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中国の加速器利用状況

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原子力国際専攻

中国の加速器利用

- 工業用電子線照射装置
1950年代から放射線育種・高分子材料改質などの目的で利用されていた。2000年以降急増。滅菌・滅菌利用も重要。
- 医療分野
2000年以降がん治療施設が増えている。医療用小型サイクロトロン等、Shanghai Proton and Heavy Ion Center 等。
- 放射光施設
代表的な施設は3つ (BSRF, NSRL, SSRF) 。中でも2009年より稼働している最新のSSRFでは、Nature/Science 級の成果を量産。
- 高エネルギー物理学
Institute of High Energy Physics (北京) , Institute of Modern Physics (蘭州) , etc.
- 加速器質量分析
CIAE, 北京大学, XI'an

訪中の日程

2013年

- ❁ 11月12日 上海応用物理研究所: SSRF (放射光)
- ❁ 11月13日 上海腫瘍医院附属陽子重粒子線医学センター
(粒子線治療施設: 建設中)
- ❁ 11月14日 中国科学院近代物理研究所 (蘭州)
Institute of Modern Physics
Heavy Ion Research Facility
- ❁ 11月15日 中国科学院高能物理研究所 (北京)
Institute of High Energy Physics: BEPC/BSRF
Beijing Electron Positron Collider
Beijing Synchrotron Radiation
Machine Workshop (Factory)

中国の放射光源



Beijing electron Positron Collider (BEPC)

Shanghai Synchrotron Radiation Facility (SSRF)

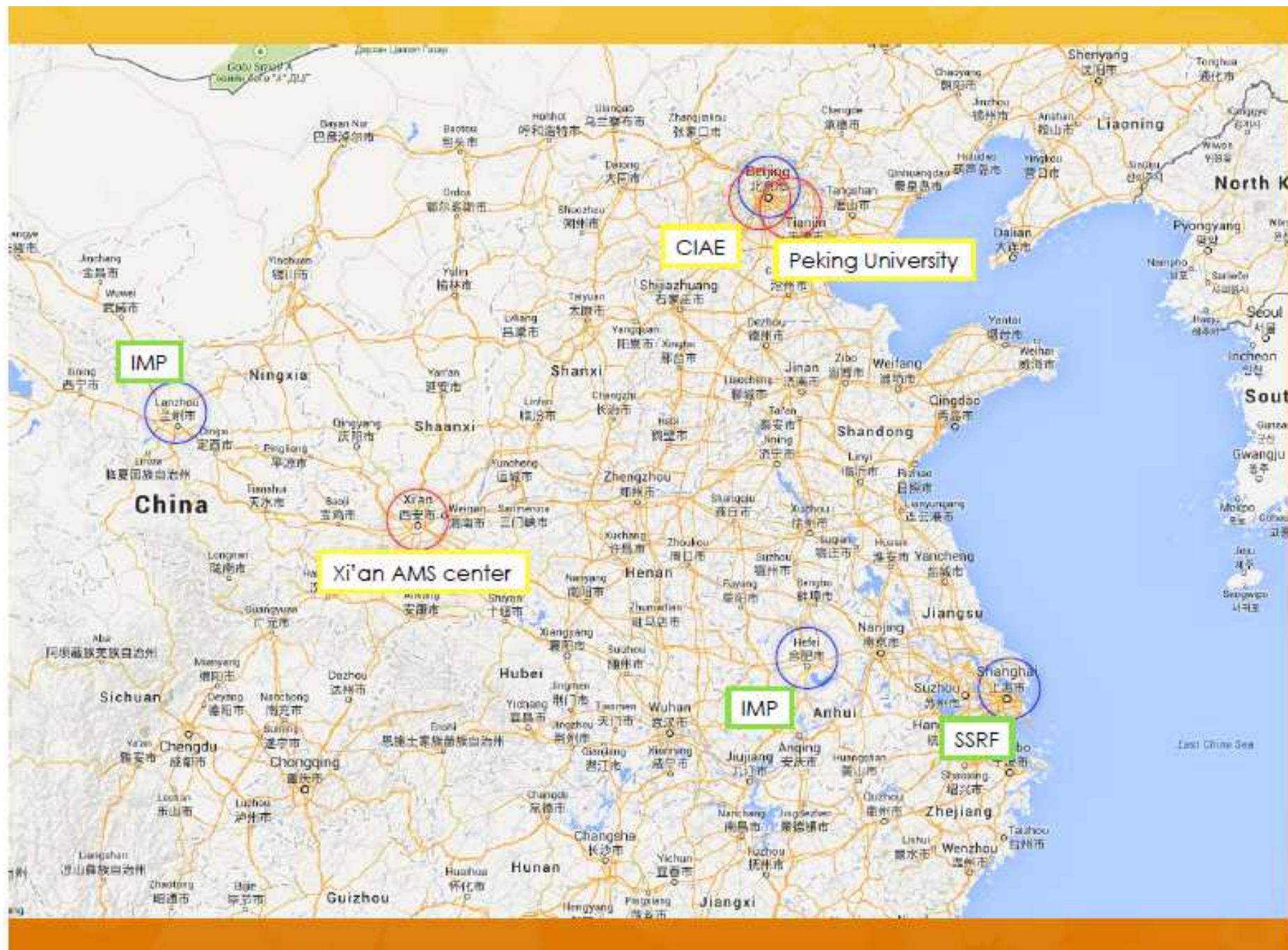


National Synchrotron Radiation Laboratory (NSRL)

高能物理研究所 (北京)

MACHINE WORKSHOP





中国の加速器質量分析施設



Institute of Earth Environment,
Chinese Academy of Sciences
(Xi'an)
3MV Tandetron



China Institute of
Atomic Energy, 13MV
Tandem accelerator
(Beijin)



Peking University
Compact AMS
(500kV Pelletron)

