RIKEN accelerator-driven compact neutron source RANS

-RIKEN Accelerator-driven compact Neutron Source

Yoshie OTAKE RAP, RIKEN JCANS collaboration
Y.Yamagata, A.Taketani, Y.Ikeda, M.Takamura・・
H.Suzuki(JAEA), M.Kumagai(Tokyo city Univ.) et al

5th UCANS @padova

Contents

- Aspects of RANS
- Target after 2 years use **←Long life Dr. Y.Yamagata's**
- Recent application results
  - 3D imaging of corrosion and water in the steel plate
  - Texture change, and dual phase observation with neutron diffraction experiment(Y.Ikeda's presentation)
  - Fast neutron imaging for the social infrastructure NDI
- The subjects we are now planning to develop in two years

RANS project goals：CANS for practical use

- Compact neutron source system easy and handy to use
  - –floor-standing type
    - – industrial use,
      - non-destructive inspection
      - industrial material development analysis,
  - –Educational use, and so on.

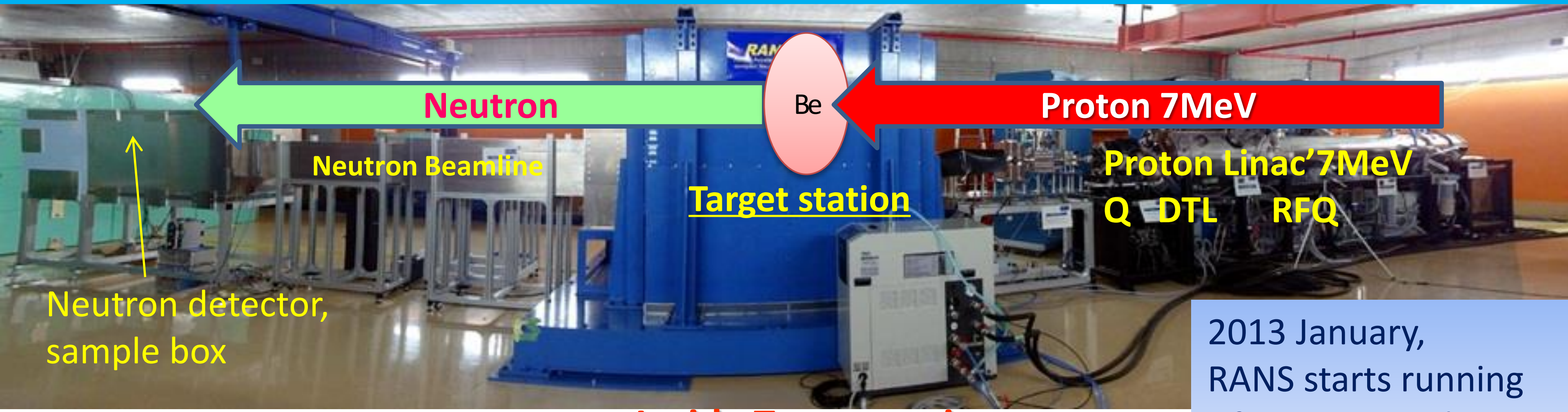
RANS-RIKEN Accelerator-driven compact Neutron Source

