加速器ベース·ホウ素中性子捕捉療法
Accelerator-based Boron Neutron Capture Therapy
第12回日本加速器学会年会(2015年8月7日)

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Many thanks to collaborators and industries;

- **Special thanks to J-PARC group and Ibaraki Prefecture!!!**
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- **University of Tsukuba:** Akira Matsumura, Hiroaki Kumada, Susumu Tanaka, Kohji Niita
- **JAEA:** Takemi Nakamura, Kazuo Hasegawa, Yasuo Kondo
- **Cosylab:** Takashi Nakamoto, Tilen Zagar
- **Nihon Advanced Technology:** Toshiyuki Ohba, Nobuaki Nagura
- **ATOX:** Toshikazu Ohuchi, Hisashi Sakurayama
- **Mitsubishi Heavy Industries:** Tomei Sugano, Tomohiro Tsuiki
- **Many other industries:** Taiyo Valve, Toshiba EDT, Nichicon, DAWONSYS (Korea), Nihon Koshuha, TOYAMA, NEC/TOKIN, Kanto Giken, オオツカ and many others,,,,,,,,

①BNCTとは

②3つのアプローチ(京大、いばらき、がんセンター)

③中性子スペクトラム、必要な中性子と有害成分

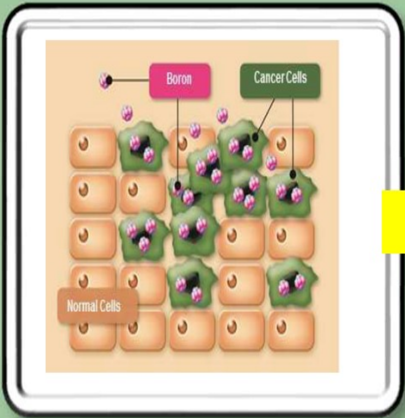
④コミッショニング計画

⑤OIST(沖縄科学技術大学院大学)計画

⑥サマリー

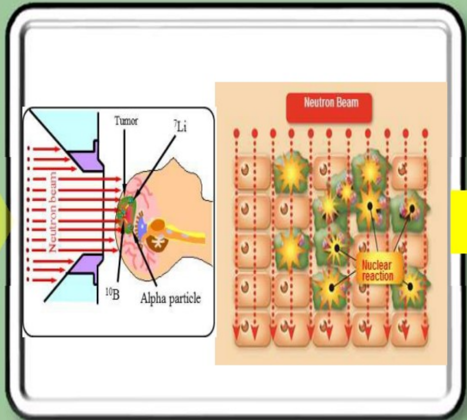
Principle of Boron Neutron Capture Therapy (BNCT)

Administer boron-containing drug



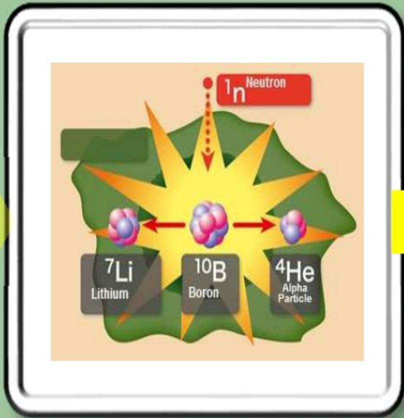
A boron-containing drug that selectively accumulates in cancer cells is used.

Neutron irradiation



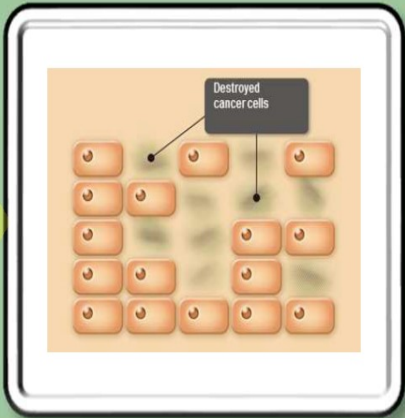
The affected site is irradiated with an energy-adjusted neutron beam.

Neutron react with boron:



Emitted alpha particles and lithium particles destroy cancer cells

Cancer cells are destroyed:



These particles only travel a distance of one cell width (about 10μm), allowing for cell-level treatment.

- **Pinpoint treatment at cell level**

  Alpha beam and lithium particles, with energy three times higher than regular X-ray radiation, selectively destroy the DNA helixes of cancer cells.

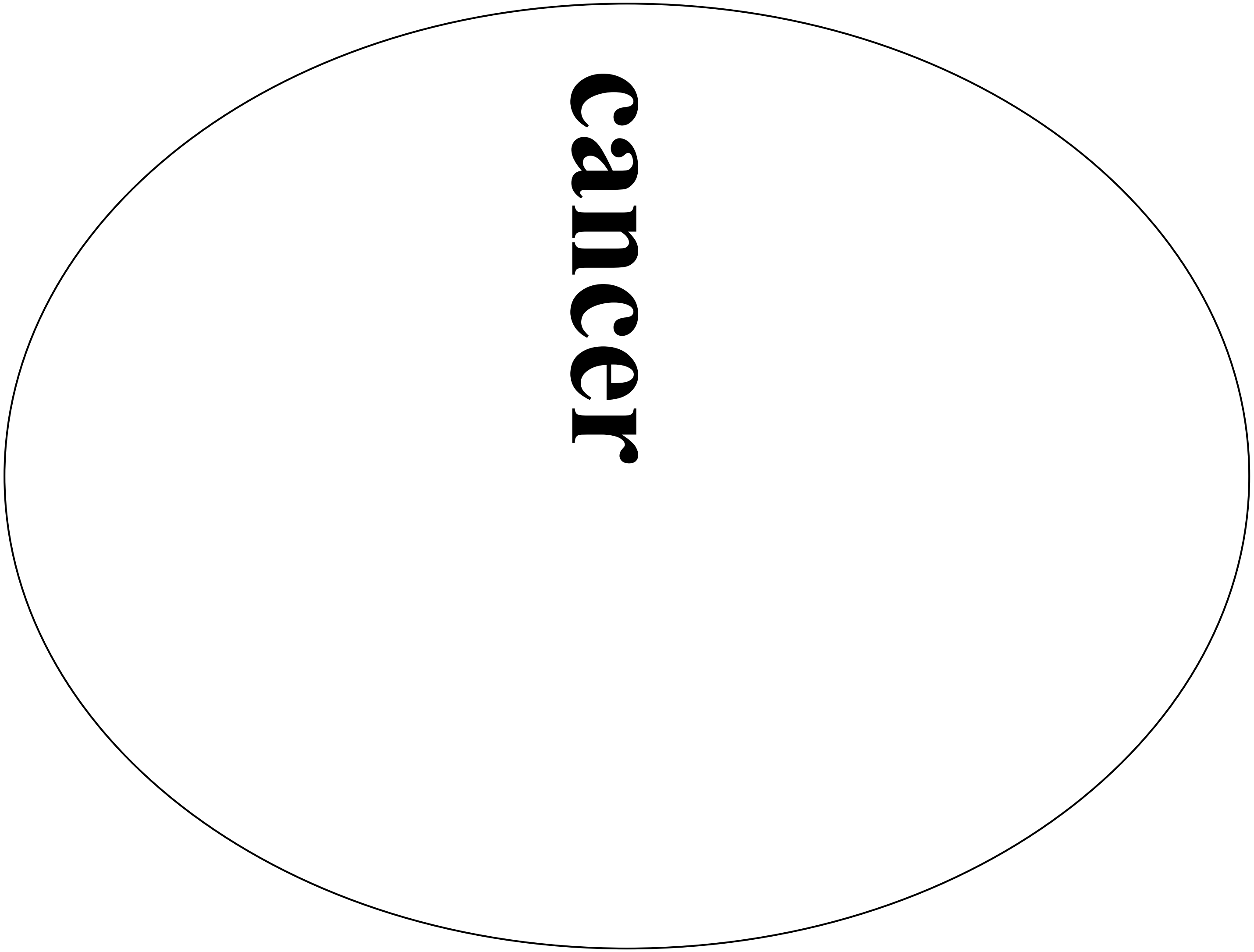
- **New treatment of refractory cancer**