World's AMS facilities

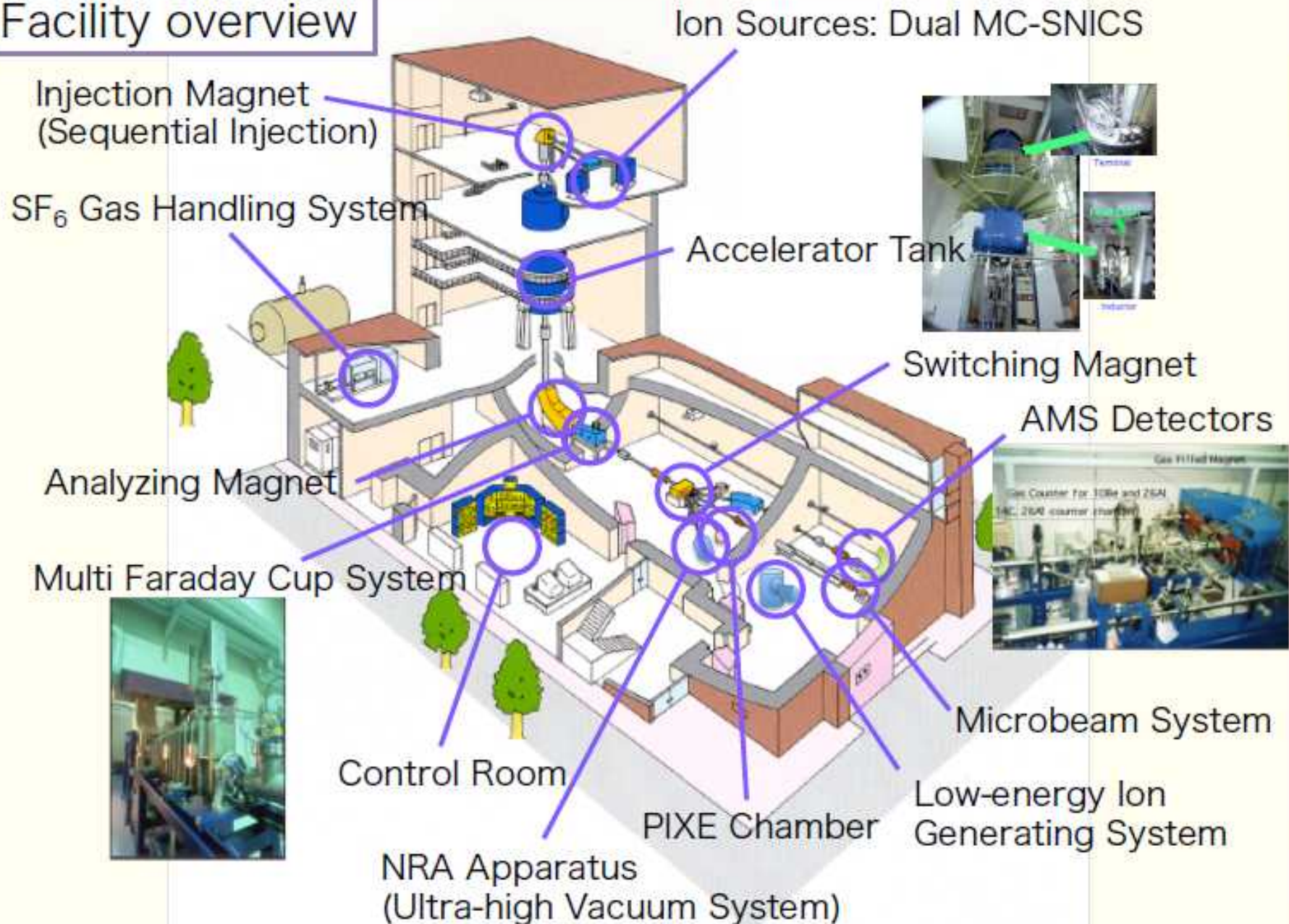
	SSAMS 0.2 MV	0.5 - 1 MV	3 MV	5 - 6 MV	8 - 14 MV	TOTAL
AUSTRALIA	ANU, Canberra		STAR (2) ANSTO, Sydney	<i>GNS (6), Wellington, NZ</i>	<i>ANTARES (10), ANSTO ANU (14), Canberra</i>	5
CHINA		Peking Univ (0.5), Beijing	CAS, Xish	PKUAMS (6), Beijing	CIAE (13), Beijing	4
EUROPE	Lund, SWEDEN	Seville (1), SPAIN Trondheim (1), NORWAY Poznan (0.5), POLAND Tandy ETH (0.5), SWITZERLAND MICADAS ETH (0.25), SWITZ MICADAS (0.25), HEIDLEBERG	Jena, GERMANY Kiel, GERMANY Gronigen, HOLLAND Florence, ITALY Lecce, ITALY CIRCE, Naples ITALY VERA, AUSTRIA CEA Saclay, FRANCE	CEREGE (5), FRANCE Uppsala (5), SWEDEN Aarhus (6) DENMARK ETH (5), SWITZERLAND Utrecht (6), HOLLAND Erlangen (6), GERMANY	Munich (14), GERMANY Bucharest (8), ROMANIA	23
INDIA			IOP Bhubaneswar		IUAC (15), New Delhi	2
JAPAN & Sth KOREA	Yokoyama Lab.	KIGAM, TAEJON, Sth KOREA Yamagata, JAPAN NIES-2	Nagoya Univ, JAPAN JAERI, JAPAN National Univ, Seoul, SK	NIES (5) . UT-TAC (6) Tsukuba MALT (5), Tokyo, JAPAN Tono Geoscience (5), JNC		11
UK	SUERC	Queens Univ (0.5), BELFAST	Oxford	SUERC (5)		4
USA & CANADA		CAIS (0.5), GEORGIA Irvine (0.5), CALIFORNIA NOSAMS (0.5), WHOI	ISOTRACE, Toronto NOSAMS, WHOI NSF, ARIZONA NSF, ARIZONA		CAMS (10), LLNL PRIME (10), Purdue	9
BIO-MED & Commercial	Xceleron, USA GKS, USA GKS, UK Beta, USA	ACCIUM (0.5), Seattle, USA MIT (1), USA CAMS (1), LLNL BIO-MICADAS, Vitalea Sci, USA BIO-MICADAS, ETH IAA (0.5), Kanagawa, JAPAN Paleo Labo (0.5), JAPAN	IAA, Kanagawa, JAPAN	CBAMS (5), Xceleron, UK		13
NEW 2008-2010		GNS (0.6) Wellington, NZ ANSTO (1) AUSTRALIA		Cologne (6) GERMANY Dresden (9) GERMANY ANSTO (6) AUSTRALIA		5
TOTAL	8	23	20	17	8	76
		HVE	NEC	<i>italics = shared / modified accel facility</i>		