- Transportable non-destructive inspection of large scale bridges

Fast neutron large area imaging system

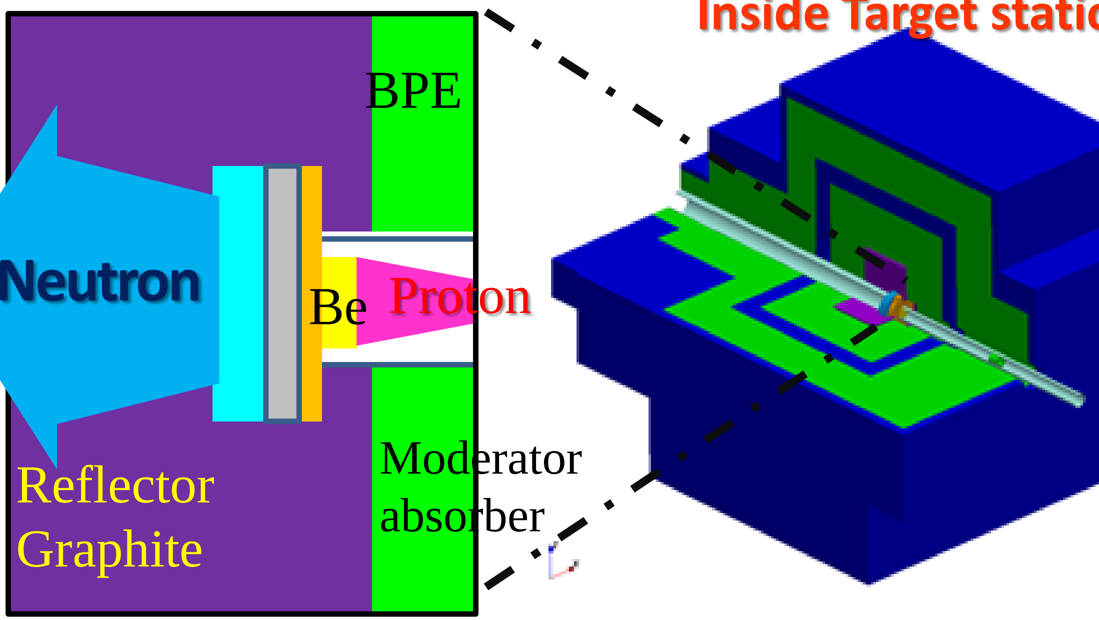
Transportable X-ray instrument for bridges
Prof.M.UESAKA
(Univ.Tokyo) 3.95MeV
X-band e-linac

RANS compact Neutron source for **realization of practical use**, and development of **trans-portable** instrument for infrastructure safety



