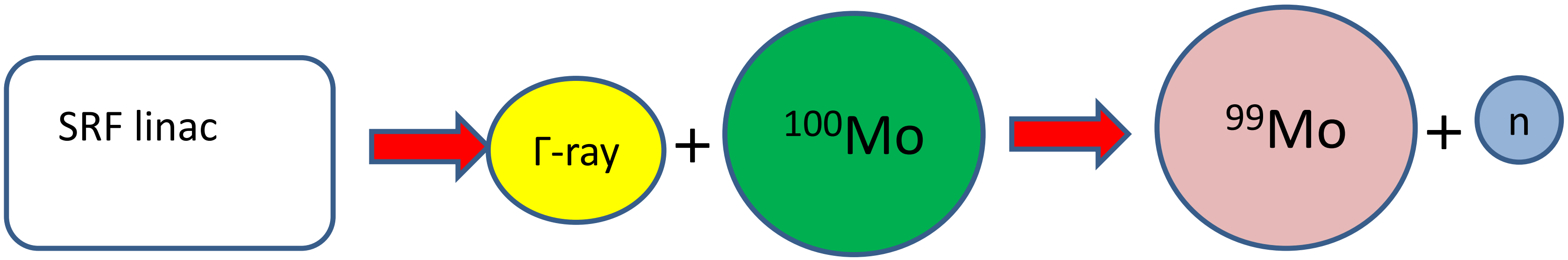
Possible layout of SRF linac for ^{99}Mo generation

Beam current	Beam loading	Coupler/cavity	Number of cavities and their gradients
1mA	30kW	1	9cell cavity × 2～3 (10～15MV/cavity = 10～15MV/m)
10mA	300kW	2	2 or 3 cell cavity × 5～10 (3～6MV/cavity = 9～18MV/m)

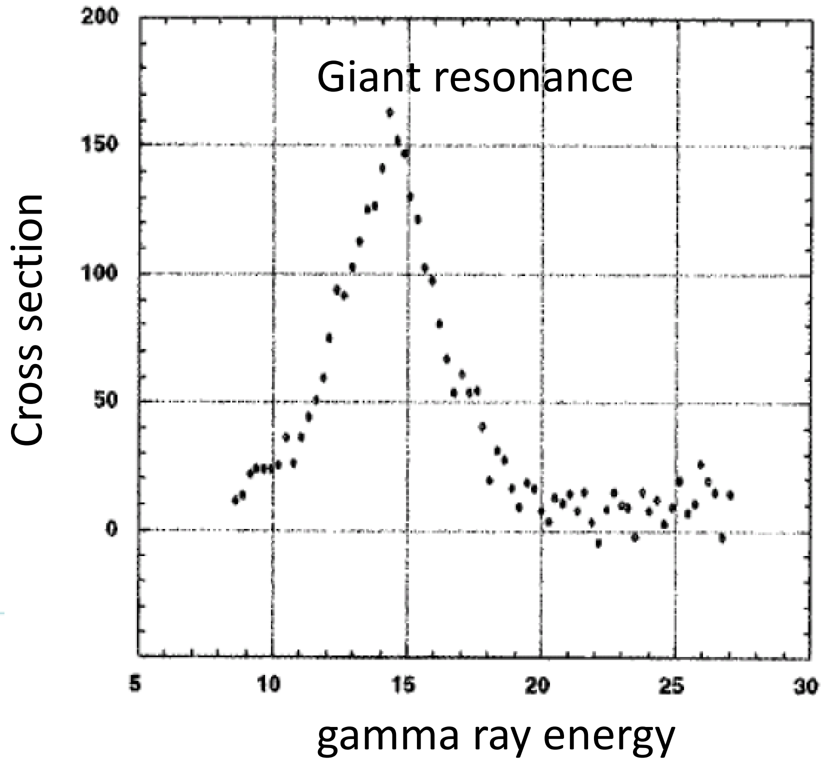
A cyromodule includes 3 cavities
(similar configuration with cERL)

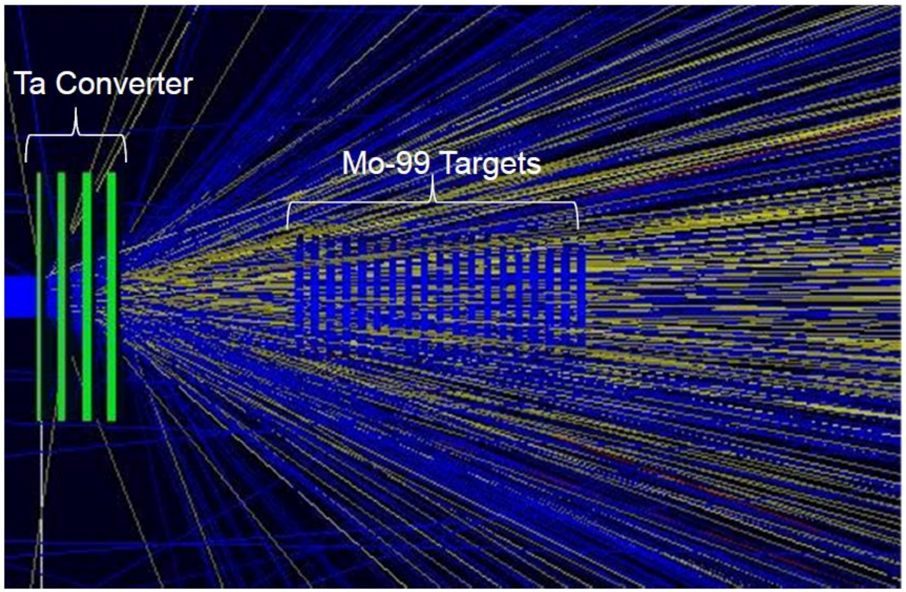


Next step: heavy metal converter



^{99}Mo reaction process





γ ray is generated at heavy metal converter

Summary

- Mo-99/Tc-99m is widely used for the medical inspection.
- These are 100% imported and most of them are produced by using the nuclear reactors now.
- For the stable supply, we propose the production of Mo-99 by SRF accelerator.
- The 10mA ~30MeV electron beam might supply the large amount of Mo-99 in Japan.
- The SRF technology (developed for EXFEL, ILC, cERL,...) looks matured to satisfy these requirements.
- R&D for conversion target and sample preparation (Mo-100/Mo-99) will be necessary.

Thank you for your attention