Introduction of MALT facility



	Pelletron™ Tandem Accelerator
Voltage [MV]	1.0~5.0
Maker/Type	NEC Pelletron 5UD
Completion	1993
Location	Bunkyo-ku, Tokyo, Japan
Management	Accelerator Division, Dept. of Nuclear Engineer and Management, School of Engineering, The University of Tokyo
Charging system	Pellet Chains System
Ion source	MC-SNICS 1 (S1: Multiple Use) MC-SNICS 2 (S2: ^{14}C -AMS dedicated)
Accelerated ion species	H^+ , $^{15}\text{N}^{2+}$, C^{4+} , Be^{3+} , Al^{3+} , Cl^{7+} , I^{8+}
Usage	AMS (Accelerator Mass Spectrometry) (^{10}Be , ^{14}C , ^{26}Al , ^{36}Cl , ^{129}I) PIXE NRA (^{15}N (p, α) ^{12}C)

Facility overview





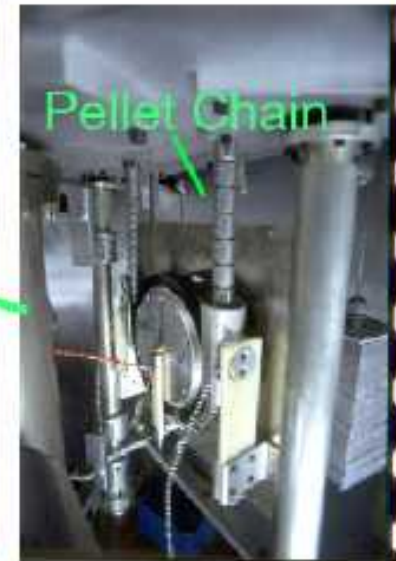
Pellet Chain and Accelerator tubes



Looking up the Accelerator Tank



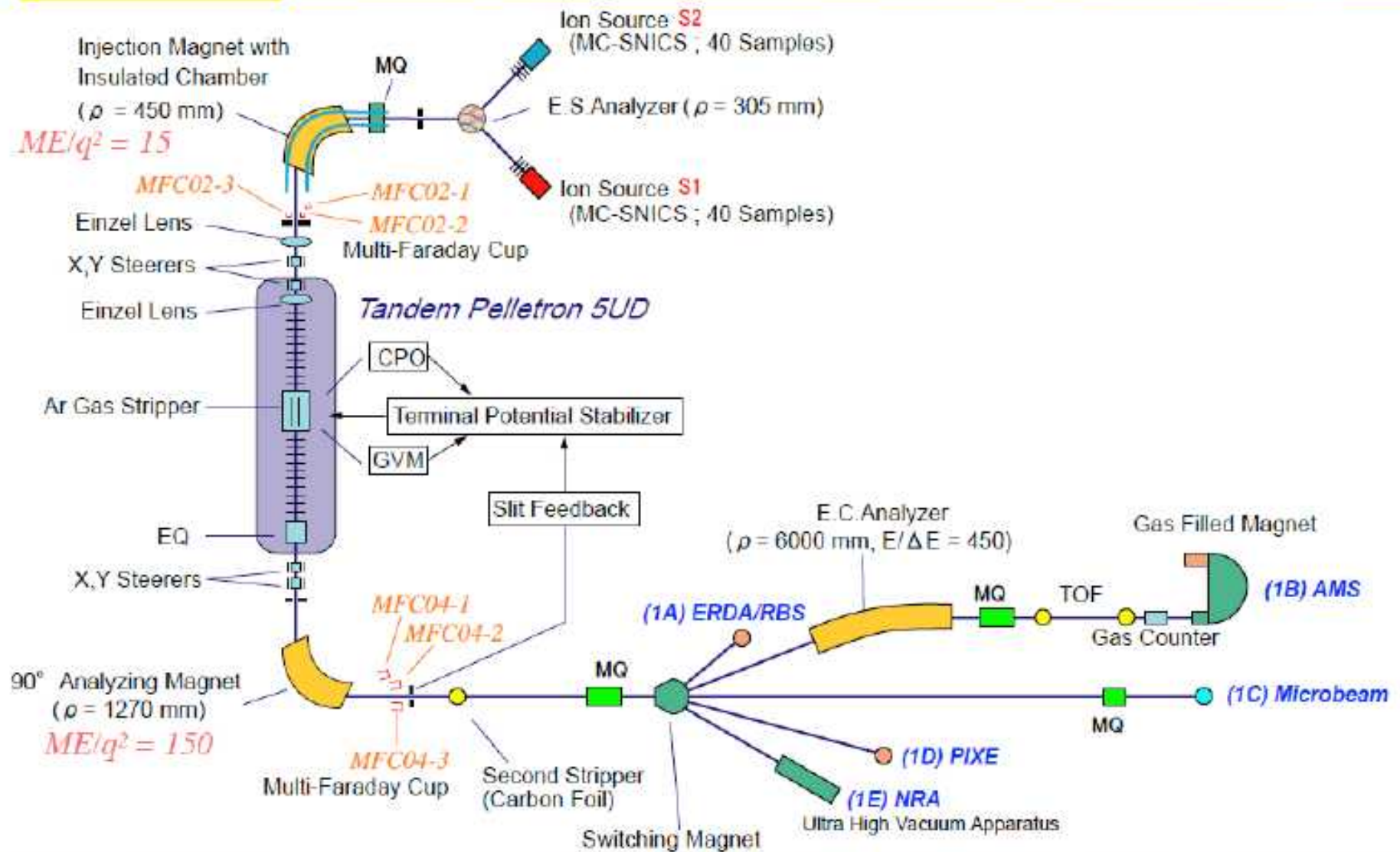
Terminal



Pellet Chain

Inductor

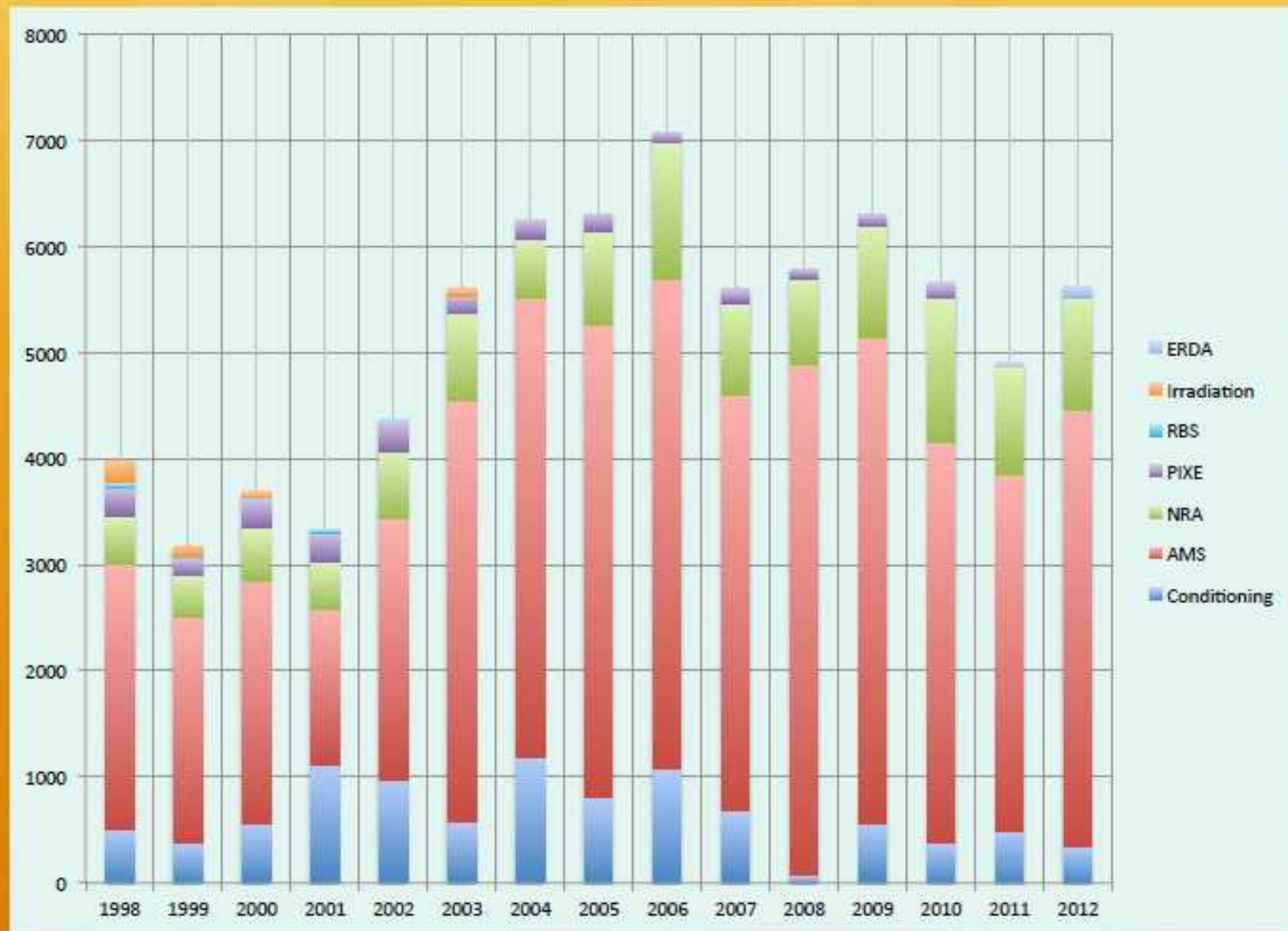