2013 January,
RANS starts running
After ten month
construction.

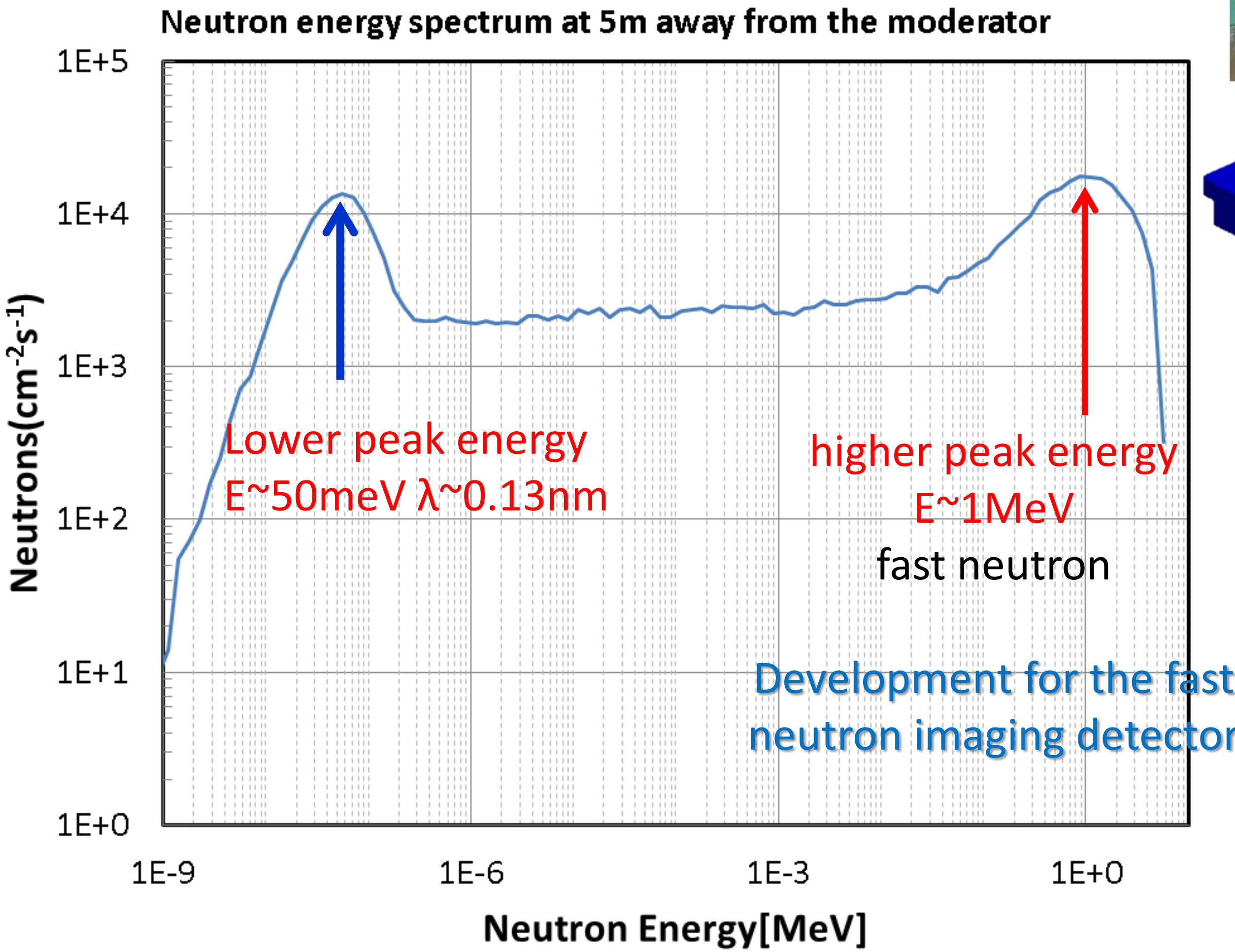
Inside Target station

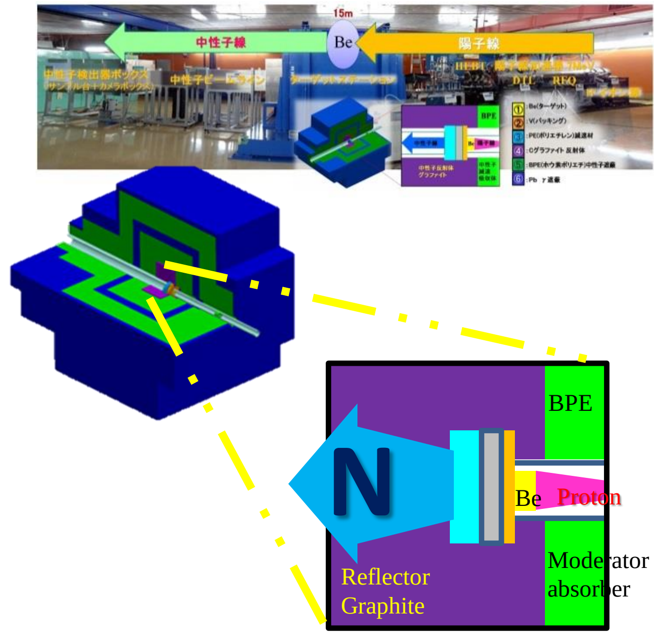


① : Be(Target)
② : V(backing) Hydrogen diffusion
③ : PE(polyethylene)Moderator
④ : C(graphite) Reflector
⑤ : BPE(Boron PE)Neutron Shielding
⑥ : Pb γ-ray shielding

RANS’ neutron spectrum (PHITS simulation)

@ maximum averaged current 100μA





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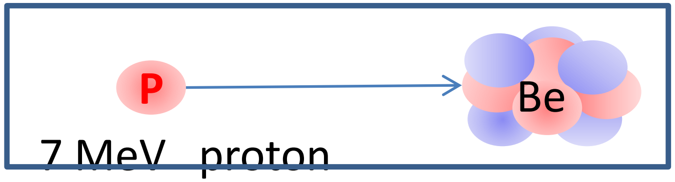
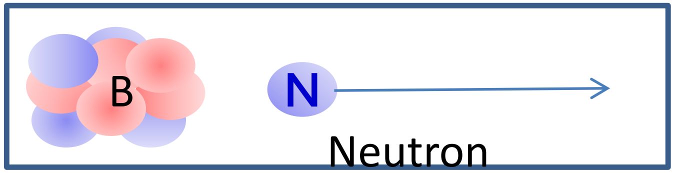
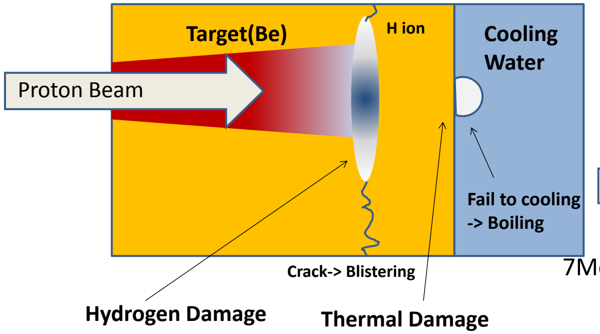
Long life Be(p,n) target   Yutaka Yamagata RIKEN



