Overview of research and applications of neutron beams: present status and future activities in Japan

N. Metoki

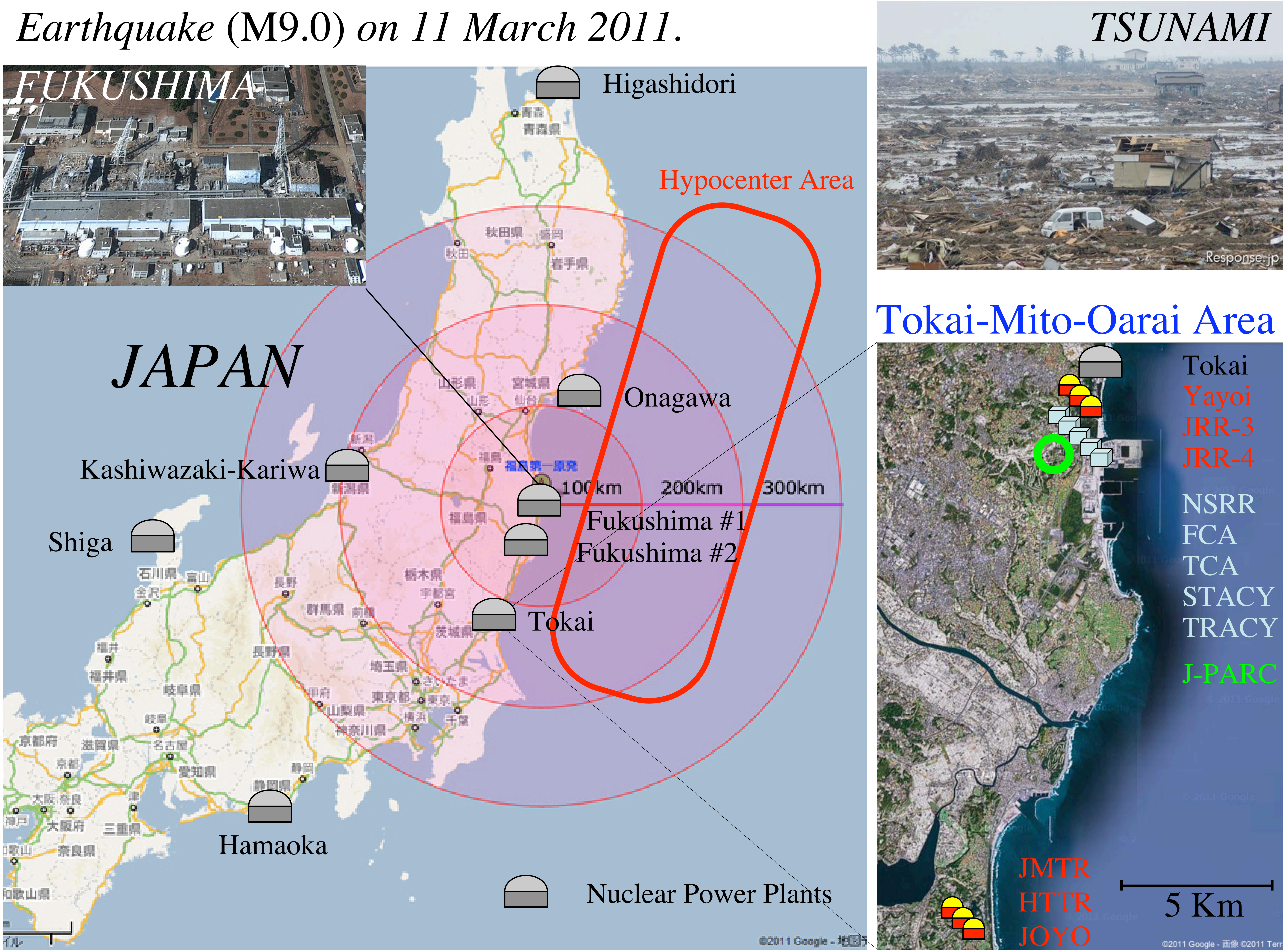
Japan Atomic Energy Agency, Tokai, Naka, Ibaraki 319-1195, Japan

1. The Influence of Earthquake on JRR-3.
2. Scientific Highlights
3. Complementary use of JRR-3 and J-PARC/MLF, continuous and pulse neutron.

I thank organizer (IAEA) and the kingdom of Morocco for inviting me to this nice conference.

Japanese people thank many international supports for the recovery from the earthquake and the accident of nuclear power plants.

Earthquake (M9.0) *on 11 March 2011.*



Tokai, Ibaraki: Center of Neutron Science in Japan

The University of Tokyo
The Institute for
Solid State Physics
Neutron Scattering Laboratory

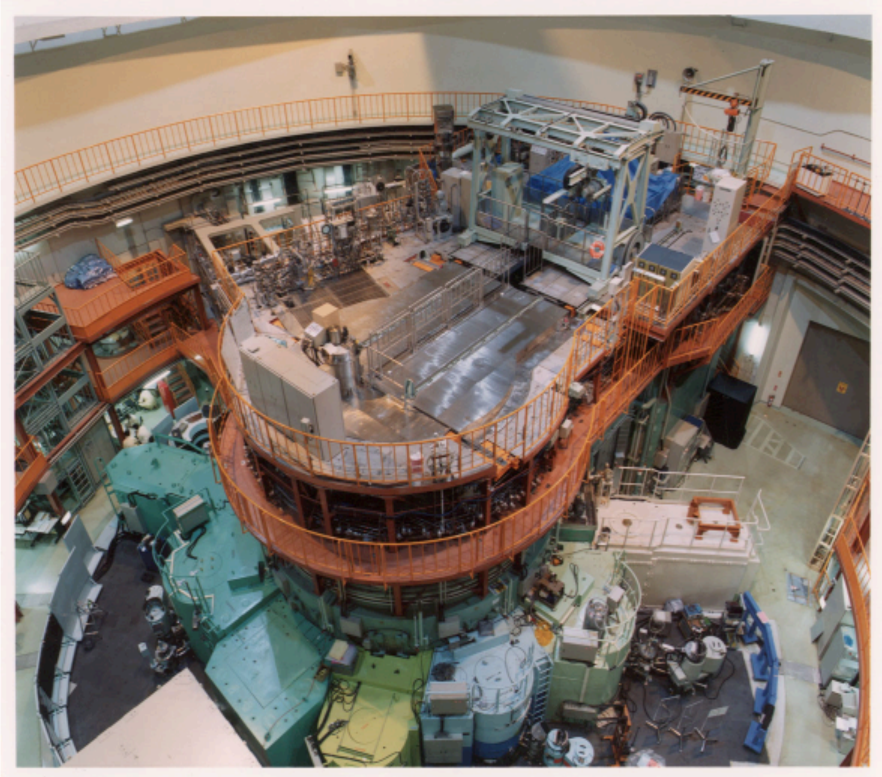
Ibaraki
Quantum Beam Research Center

Outside entrance restricted area
Joint Neutron Center in Japan

- J-PARC user office
- KEK Tokai office
- Ibaraki pref. & Ibaraki Univ.
- CROSS, NIMS

Outline of JRR-3

- **First Critical :** 12_{th} Sep. 1962, Upgraded : 22_{nd} March, 1990
- **Purpose :** Beam experiments, Irradiation, RI production, Activation analysis, Silicon semiconductor
- **Type :** Light water moderated and cooled, pool type reactor with low-enriched uranium
- **Thermal Power :** 20MW
- **Thermal Neutron Flux :**
  Approx. $3\times10^{18}\,m^{-2}s^{-1}$
- **Operation Mode :**
  Operation, 26 days/cycle
  6〜7cycle Operation/year