Beam line



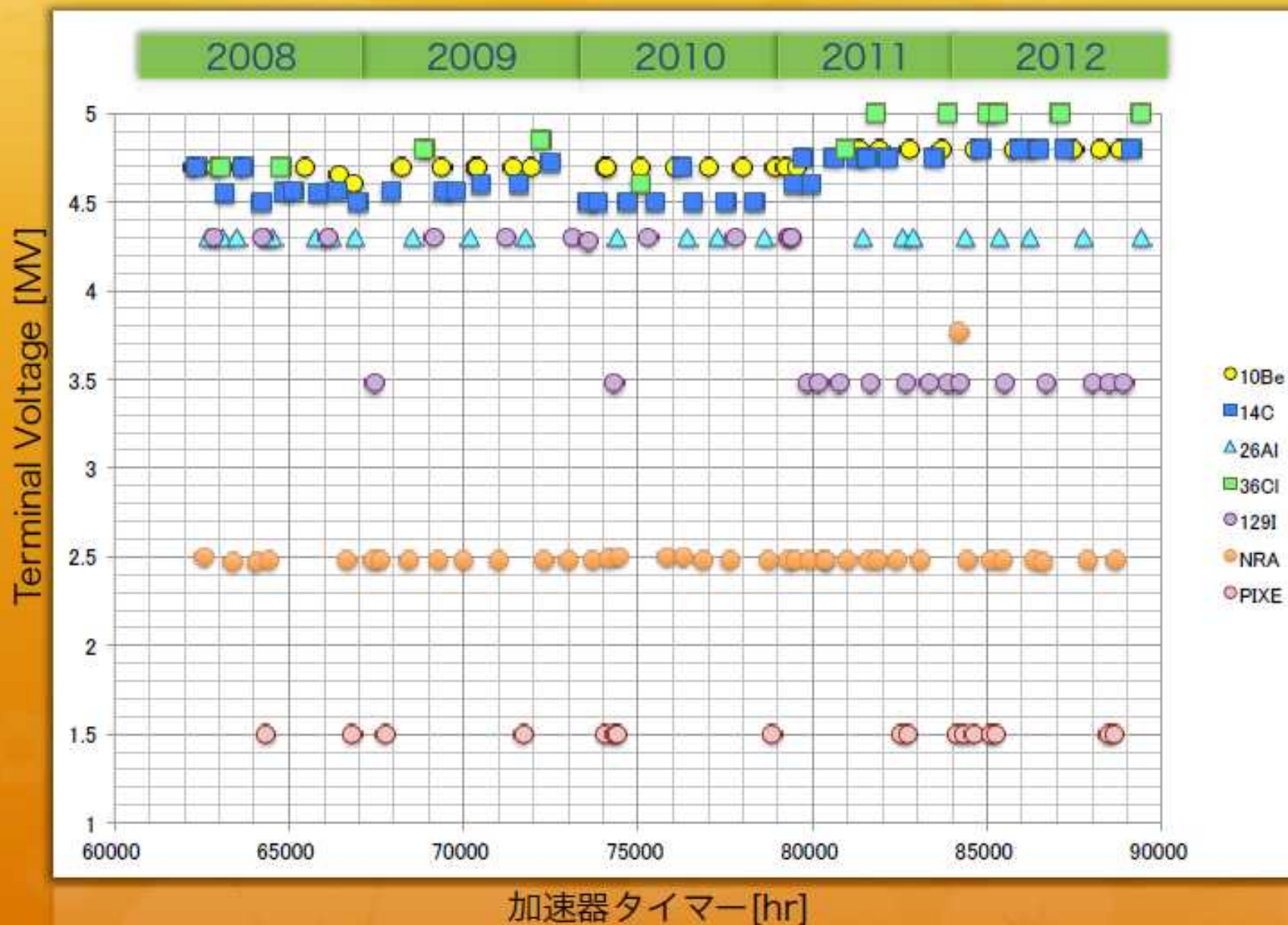
Brief history

Total Operation Time [hr]	date.yr	mon.	day	Topics	Troubles
	1991-1993			Construction of new Tandem Pelletron 5UD	
	1994			Beam line construction at 2C (NRA line)	
	1996			First data on Metal/Si interfaces by NRA	
	1997	Aug.		Resistors of accelerator tubes replacement, Large inner diameter stripper canal	
	1998			Developments of AMS detectors (GC - GFM - TOF)	
17,135	1999	Aug.		14C dedicated ion source (S2) (Alphatros abandoned)	
19,347	2000	May		AMS auto measurement system	
20,229		Aug.		improvement of S1 ion source (new housing, cooling system)	
23,100	2001	Apr.		NRA line move from 2C to 1E	
24,946	2001	Dec.	4		Accelerator tube leak (2001.12.04 -> 2002.01.25)
45,351	2005	Oct.		Beam line construction at 1C (Micro beam) PIXE line move from 2E to 1D	