  Including invasive cancer, multiple cancer, recurrent cancer, radiation-resistant cancer, cancer patient not indicated for surgery of radiation therapy, etc

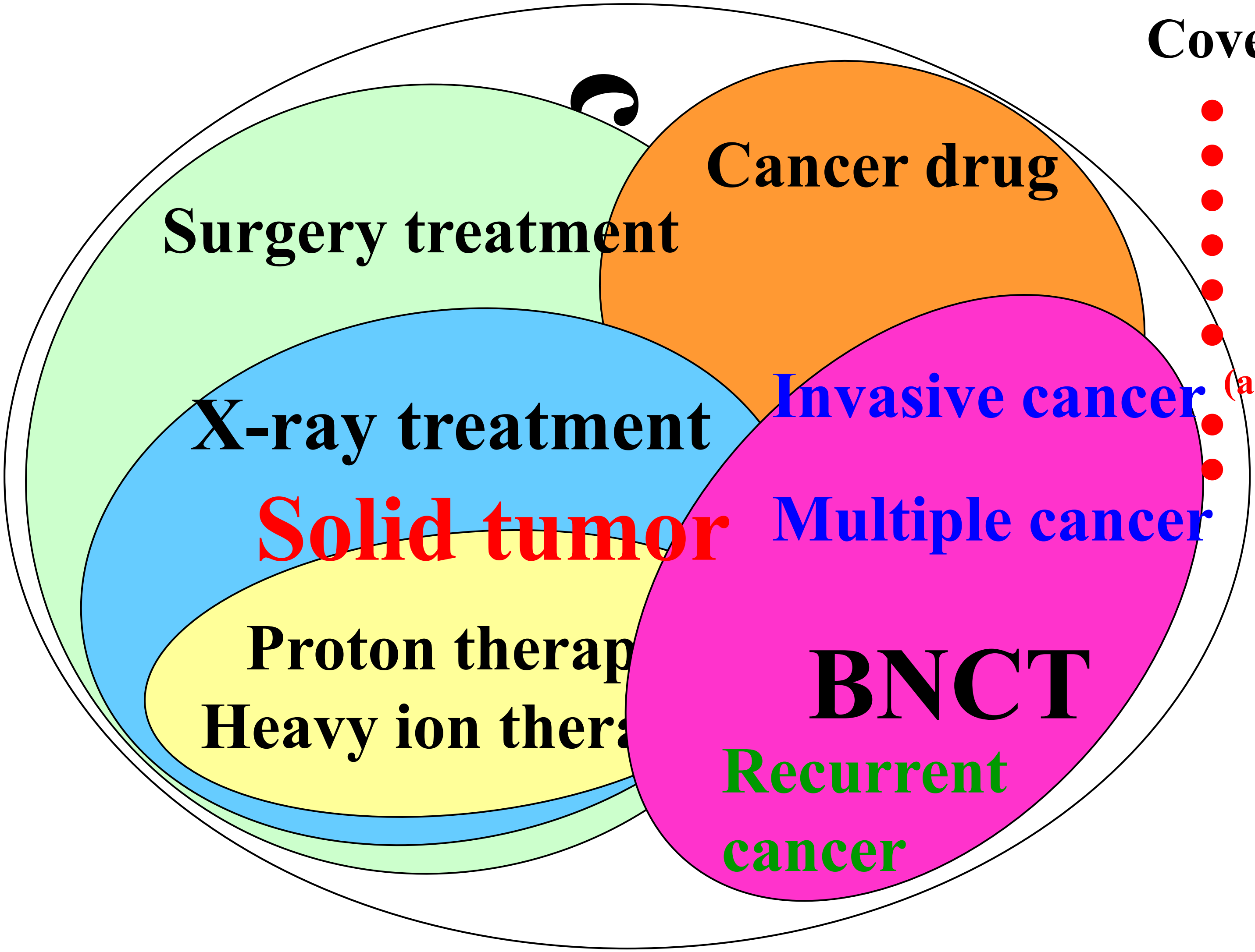
- **Causes minimal stress and provides high quality of life**

  Treatment is completed in only one session of 30-minute irradiation without incision. Indication for medication can be determined with PET in advance.

Position of BNCT in cancer therapy



Position of BNCT in cancer therapy



Coverage of BNCT

- Brain malignancy
- Head neck cancer
- Malignant melanoma
- Lung cancer
- Multiple liver cancer
- Mesothelial cancer (asbestos exposure victim)
- Recurrent breast cancer
- Various recurrent cancer

Neutron Source: Replace the Research Reactor with Accelerator
➔ Accelerate Drug development