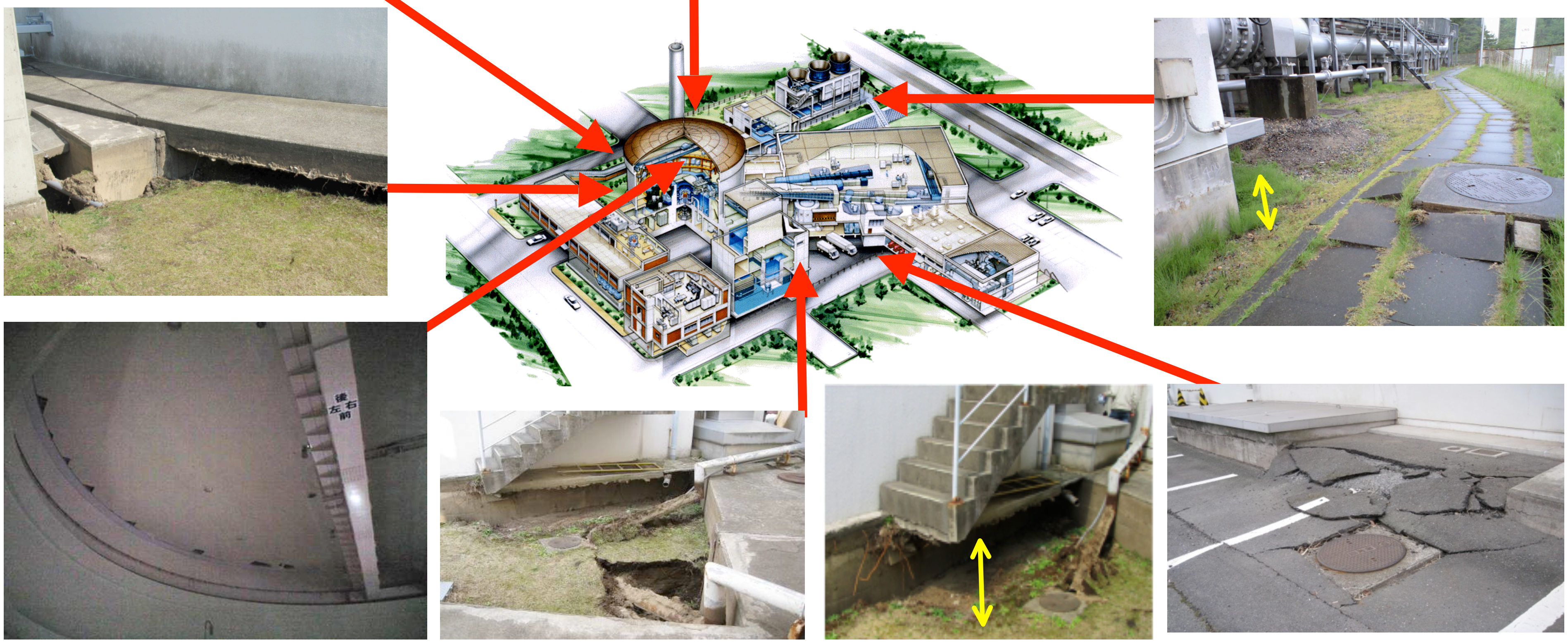


American Nuclear Society
Nuclear Historic Landmark
Award August 2007

Damage in JRR-3

JRR-3 was in its regular maintenance period planned, when the earthquake hit. The reactor building with their solid foundations survived without serious damage and no radioactive leakage has been occurred. But the ground near buildings moved and sunk considerably.

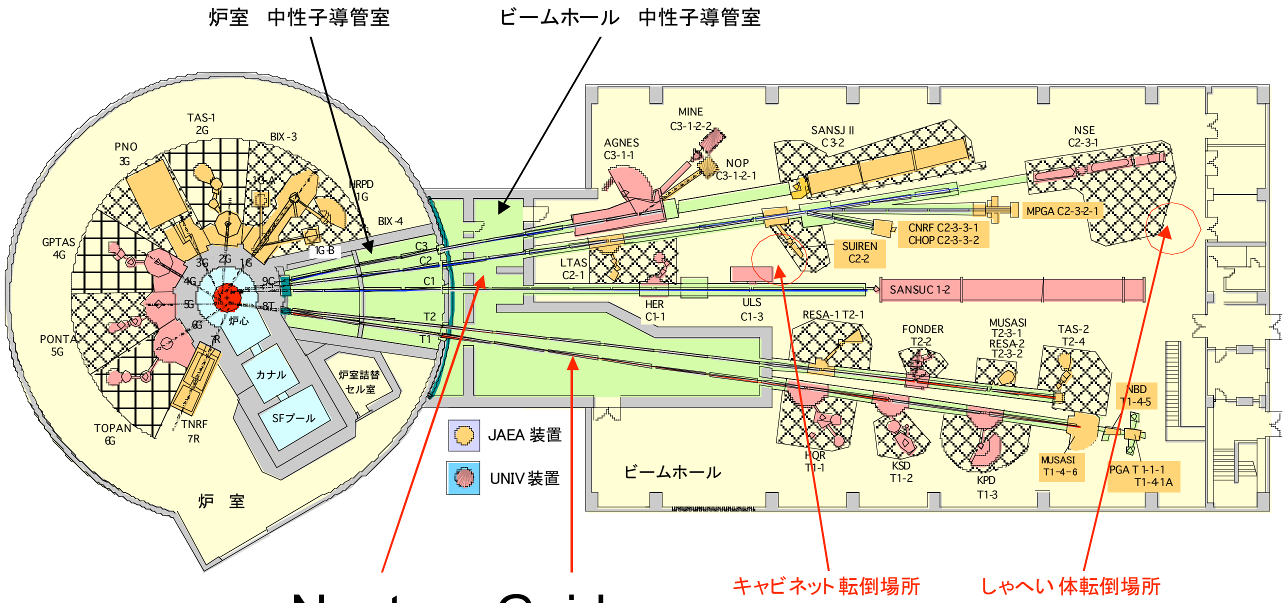
Exhaust air duct



Roof of reactor building

Ground subsidence

Damage of instruments is negligible.



Guide Hall

No Serious Damage

In a mess as usual !