50,000	2006	Jun.	26	50,000 hr milestone	
56,714	2007	Jun.	19		Pellet chain replacement (Ch2) Operating with single chain (2007.6.19 -> 2007.8.4)
57,650	2007	Aug.	13		Insulation sheet at the injection magnet puncture
60,000		Dec.	24	60,000 hr milestone	
61,062	2008	Feb.	9		Poltergeist -> Accelerator stop
62,255	2008	May	20	New ion source install at S1	
67,092	2009	Mar.			Earthquake-resistant construction (2009.2.2 -> 2009.3.31)
73,389	2010	Apr.		S2 ion source version up to high current type	
70,000	2010	Oct.	17	70,000 hr milestone	
79,038	2011	Mar.	11		Earthquake disaster -> no actual damage
	2011	May	30		Stripper turbo failure/Exit Q out of control (2011.5.30 -> 7.15)
80,000	2011	July	26	80,000 hr milestone	
90,000	2013	May.	22	90,000 hr milestone	

Accelerator operation time



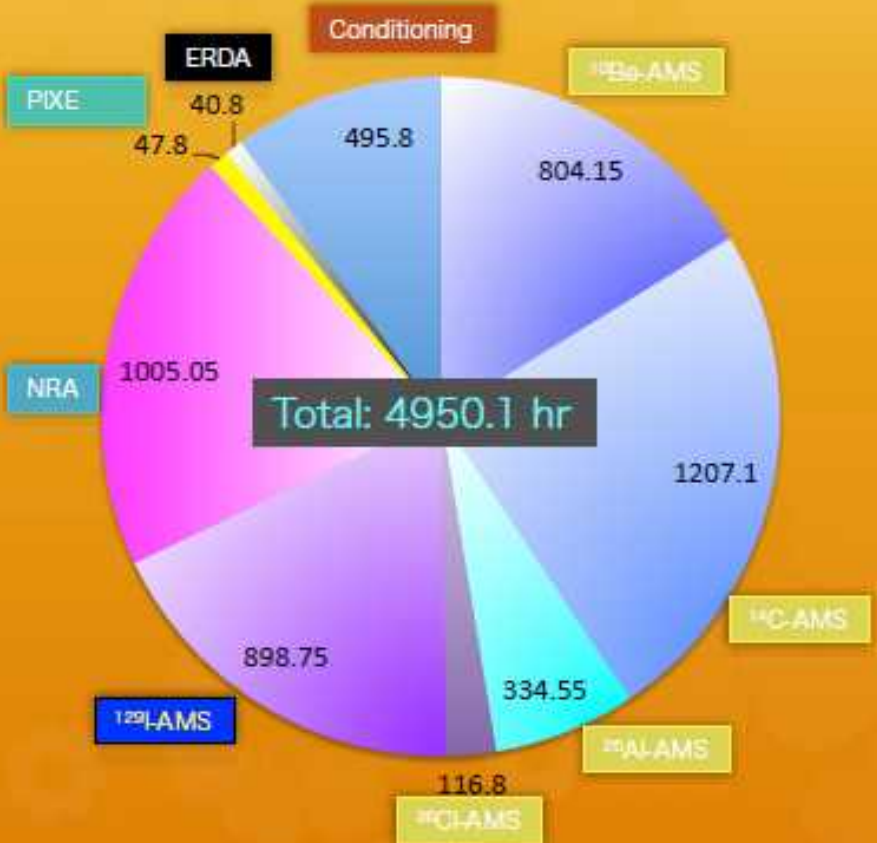
Operational terminal voltage, recent years