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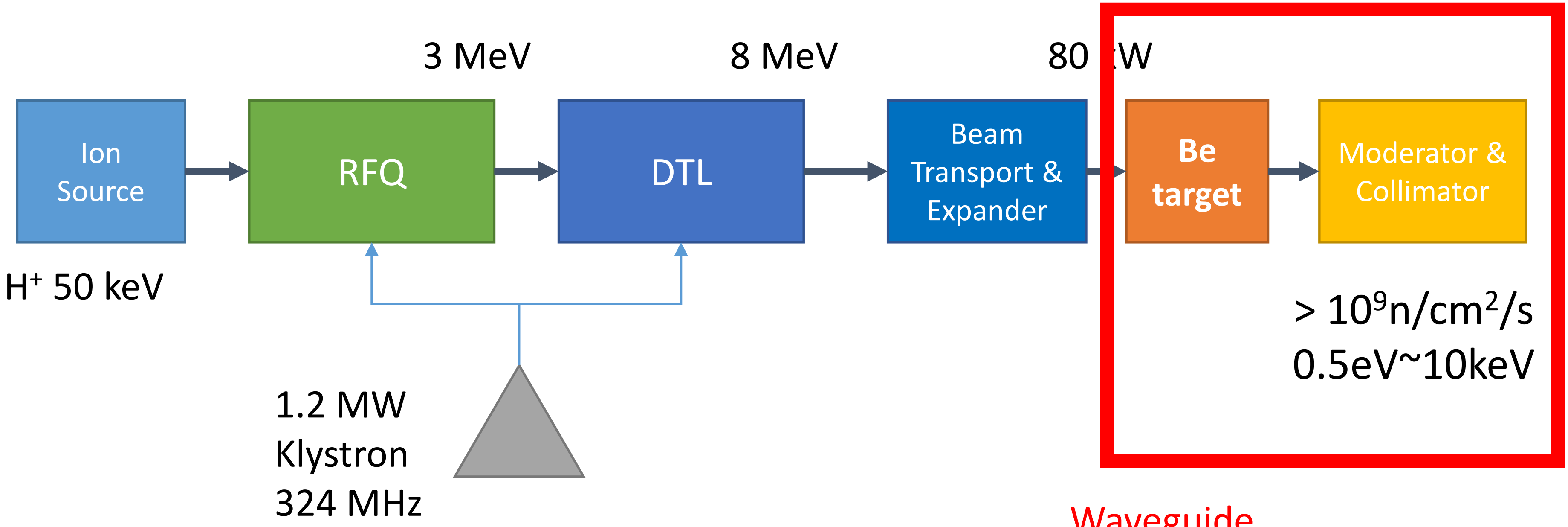
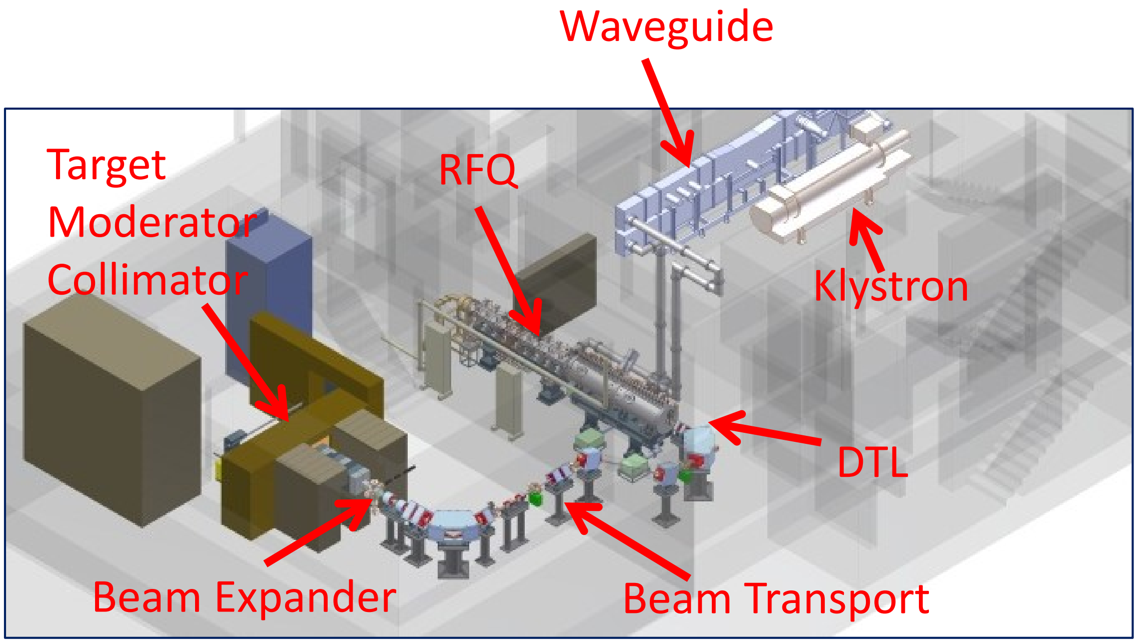
Basic configuration of proton linac for i-BNCT



Peak current	Max. 50 mA
Pulse width	Max. 1 ms
Pulse repetition	Max. 200 pps
Duty	20%
Beam power	80 kW



日本では3つのグループ

- ◆ いばらき　8MeV Linac、ベリリウム標的)
  - ➢ コミッショニング中
- ◆ 京都大学(30MeVサイクロトロン、同上)
  - ➢ 患者に対して治験実施中
- ◆ がんセンター(2.5MeV Linac、リチウム標的)
  - ➢ コミッショニング中??

がんセンターホームページ

京大、田中浩基氏プレゼン

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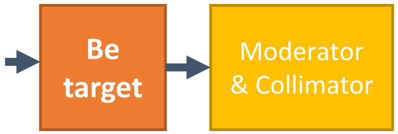
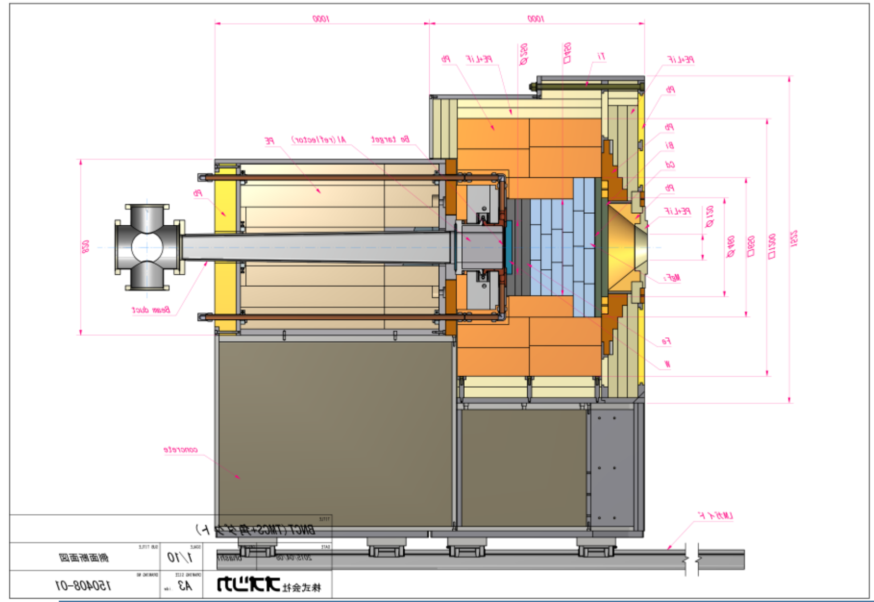
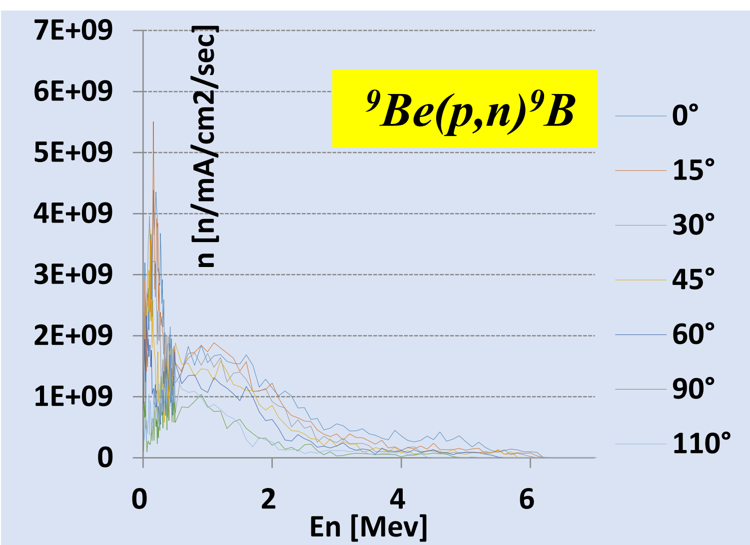


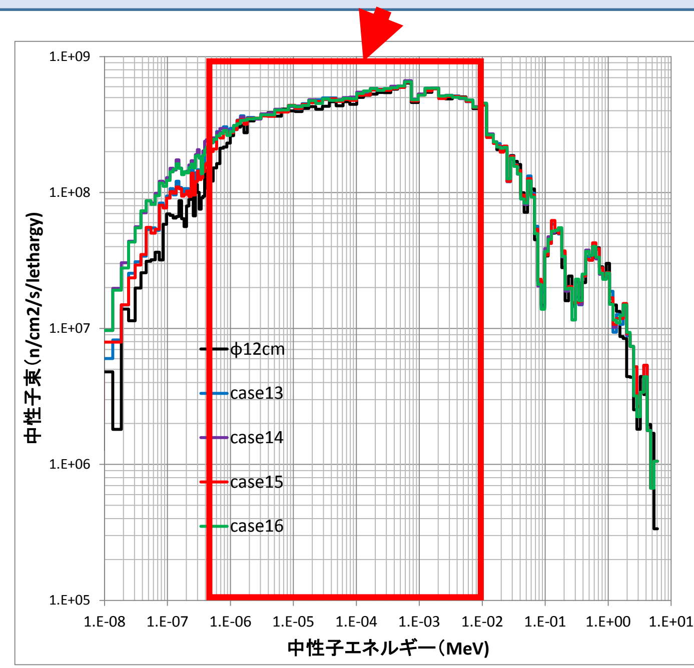
Design using MCNPX



Neutron energy spectrum at the Be target for various production angles
Primary proton energy is 8 MeV