Neutron Guide

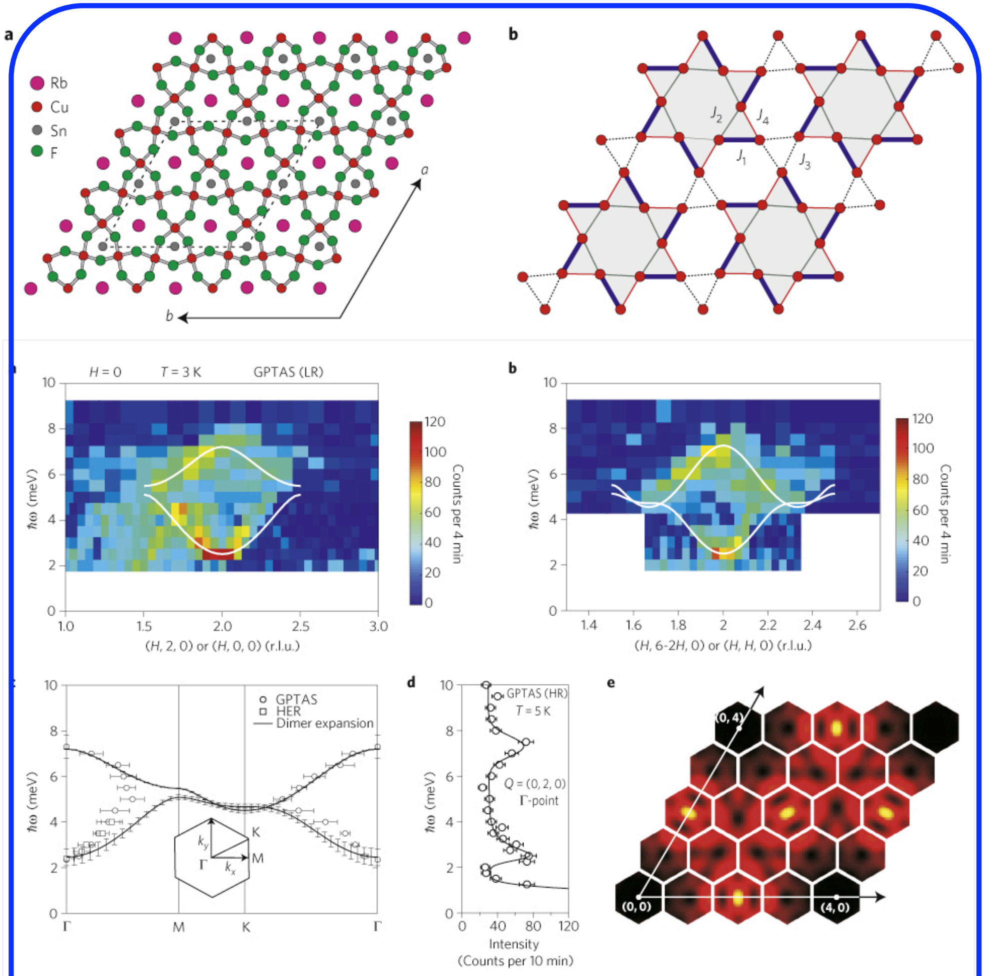
No mechanical damage,
No vacuum leak
Slight misalignment (≲1mm)

Cabinet fall down

Shielding fall down

Users are looking forward to safe re-start of JRR-3 in the earliest schedule (not officially announced)

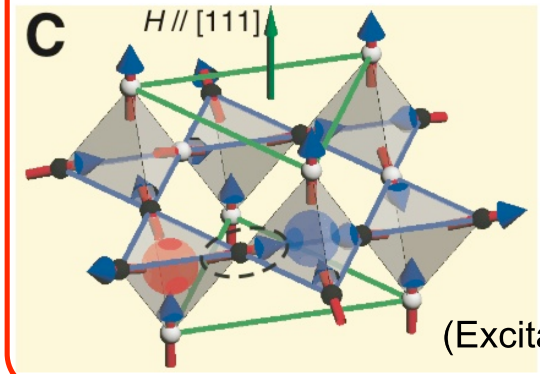
Scientific Highlight from Japan: Dynamics



Pinwheel valence-bond solid and
triplet excitations in the frustrated magnet.

K. Matan *et al.*, Nature Physics 6, 865–869 (2010)

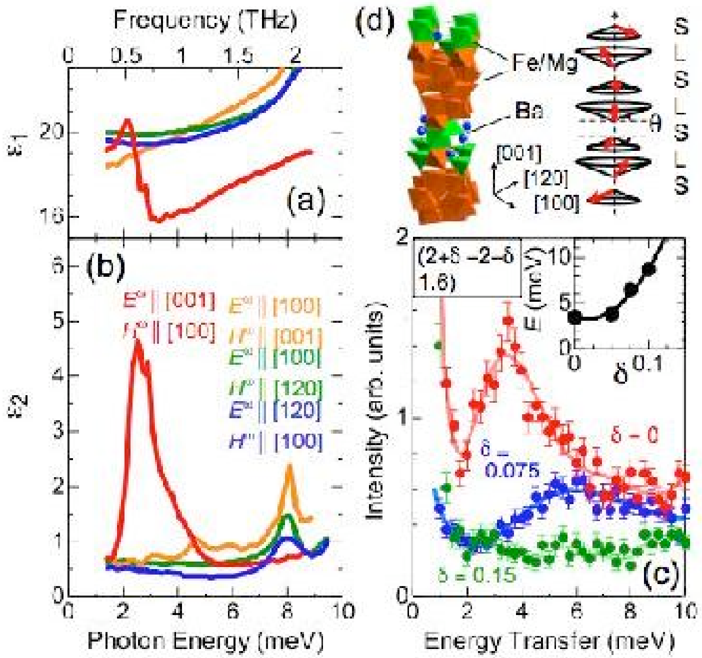
Magnetic Monopole in spin-ice



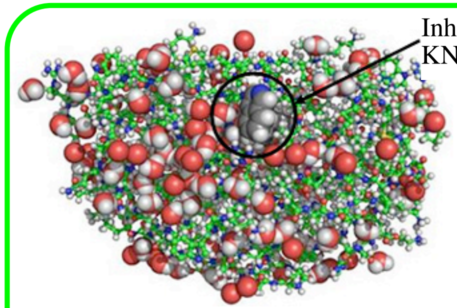
(Excitation is equivalent.)

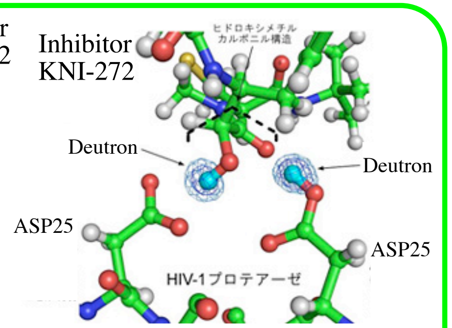
H. Kadowaki *et al.*,
JPSJ 78 (2009) 103706

Multi-ferroic compounds



Scientific Highlight from Japan: Structure

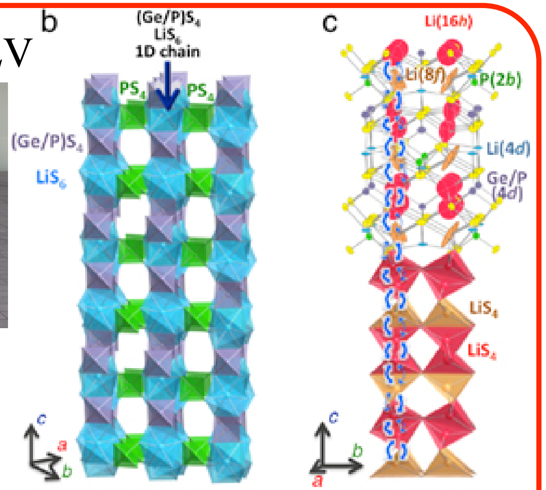




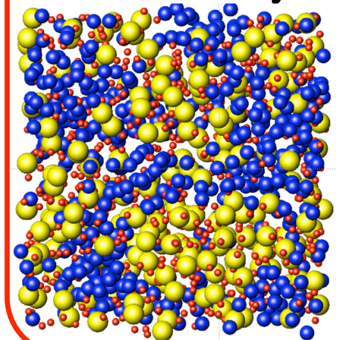
HIV-1 protease become inactive.
hydrogen bonding of inhibitor

Save children by neutron structural biology.