Accelerator usage details, MALT, The University of Tokyo

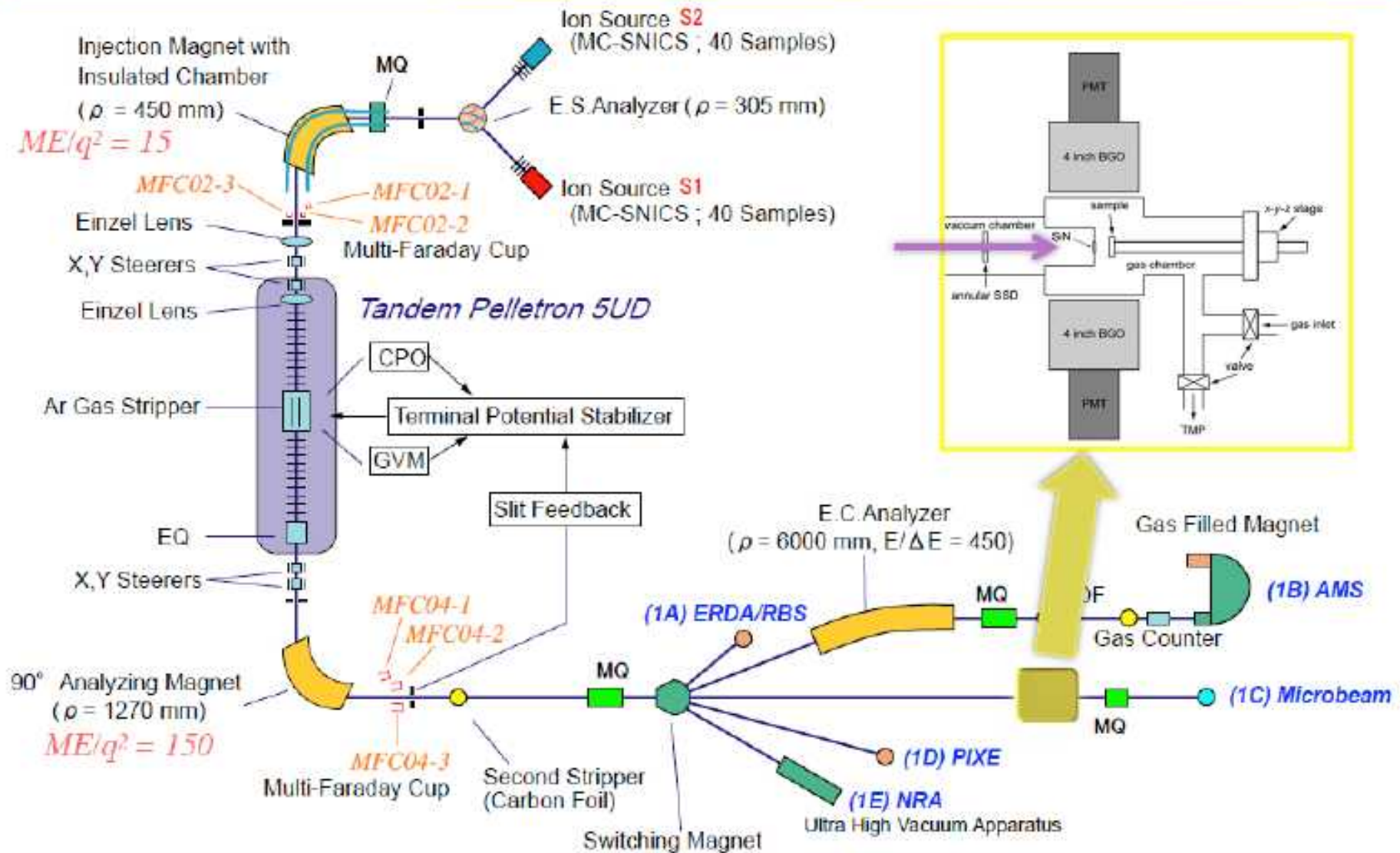
2011

2012

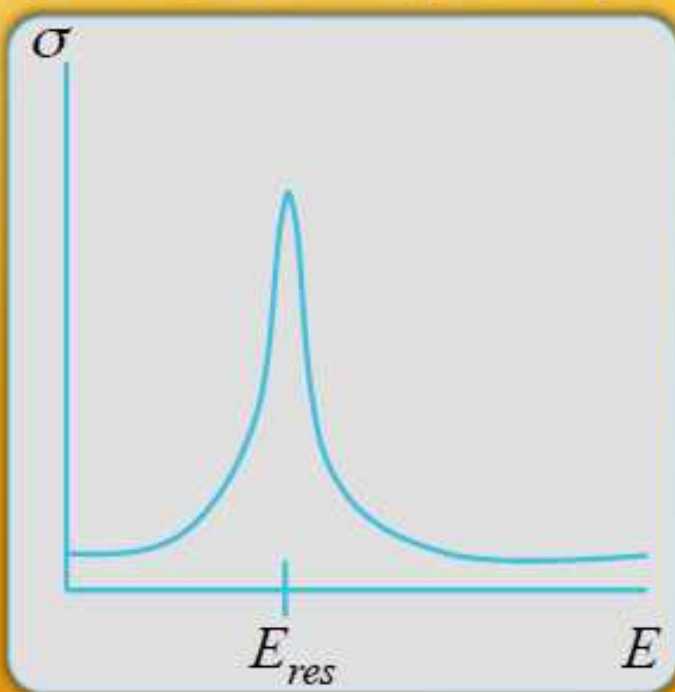


- 10Be
- 14C
- 26Al
- 36Cl
- 129I
- NRA
- PIXE
- ERDA
- Maintenance

NRA experiments



Hydrogen analysis by resonant nuclear reaction



$$x(E) = (E_0 - E_{res}) / (dE_0 / dz)$$

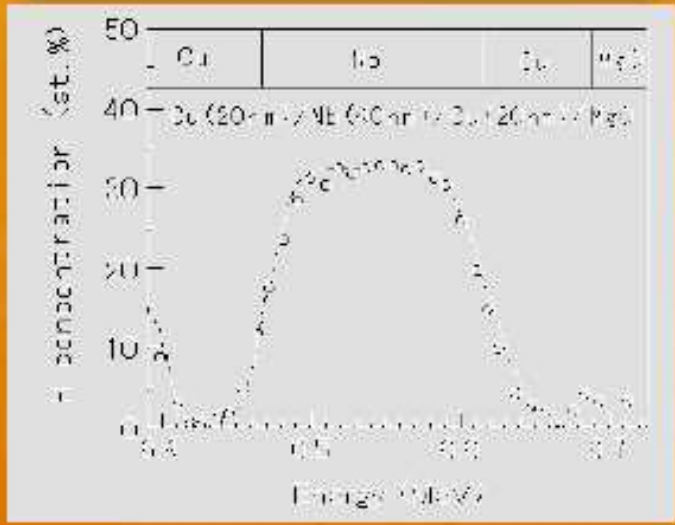
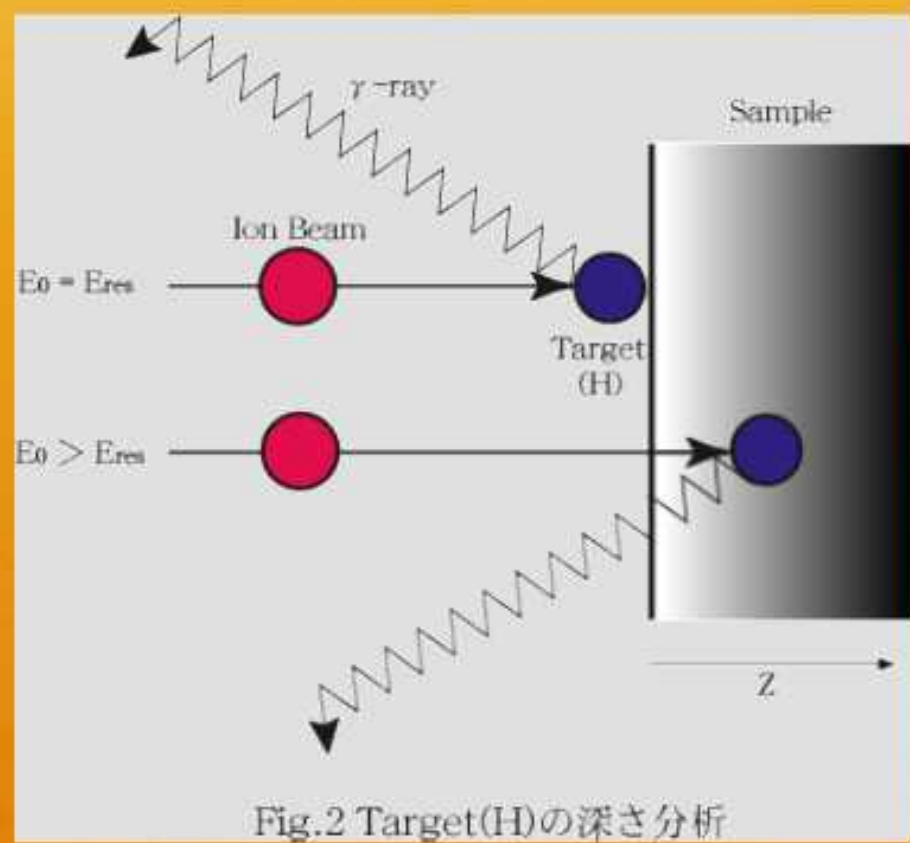
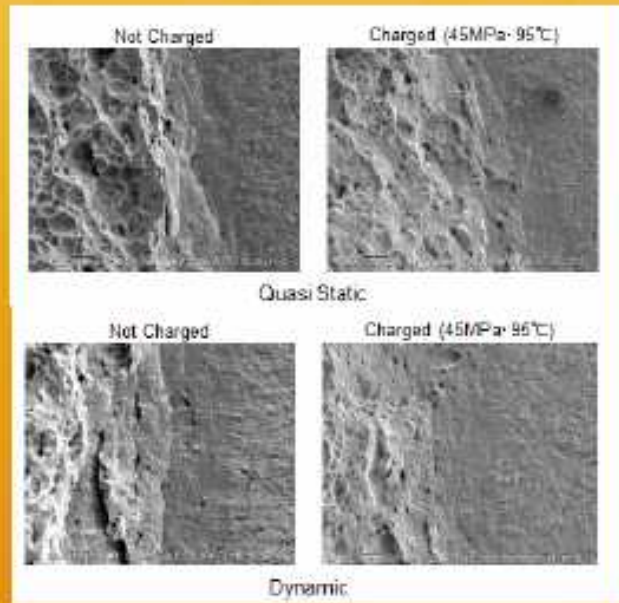


Fig.2 Target(H)の深さ分析