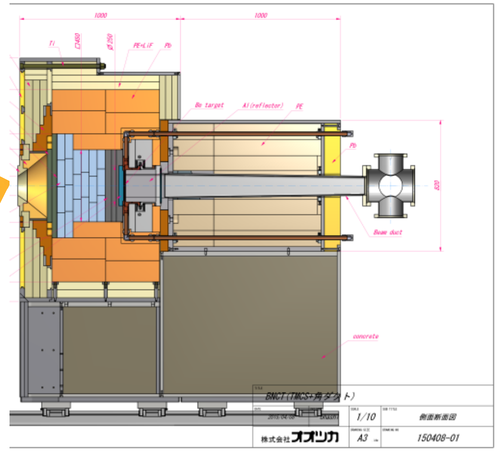


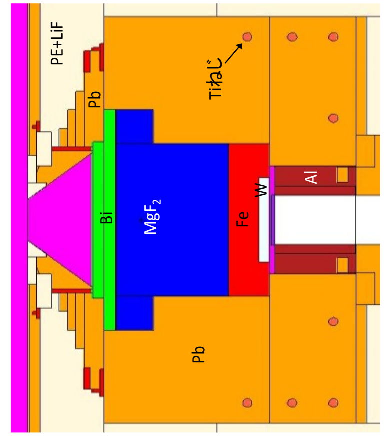
Neutron energy spectrum at the patient position: 0.5 eV ~ 10 keV

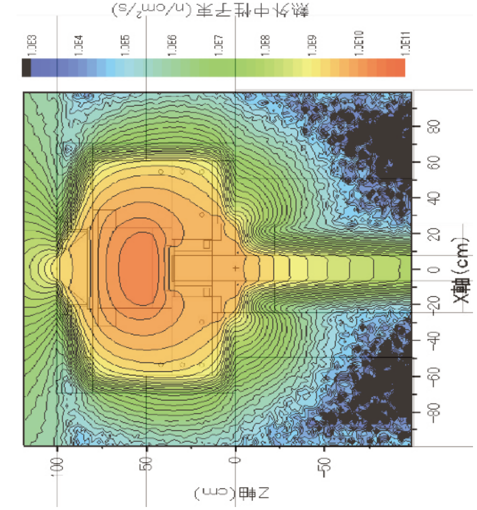


中性子フラックス　と　有害成分

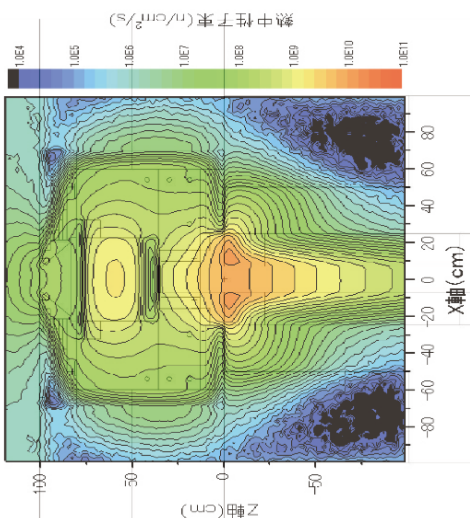
0.5eV~10keV Neutron flux
> $4.3 \cdot 10^9$ n/cm²/s