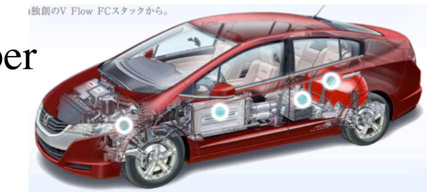
Li-ion battery for EV



Fuel battery

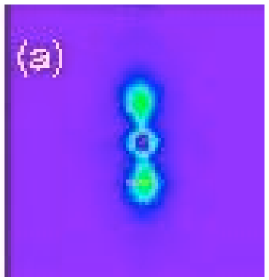


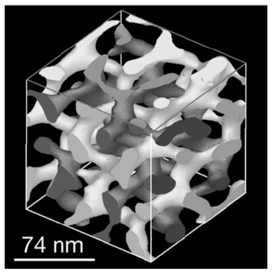
H absorber

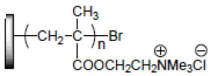


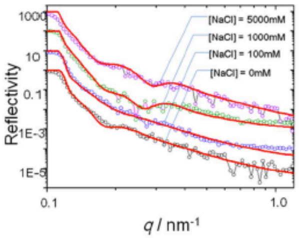
Save the earth by neutron

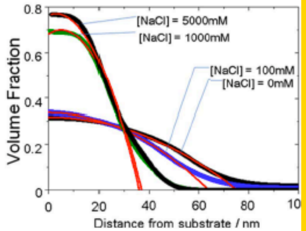
Soft matter study by SANS
Surface & interface

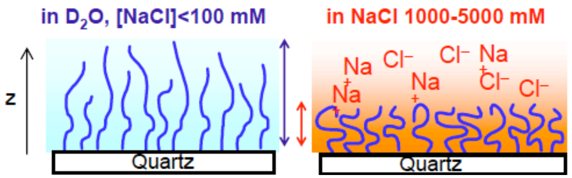








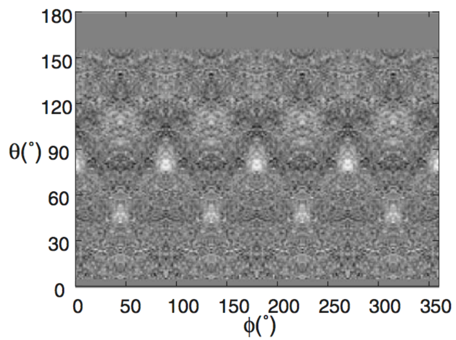




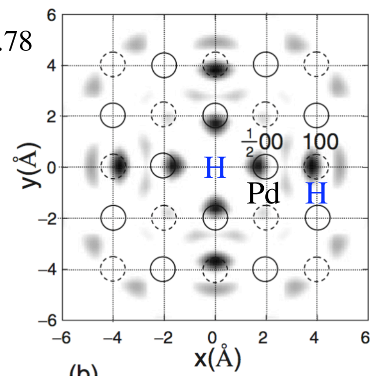
Polymer brush

Neutron holography started in Japan

Raw data

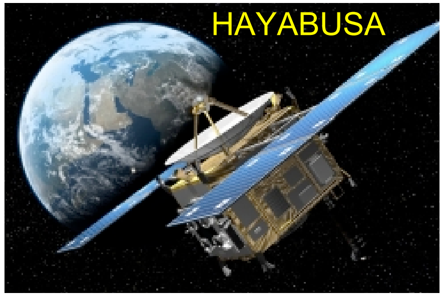


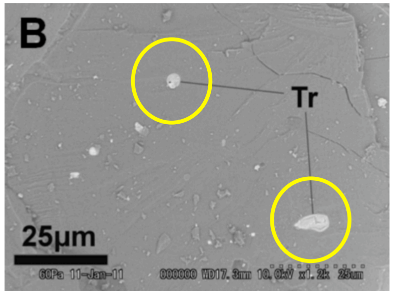
$PdH_{0.78}$



Scientific Highlight from Japan:

Neutron Activation Analysis of a particle from Asteroid Itokawa.



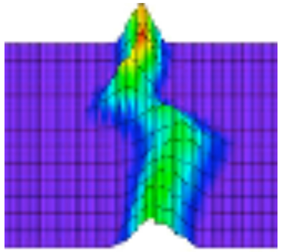


Element	Itokawa No. 49-1	Itokawa No. 49-2	Upper continental crust*	Olivine in ordinary chondrite†
Na (ng)	2.14 ± 0.07	1.56 ± 0.08	N/A	N/A
Sc (ng)	0.0039 ± 0.0001	0.0040 ± 0.0001	N/A	N/A
Cr (ng)	0.061 ± 0.003	0.076 ± 0.002	N/A	N/A
Fe (ng)	347 ± 6	350 ± 6	N/A	N/A
Co (ng)	0.29 ± 0.01	0.23 ± 0.01	N/A	N/A
Ni (ng)	6.65 ± 0.16	5.33 ± 0.15	N/A	N/A
Zn (ng)	0.07 ± 0.02	0.067 ± 0.017	N/A	N/A
Se (ng)	<0.012	<0.013	N/A	N/A
Sm (ng)	<26	<48	N/A	N/A
Eu (ng)	<410	<410	N/A	N/A
Hf (ng)	<0.0022	<0.0025	N/A	N/A
Ir (pg)	0.031 ± 0.007	0.037 ± 0.012	N/A	N/A
Estimated mass (μg)	1.66	1.67	N/A	N/A
Na (ppm)	1290 ± 50	931 ± 48	24300	N/A
Sc (ppm)	2.3 ± 0.1	2.4 ± 0.1	14.0	2.1–8.7
Cr (ppm)	37 ± 2	45 ± 1	92	160–600
Fe (%)	20.9 ± 0.4	20.9 ± 0.4	3.92	14.17–20.79
Co (ppm)	176 ± 3	140 ± 3	17.3	7–47
Ni (%)	0.40 ± 0.01	0.32 ± 0.01	0.0047	0.010–0.029
Zn (ppm)	45 ± 12	40 ± 10	67	19–20
Se (ppm)	<7.2	<7.8	0.09	N/A
Sm (ppm)	<16	<29	4700	0.20–0.26
Eu (ppm)	<250	<250	1.0	0.03
Hf (ppm)	<1.3	<1.5	5.3	N/A
Ir (ppb)	19 ± 4	22 ± 7	0.022	N/A
Ni/Co	23 ± 1	23 ± 1	2.7	5.5–14.3
Fe/Sc	86000 ± 2700	84000 ± 3200	2800	24000–87000

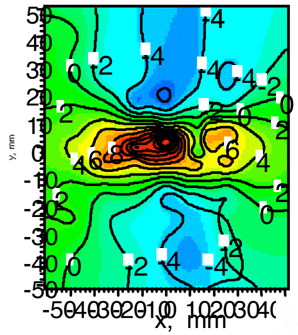
KUR M. Ebihara *et al.*, *Science* **333** (2011) 1119