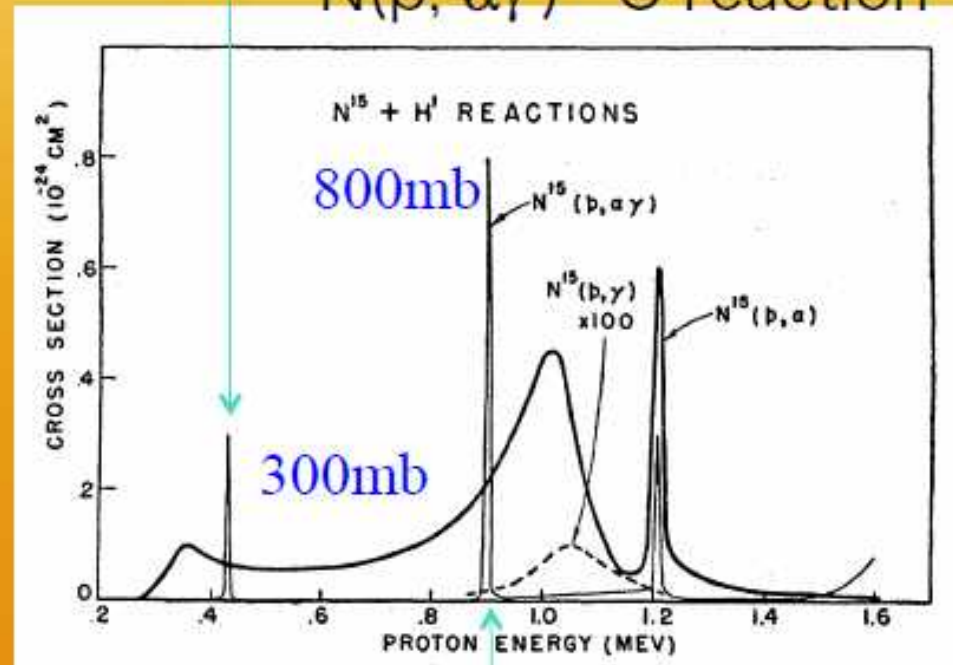
Development of new NRA system using 13MeV ^{15}N beam

Instead of 6.4 MeV ^{15}N



Hydrogen embrittlement

$^{15}\text{N}(p, \alpha\gamma)^{12}\text{C}$ reaction



Make possible for Hydrogen analysis of longer range

Semi-macroscopic analysis for structural materials

Summary of MALT Accelerator System

5MV Tandem Accelerator

Maximum ion energy : $5 \cdot (q+1)$ MeV

H⁺ 3.0 MeV;
N²⁺ 6.5 MeV;
Be³⁺ 17.2 MeV;
C⁴⁺ 25.0 MeV;
Cl⁷⁺ 40.0 MeV;
etc.