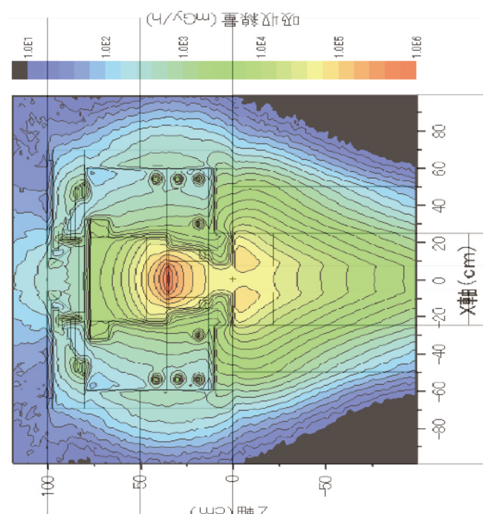




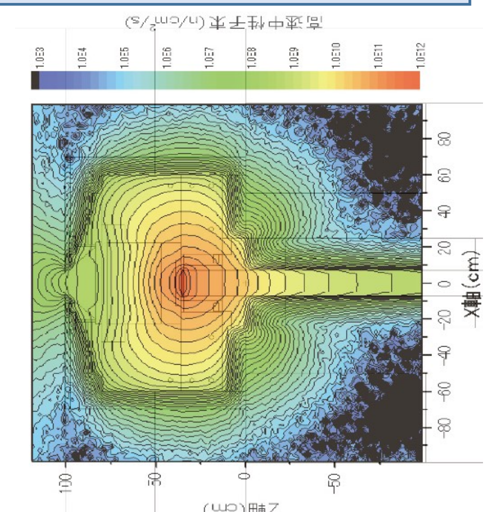
Neutron < 0.5 eV
1.8×10^8



γ-ray
0.74Gy/h

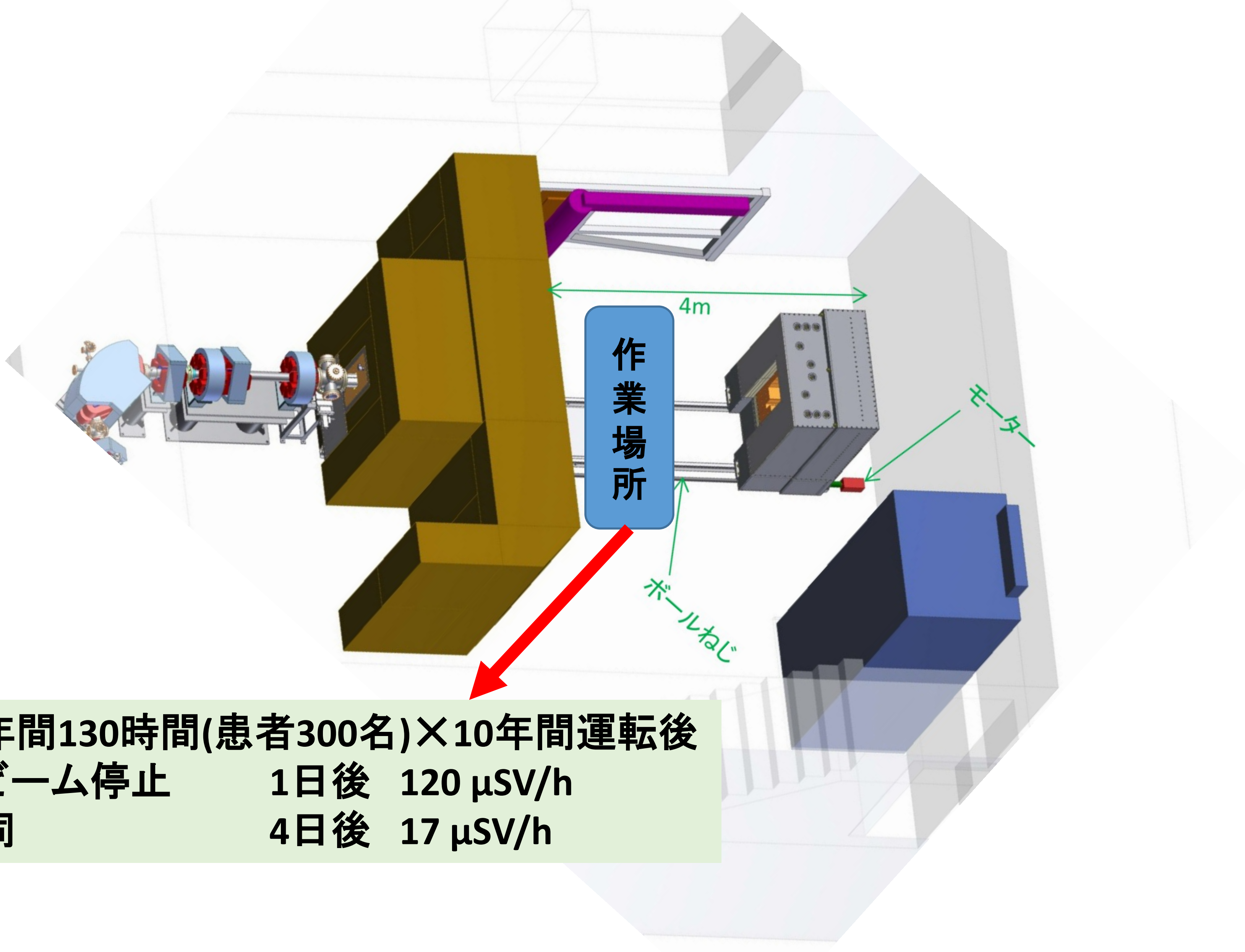


Neutron > 10 keV
4.7×10^8



As low as possible

年に1回程度のターゲット交換作業時の残留放射能による空間線量率
PHITS + DCAIN-SP　接続計算による評価



年間130時間(患者300名)×10年間運転後
ビーム停止　1日後　120 μSV/h
同　4日後　17 μSV/h

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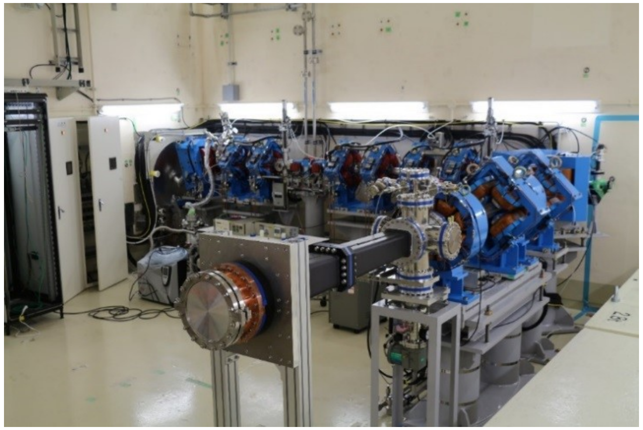
Installation of RF system and beam transport by 2014