Residual Stress Study

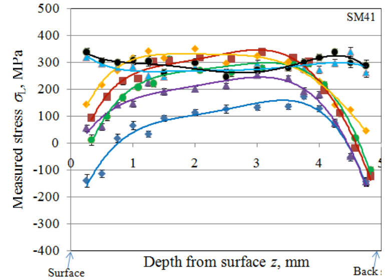
Turbine blade

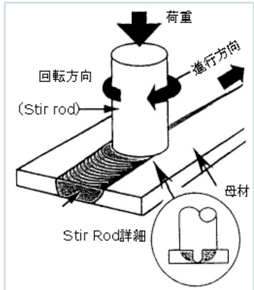


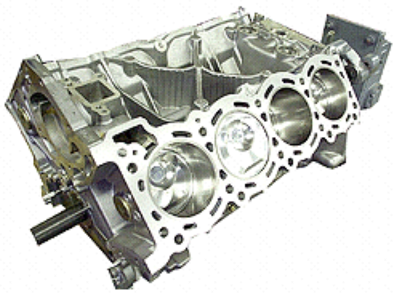
Welding



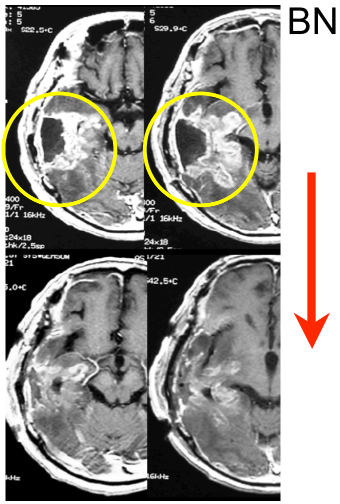
Engine



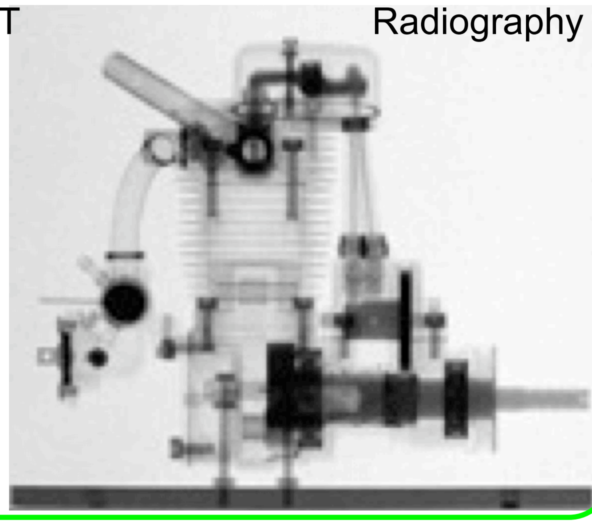




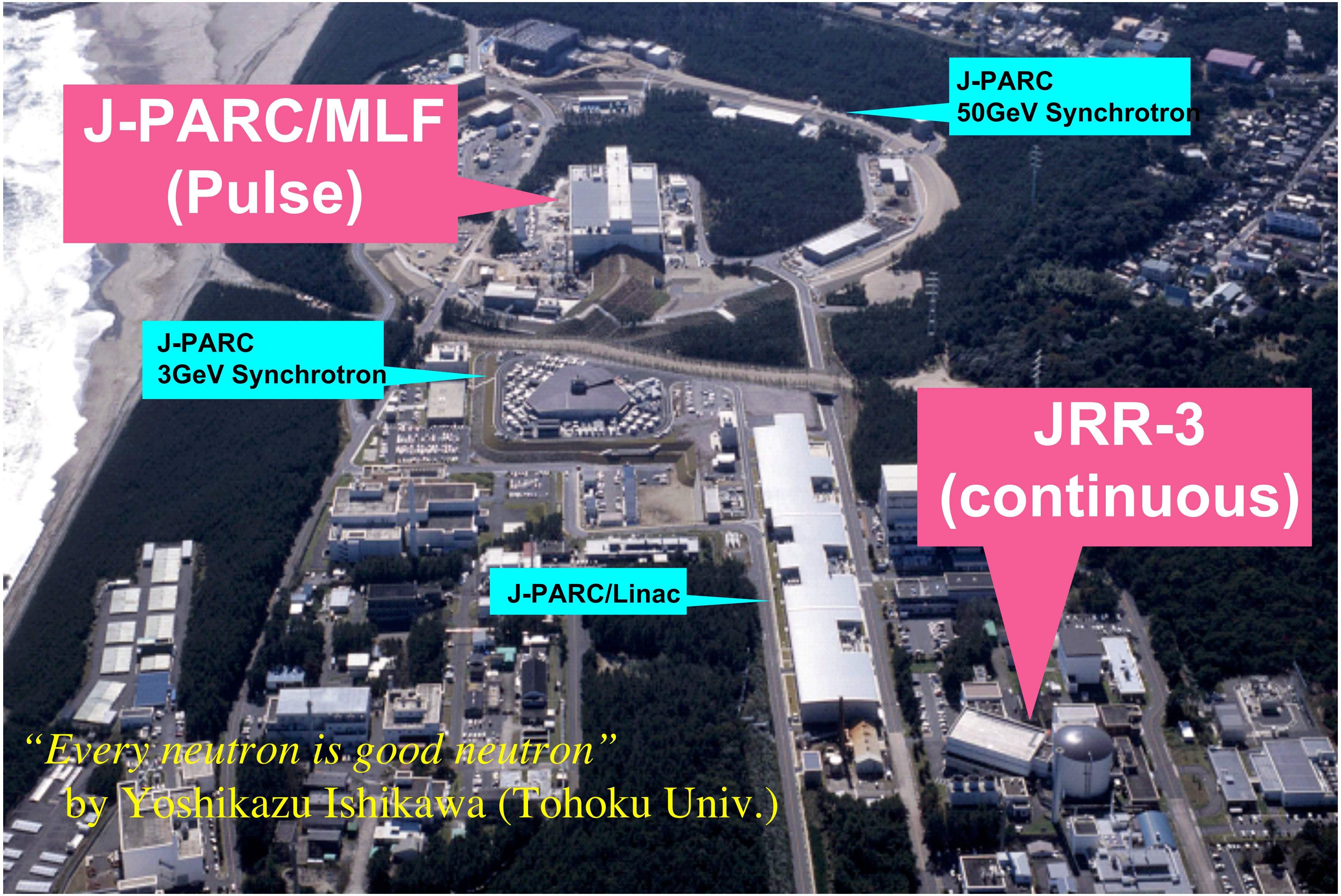
BNCT

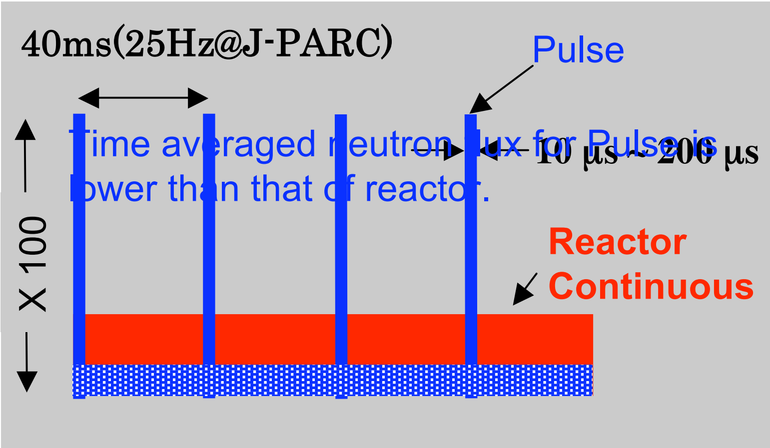


Radiography



Nuclear Science Research Institute