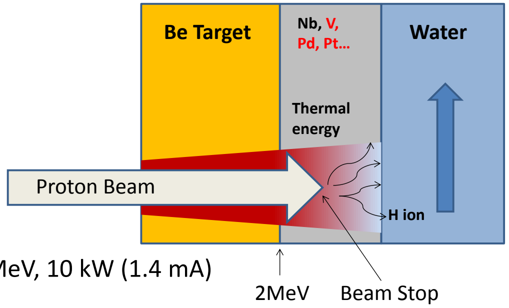


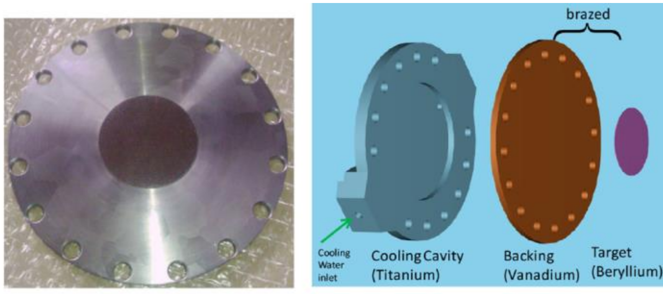
↓V backing +Be

- Be(p,n) reaction seems to be ideal for low energy neutron source, while major problem in Be target is the **blistering (hydrogen embrittlement damage)** of target caused by low energy proton beam.
- We proposed a new structure target with backing of highly hydrogen diffusible material.
- The performance estimation and design was done by using ion injection simulation (SRIM), and finite element simulation (hydrogen diffusion, thermo-fluid analysis, structural analysis).
- We expect that the newly-designed target has life time more than several thousand hours.



Target destruction by blistering





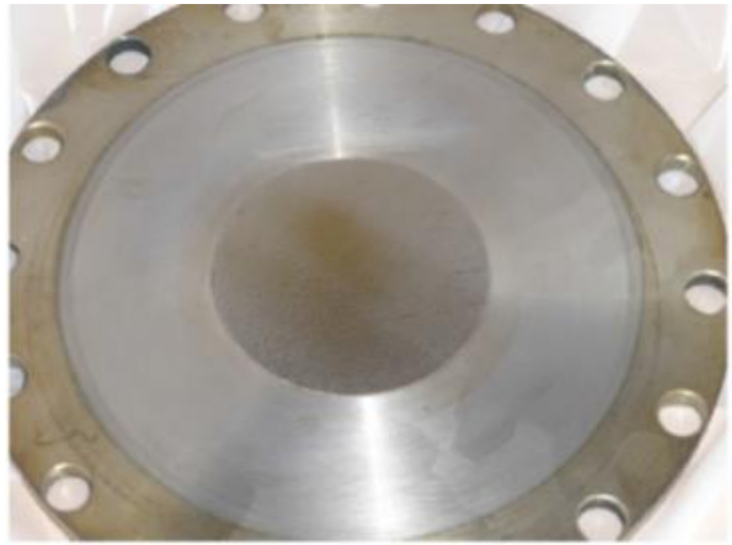
(a) Beryllium brazed target (b) Structure of target and cooling cavi