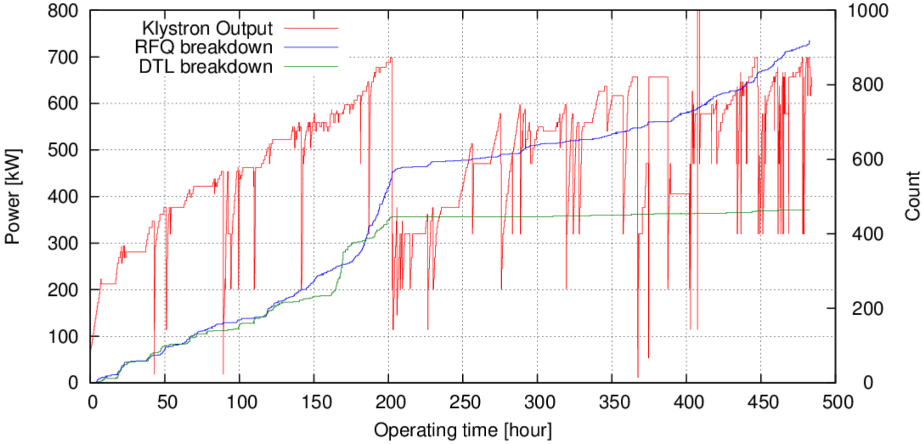
1.2 MW Klystron

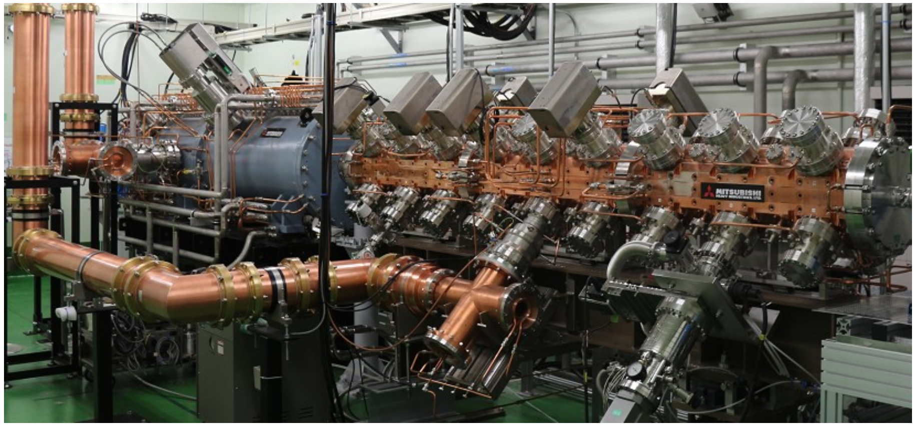
Modulator
1 ms, -90kV,
33A, 200 Hz

Beam transport & expander



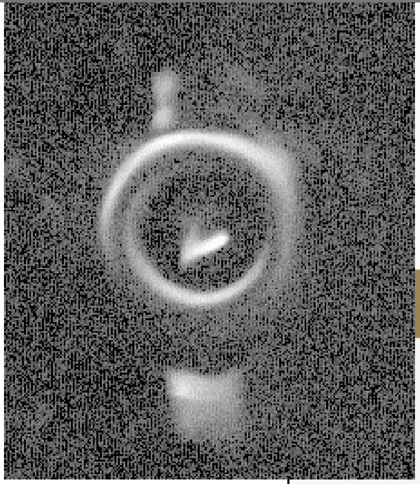
RF Conditioning

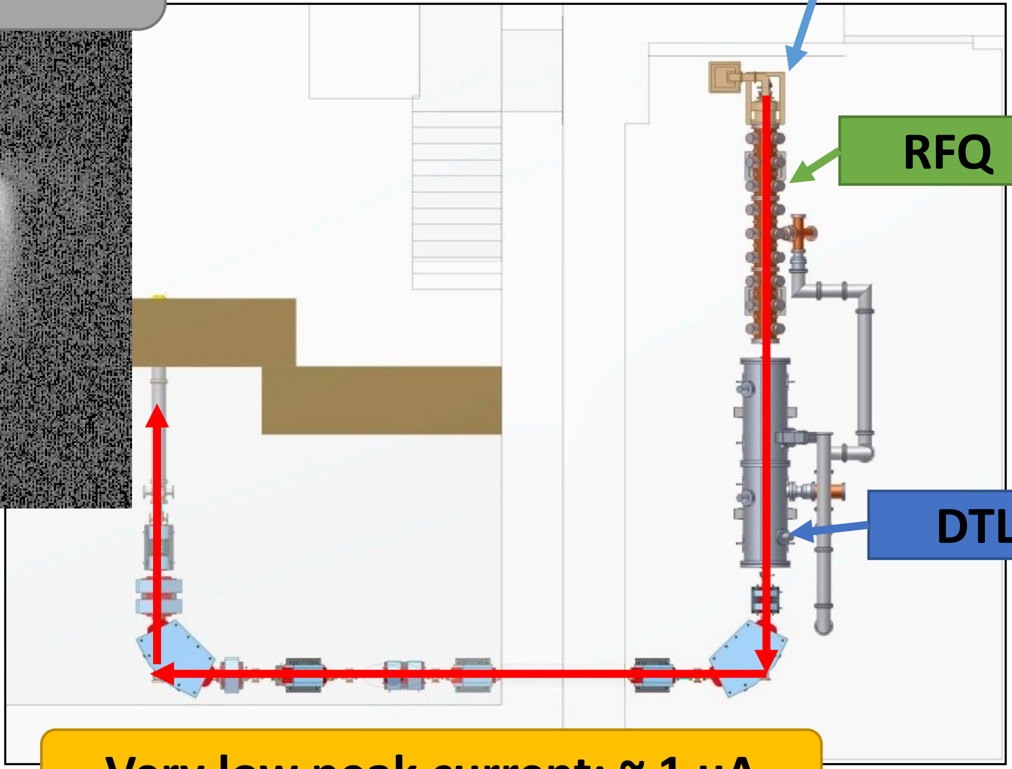




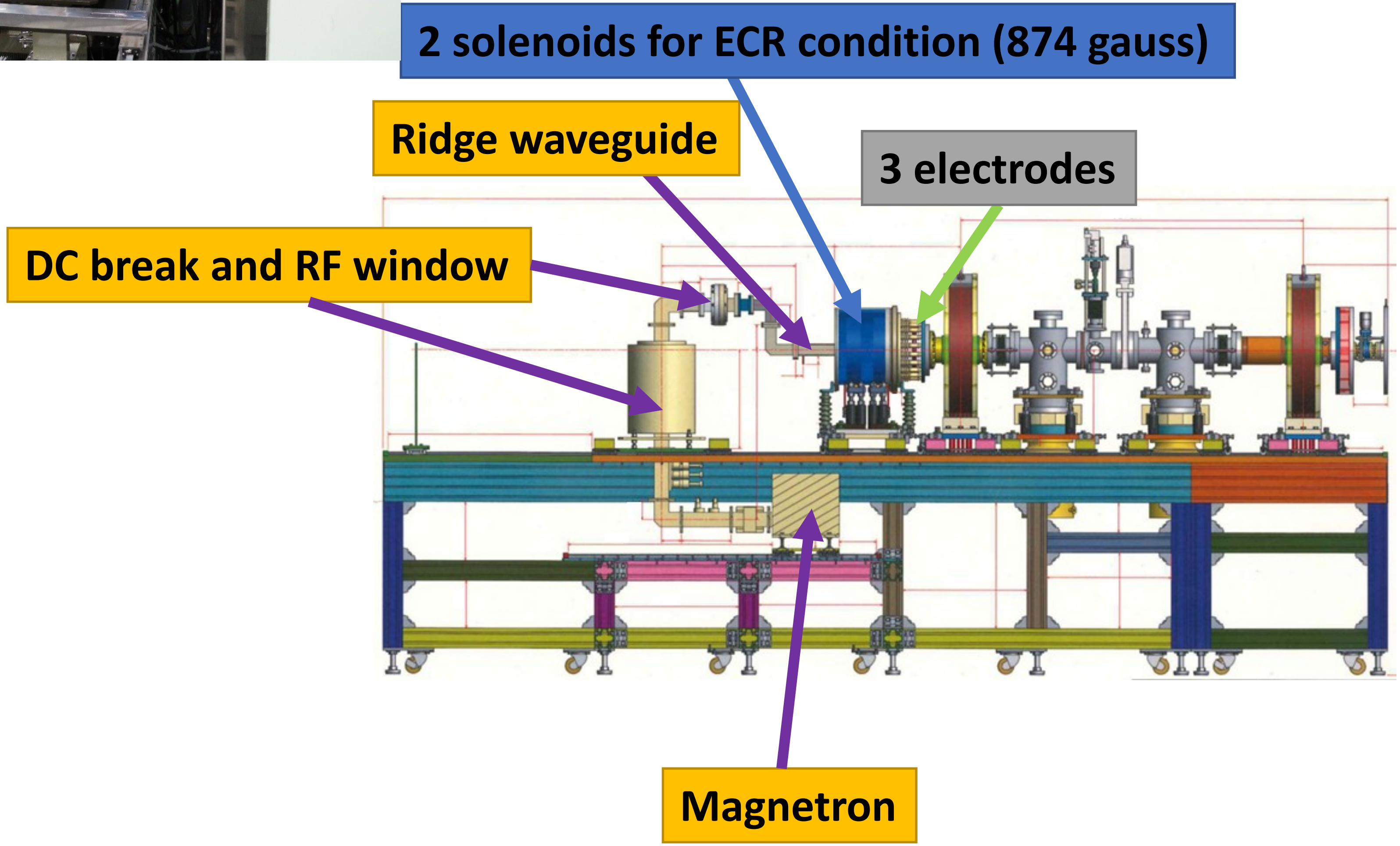
First beam commissioning was completed in December 2014