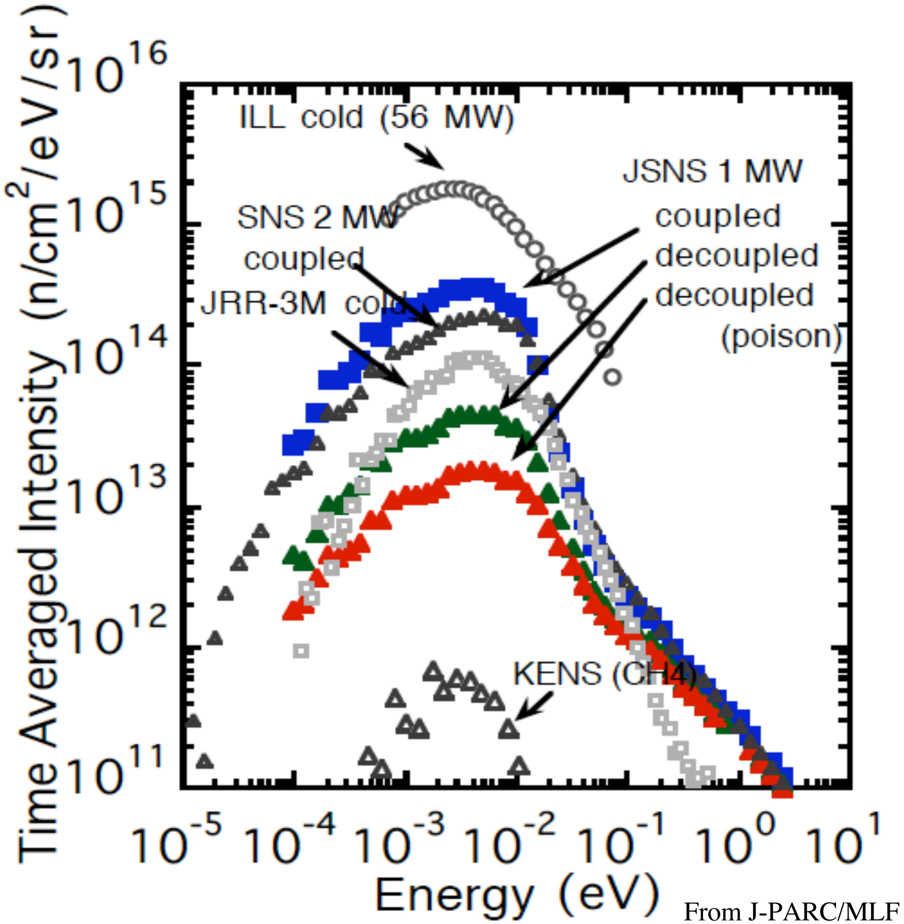


Reactor (continuous)

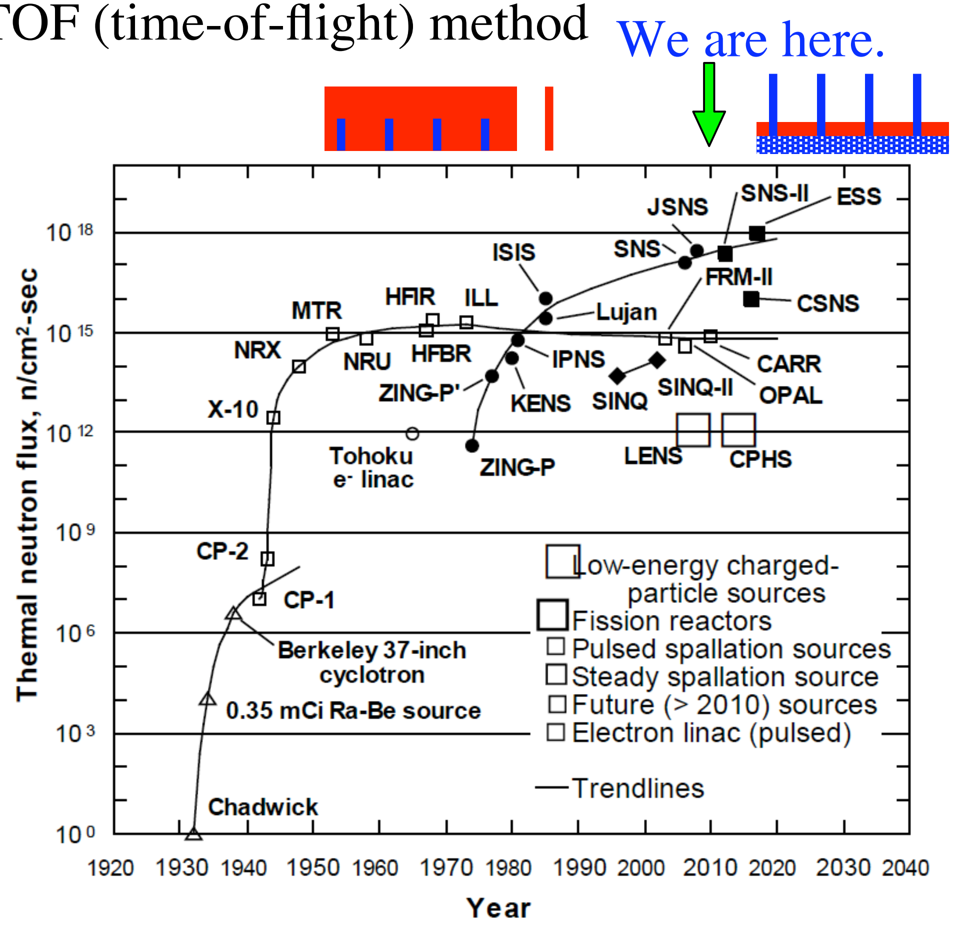
- Strong time-averaged flux, max. for mankind.
- Continuous beam (time-dependent phenomena)
- Monochromatic beam (optical devices, spin polarization analysis, simple correction)

Pulse (accelerator driven)

- Strong Peak flux overcomes time-averaged flux of research reactor very recently.
- TOF (time-of-flight) method