Cs-sputter solid ion source

By proper target, from H (D) to Pu can be accelerated

Good Mass analysis system

Good energy resolution

Freely designable beam line

Own development detectors
New beam line development
Possibility for X-ray, neutron sources as secondary radiation

Ongoing development

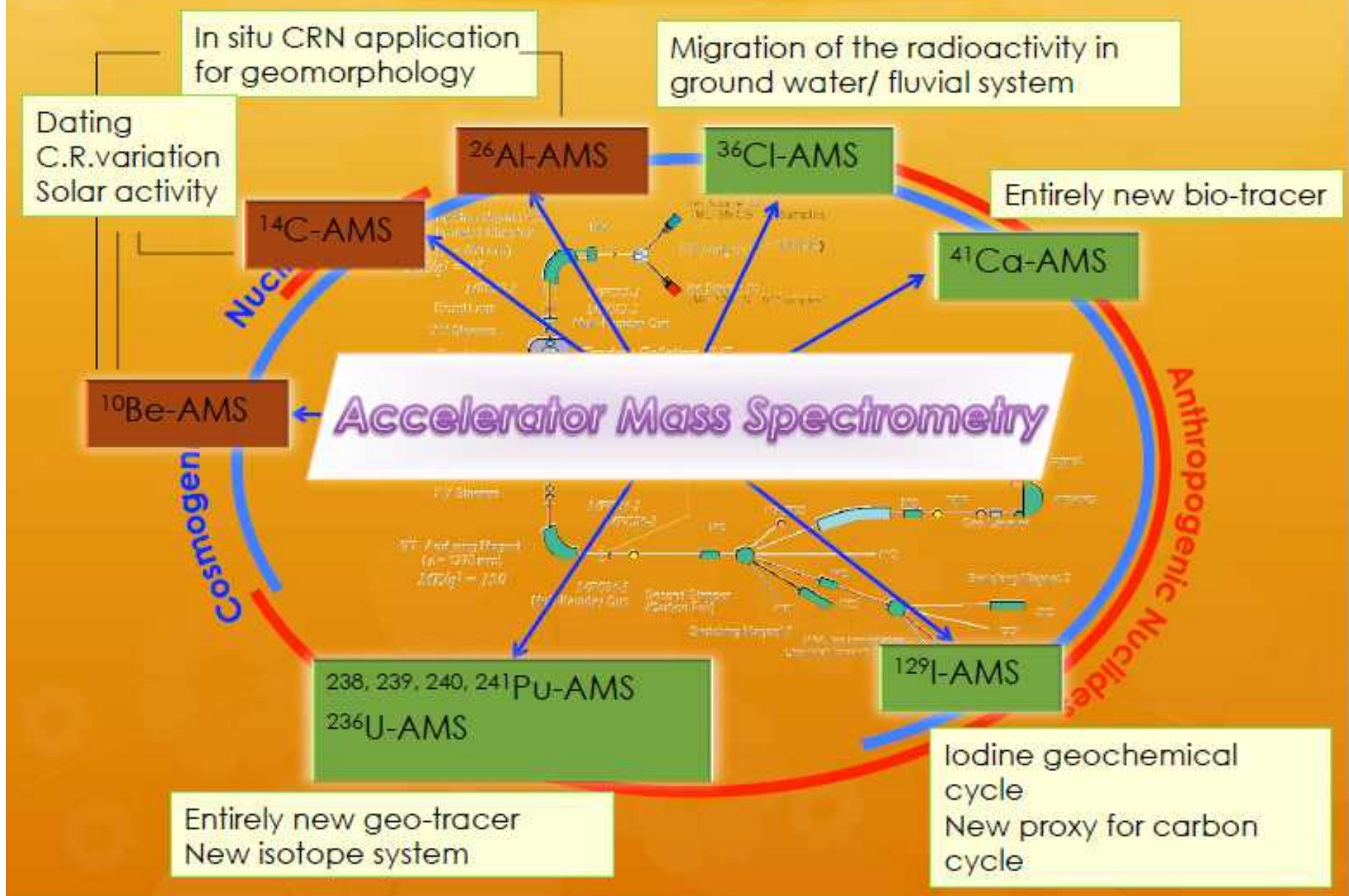
High-efficiency ion source, New target, New technique for Isobar suppression

Electron affinities of the elements [eV]

IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIIIA
H 0.754							He 0.078*
Li 0.618	Be 0.195*	B 0.277	C 1.263	N -0.07	O 1.461	F 3.399	Ne <0
Na 0.548	Mg <0	Al 0.441	Si 1.385	P 0.747	S 2.077	Cl 3.617	Ar <0
K 0.501	Ca 0.043	Ga 0.30	Ge 1.2	As 0.81	Se 2.021	Br 3.365	Kr <0
Rb 0.486	Sr <0	In 0.3	Sn 1.2	Sb 1.07	Te 1.971	I 3.069	Xe <0
Cs 0.472	Ba <0	Tl 0.2	Pb 0.364	Bi 0.946	Po 1.8	At 2.8	Rn <0

*Metastable

AMS frontier application: Earth and Environmental application



AMS frontier application: related to Nuclear activity/accident

^{14}C anomaly in the bio-system

^{36}Cl anomaly in Seawater
Migration of the radioactivity in
ground water/ fluvial system

^{14}C -AMS

^{36}Cl -AMS

Entirely new bio-tracer

^{41}Ca -AMS

Accelerator Mass Spectrometry

^{90}Sr -AMS

Dose
reconstruction

Signal for Anomalous Neutron flux

Fission Products

$^{238}, ^{239}, ^{240}, ^{241}\text{Pu}$ -AMS
 ^{236}U -AMS

^{129}I -AMS

Reconstruction of ^{131}I
Iodine geochemical
cycle

Detailed analysis of the nuclear
materials originated in the accident
Entirely new probe for the geochemistry



まとめ

- ❁ 中国における加速器利用のフロンティア（医学利用・放射光・高エネルギー物理学）に関わる施設を視察した。
- ❁ 海外で修学した優秀な中国人科学者により、研究のレベルは世界に追いついて来ている。
- ❁ 加速器質量分析の世界でも、近年最新の加速器を導入しており、急速にレベルが上がって来ている。
- ❁ 東京大学MALTの加速器（5UD Pelletron）の概要を説明した。