Fluorescent screen on target

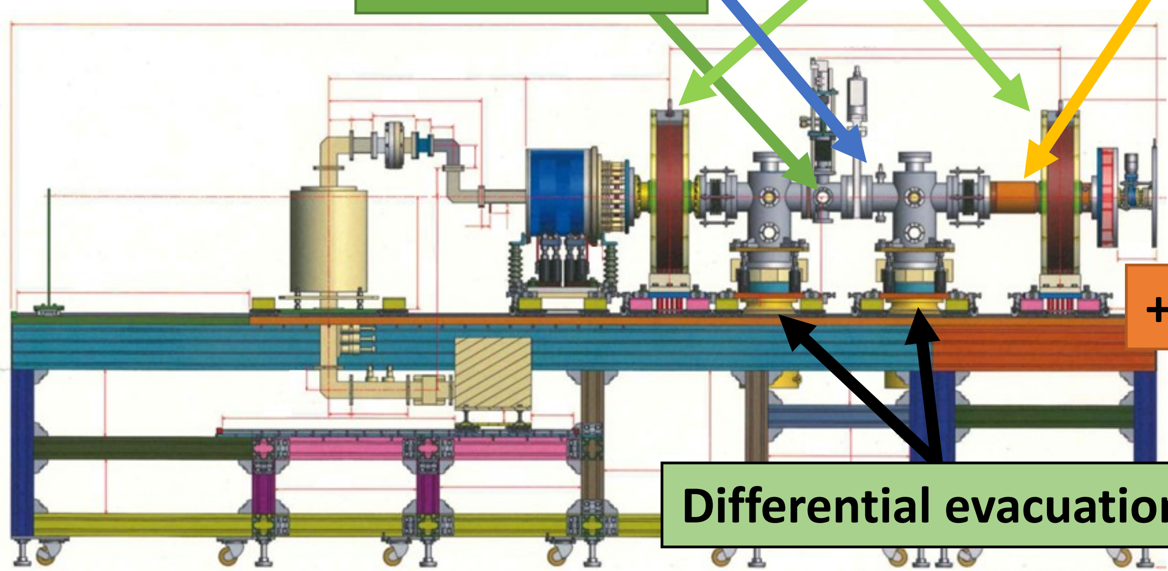


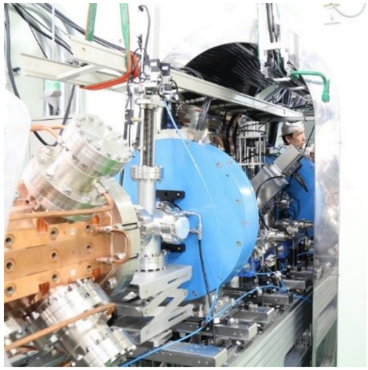


ECR Ione source for Ibaraki-BNCT

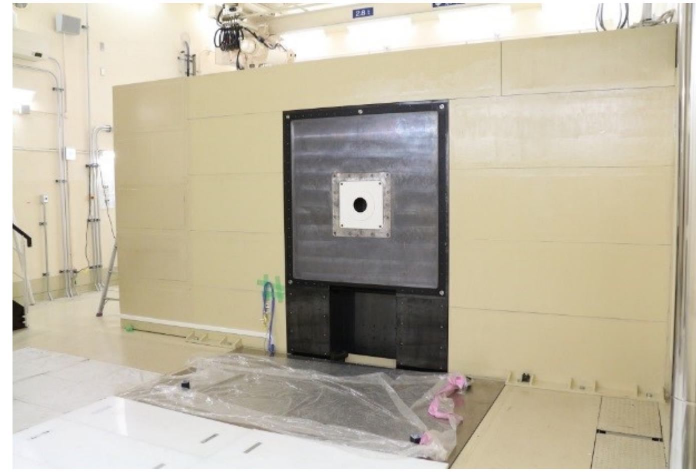


LEBT


Chopper
Beam dump to remove unnecessary ions H_2^+ and H_3^+
Solenoid focus
Beam reducer
+ Emittance Monitor (Future)
Differential evacuation

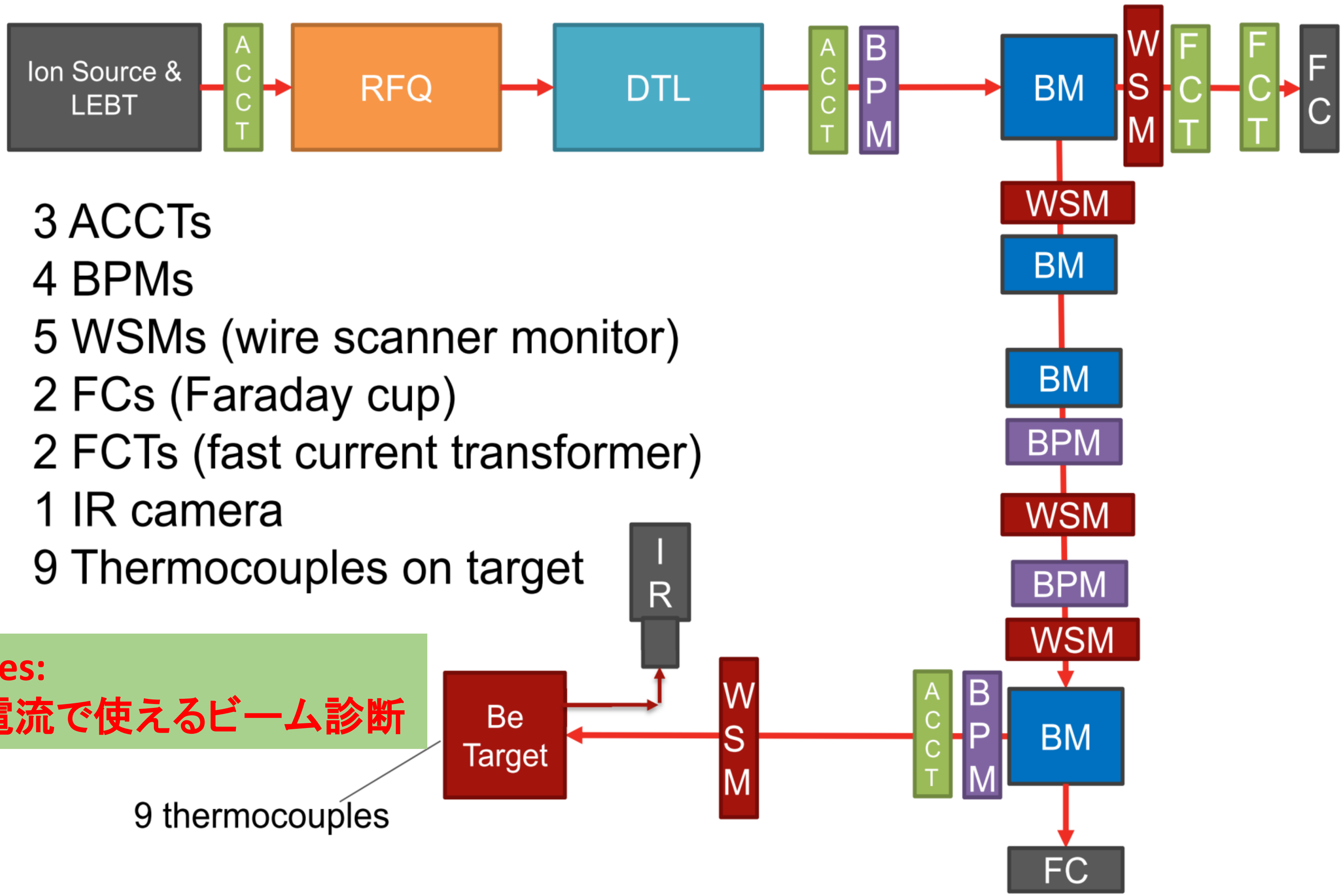


照射室完成
大塚製作所、関東技研に感謝



現在：中性子コミッショニング中 ➔ 今年度内動物実験、細胞実験
来年度：医学研究開始

Beam Diagnostics (for high current)



3 ACCTs
4 BPMs
5 WSMs (wire scanner monitor)
2 FCs (Faraday cup)
2 FCTs (fast current transformer)
1 IR camera
9 Thermocouples on target