From J-PARC/MLF

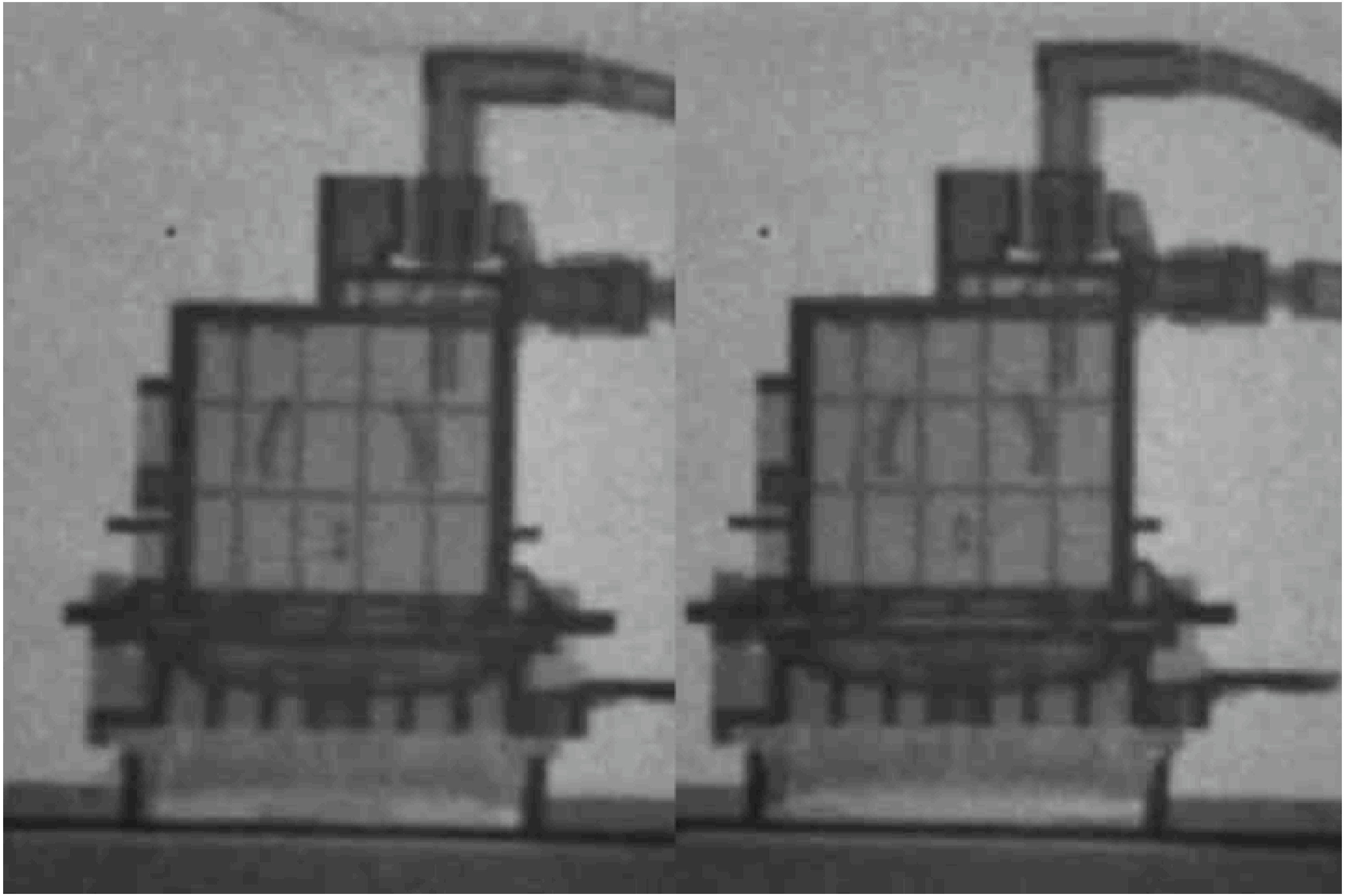


Japanese Society for Neutron Science (JSNS) reports

JRR-3 plays an important role in the fields of

(1) Dynamical neutron imaging.
(2) Small Angle Neutron Scattering.
(3) Inelastic & Spin polarization analysis.
(4) Neutron Activation Analysis, Nuclear Data.
(5) Instrumentation, development of new devices.
(6) Irradiation (NTD-Si, RI products).
(7) Education.

(1) Dynamical image: ink jet printer head (RICOH)



(2) Small Angle Neutron Scattering Instruments in Japan

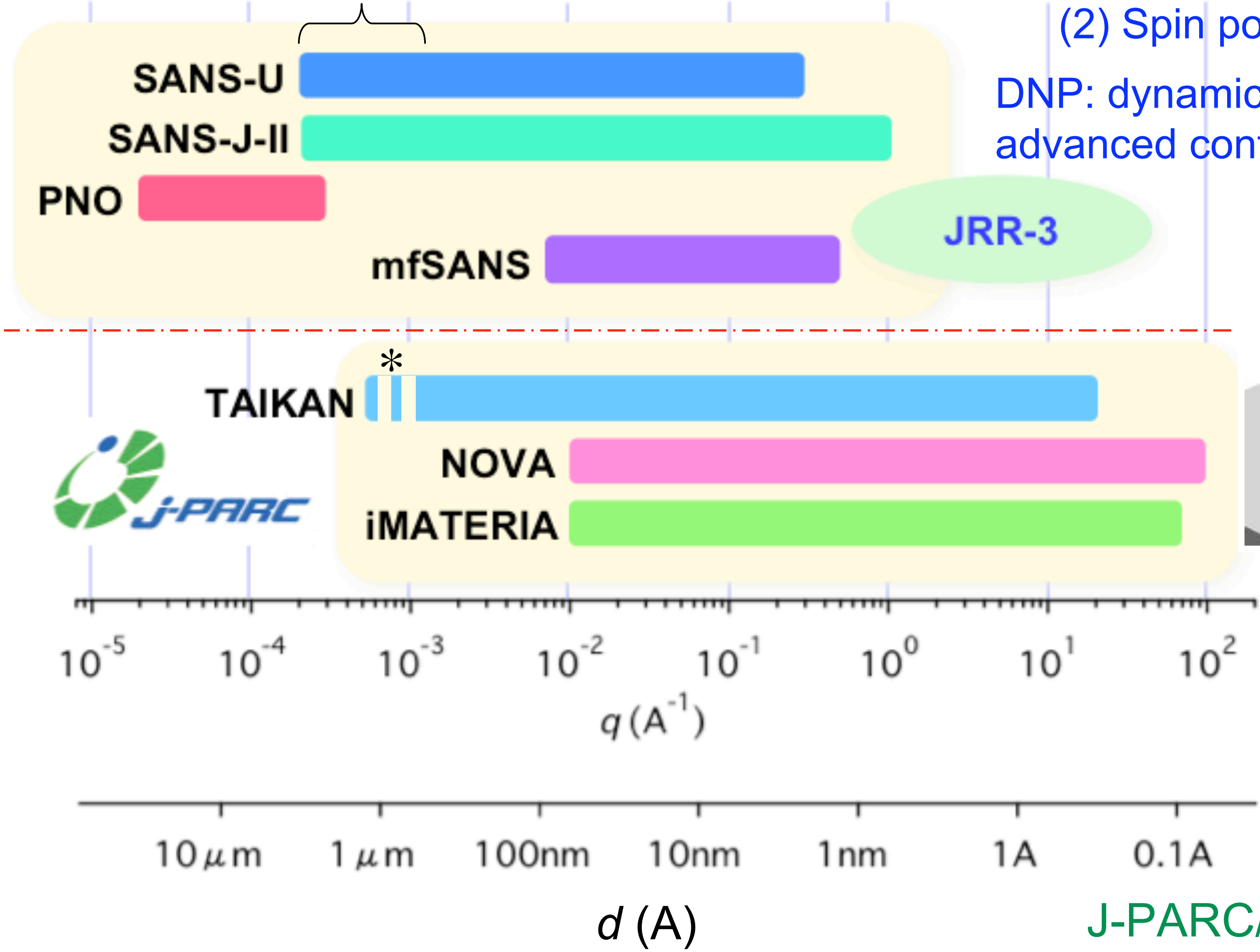
Only the longest wavelength contributes.
No remarkable gain with TOF.

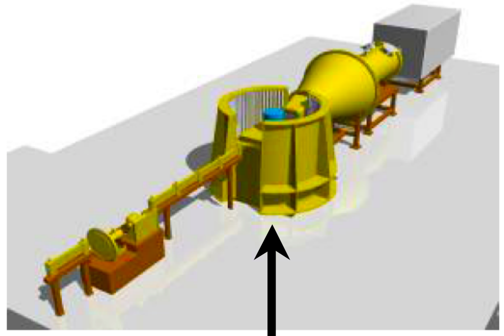
Monochromatic beam for JRR-3

(1) Data correction is easy.