Issues:
大電流で使えるビーム診断

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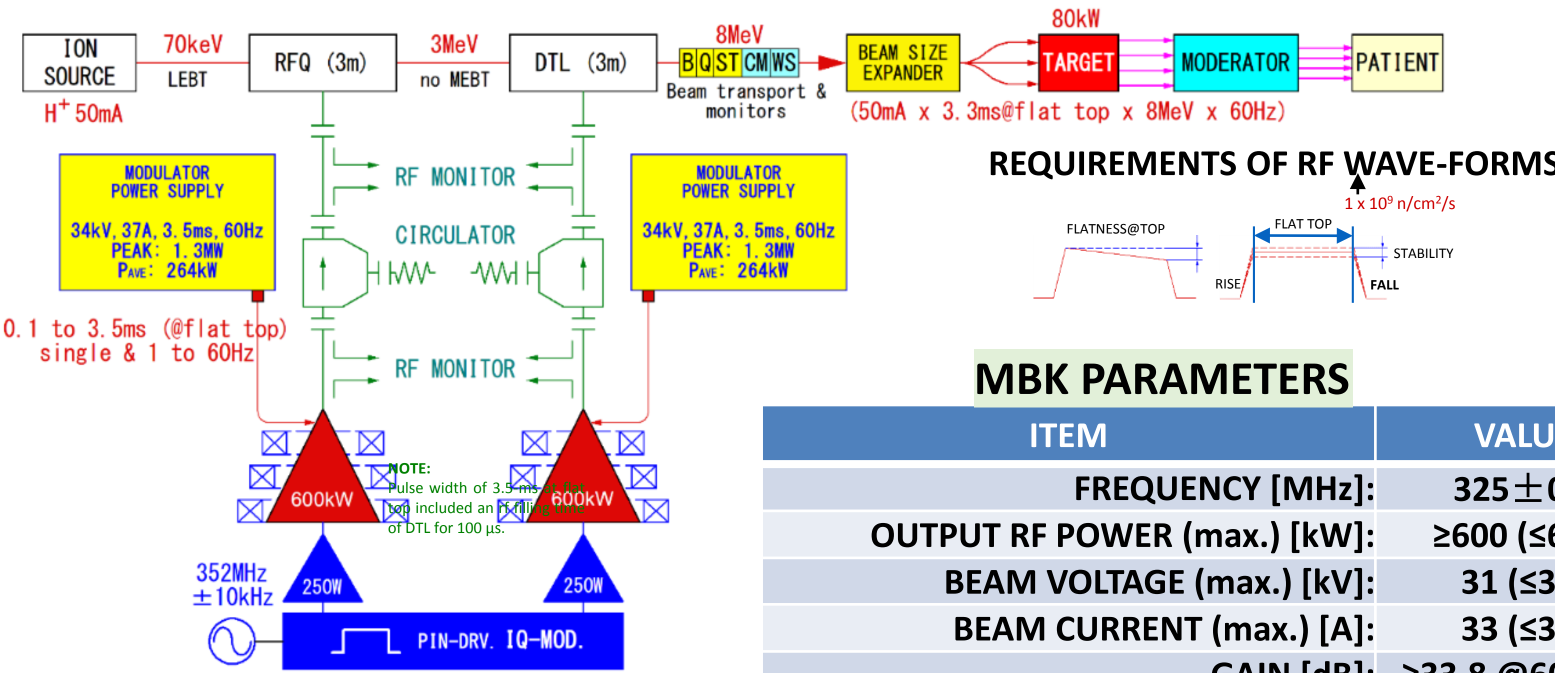
OIST-BNCT possible configuration: 3MeV (RFQ) + 5 MeV (DTL) + 2 MBK case design

REQUIREMENTS OF RF WAVE-FORMS



MBK PARAMETERS

ITEM	VALUE
FREQUENCY [MHz]:	325±0.1
OUTPUT RF POWER (max.) [kW]:	≥600 (≤625)
BEAM VOLTAGE (max.) [kV]:	31 (≤34)
BEAM CURRENT (max.) [A]:	33 (≤37)
GAIN [dB]:	≥33.8 @600 kW
EFFICIENCY AT SATURATION [%]:	≥55

BEAM PARAMETERS

ITEM	VALUE
BEAM ENERGY [MeV]:	8 (3 +5)
BEAM ENERGY JITTER [%]:	<±0.5
PEAK BEAM CURRENT [mA]:	50
AVERAGE BEAM CURRENT [mA]:	10.5
BEAM POWER [kW]:	84
PULSE WIDTH@FLAT TOP [ms]:	0.1 to 3.3
MAX. REP. RATE [Hz]:	60

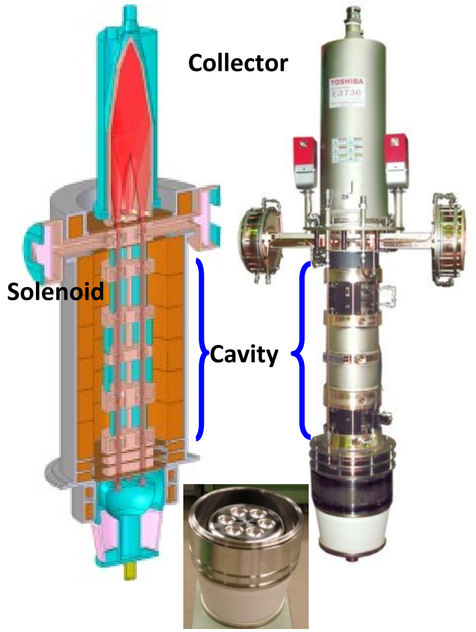
MODULATOR POWER SUPPLY SPECIFICATION (for each)

ITEM	VALUE
P_{PEAK} (max.) [MW]:	1.0 (1.3)
P_{AVE} (max.) [kW]:	215 (264)
VOLTAGE (max.) [kV]:	31 (34)
CURRENT (max.) [A]:	33 (37)
PULSE WIDTH@FLAT TOP [ms]:	0.1 to 3.5
RISE & FALL TIME (0 to 100%) [ms]:	<0.1
FLATNESS @TOP (RMS):	$<5\times10^{-4}$
STABILITY @TOP (RMS):	$<5\times10^{-4}$
REP. RATE [Hz]:	single & 1 to 60

MBK: multi beam Klystron
One of the key technologies

i-BNCT Klystron system E37619
Single beam, 1.2 MW, -90kV, 33A

TOSHIBA Multi-Beam Klystron (MBK) E3736 for ILC & XFEL(SRF)



Electron gun : 6 beams

1.2 MW Klystron

Modulator

OIST-BNCT Klystron system: 6 beams, 600 kW, -31kV, 33A

Advantage of MBK by comparing with SBK:

- higher AC to RF power conv. eff. (61/54 %)
- lower modulator power supply voltage (31/91 kV)
  ➔ compact and reliable modulator power supply
- Longer cathode life due to lower cathode loading

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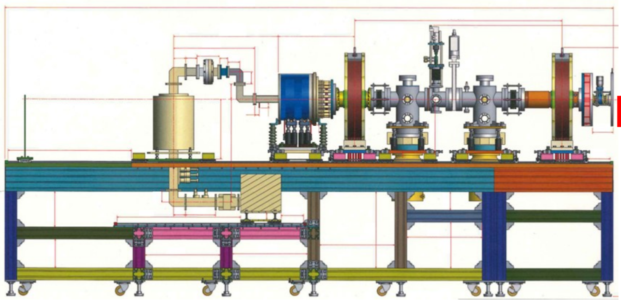
Large scale neutron source
High flux, but
limited machine time

We need both !!

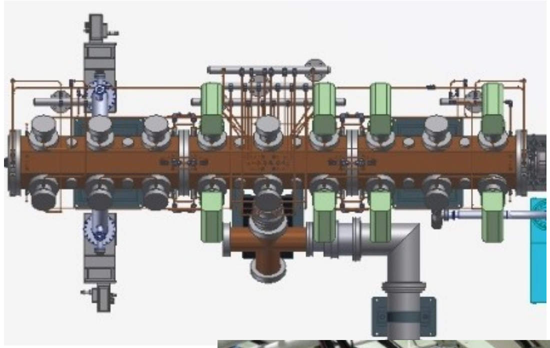
Small scale neutron source
Low flux, but
Taylor-made studies

- **HUNS:**
Hokkaido University Neutron Source
- **45MeV Electron linac**

- **RANS:**
Riken Accelerator-driven Neutron Source
- **7MeV, 700W proton Linac**



② High current, high duty RFQ + DTL



① ECR ion source
- High current
- Easy to maintenance

③ long pulse
Klystron modulator

④ MBK
For OIST-BNCT

- First and second compact BNCT (proton driver) construction

→ Ibaraki BNCT, full commissioning will be very soon (POC machine)

→ OIST-BNCT six years construction program has been just started
The role is to establish the first mass production model

- Technologies for BNCT are common with front-end of the large scale machine
- BNCT linac can be applied as a compact neutron source for material/life science and industrial applications