(2) Spin polarization is easy.

DNP: dynamical nuclear polarization
advanced contrast variation method



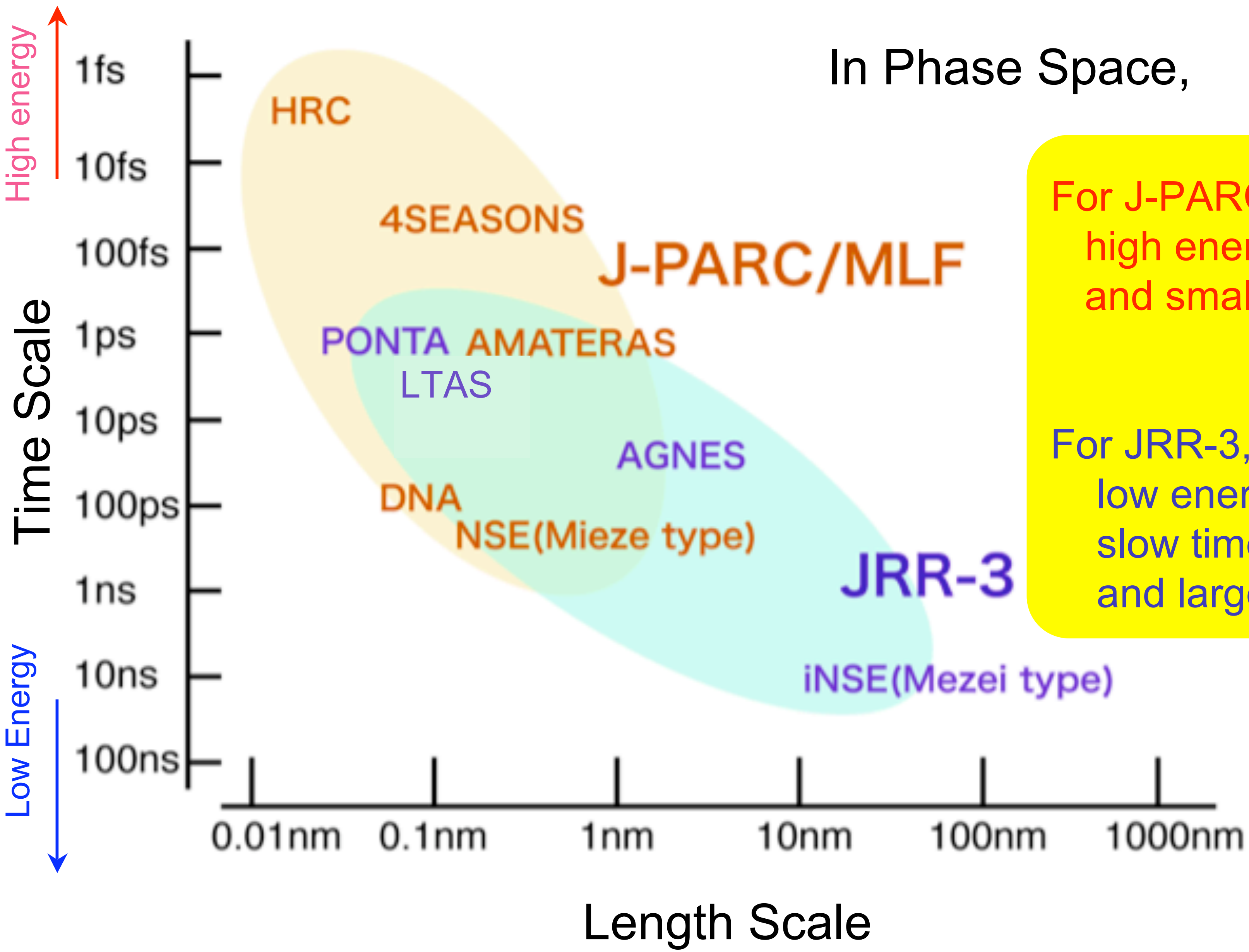


For high-q, wide angle detectors are installed for SANS in J-PARC

J-PARC/MLF
Effective for high-Q region.

* Available only with magnetic focusing device.

(3) Inelastic scattering instruments in Japan



In Phase Space,

For J-PARC/MLF, high energy, and small scale

For JRR-3, relatively low energy, slow time scale, and large scale

Japanese Society for Neutron Science (JSNS) reports

JRR-3 plays an important role in the fields of

(1) Dynamical neutron imaging.
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(3) Inelastic & Spin polarization analysis.
(4) Neutron Activation Analysis, Nuclear Data.
(5) Instrumentation, development of new devices.
(6) Irradiation (NTD-Si, RI products).
(7) Education.

Neutron source	Type	Beam character	Power, Time-averaged flux	Instruments	Location
JRR-3	Swimming pool + heavy-water reflector	Continuous	20 MW, $3x10^{14}$ n/ cm^2/ s for thermal	37 instruments	Tokai-Ibaraki
J-PARC /MLF	Spallation, Liquid hydrogen moderator	Short pulse 25 Hz,	1 MW, ~$3x10^{14}$n/cm^2/s /ev /srad (thermal, CM)	23 instruments	Tokai-Ibaraki
KUR	Swimming pool, Tank type	Continuous	5 MW, $3x10^{13}$ n/ cm^2/ s for thermal	8 instruments	Kumatori -Osaka
Hokudai Linac	Electron linac	Short pulse	45 MeV, 1 mA	3 beam lines	Sapporo-Hokkaido

Table 1 Neutron sources for beam experiments in Japan

Neutron facilities in Japan

1 middle size research reactor

1 large scale pulse source

1 small research reactor

1 small pulse source

	JRR-3		J-PARC/MLF	
Inelastic	Thermal TAS	7	Chopper	3
	Cold TAS	2	Inverse geometry	1
	Chopper	1		
	Spin echo	2	Spin echo	(1)
Elastic	Powder	3	Powder	2
	Diffraction	4	Diffraction	2
	SANS	3	SANS	1
	Double-crystal SANS	1	High pressure	1
	Reflectivity	2	Reflectivity	2
	Engineering	2	Engineering	1
Imaging	Thermal	1	Planning	
	Cold	1		
	Interferometer	1		
PGA	Thermal	1		
Others	Nuclear data+MPGA	1	Nuclear data	1
	Neutron beta decay	1	Optics & fundamental	1
	Test beam port	4	Test beam port	1
Irradiation	Reactor core	9		
	Heavy-water tank	8		
Total	(Beam instruments)	37		17

Table 2 List of the instruments at JRR-3 and J-PARC/MLF

Complementary use of J-PARC/MLF & JRR-3 is highly effective to maximize the output from neutron science in Japan.

The number and type of instruments of JRR-3 should be reconsidered for the next generation neutron science.

Conclusion

1. A big earthquake hit research reactors in Tokai, Oarai, Japan. Fortunately the damage of JRR-3 was small. Users are looking forward to safe re-start in the earliest schedule.
2. Complimentary use of JRR-3 (continuous) and J-PARC/MLF (pulse) is important to maximize the output in the field of neutron science.
3. We strongly recognize the importance of safety once again after the earthquake. The important role of research reactor as a neutron source and its safe management should be established.
4. Operation of research reactor should not give any risk, which is absolutely not acceptable.