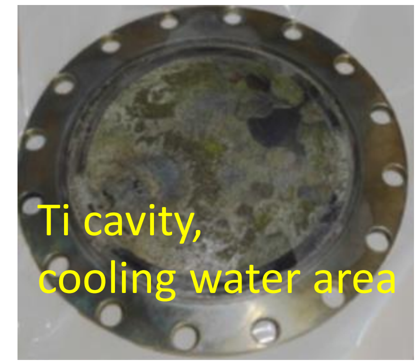
Patent PCT/HP2013/056188

After 1 year Be(p,n) target Yutaka Yamagata RIKEN

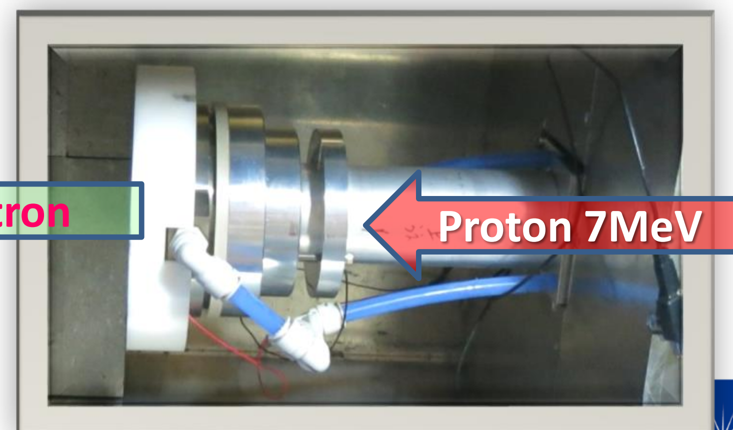
Fig. 10 Surface inspection of target after 1 year's use. No cracks or blistering can be observed on beryllium (*left*) while corrosion was observed on the cooling water side (*right*)

Picture taken in **Feb. of 2014 after about <u>3900μAh</u>**





<u>Y.Yamagata,</u> K.Hirota, J.Ju, S.Wang, S.Morita, J.Kato, Y.Otake, A.Taketani, Y.Seki, Y.Yamada, H.Ota, U.Bautista, Q.Jia
"Development of a neutron generating target for compact neutron soruces using low energy proton beams" Journal of Radioanalytical and Nuclear Chemistry
DOI 10.1007/s10967-015-4059-8



Compact neutron Application results for practical use.

A example of industrial use,

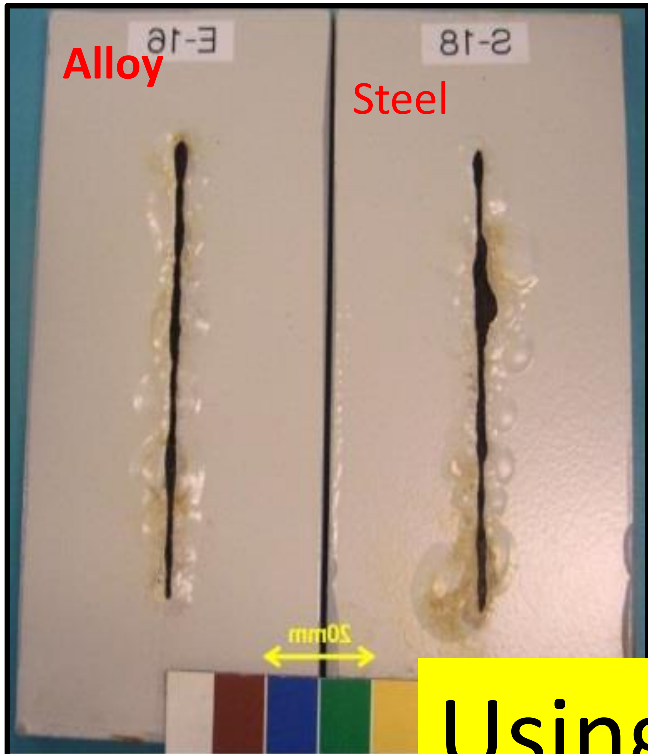
Steel

Compact neutron source is useful!!

Industrial application- Ion and steel

Corrosion Visualization

KOBELCO
Proposed by Dr. T . Nakayama



<u>Whether it is possible to visualize the steel corrosion under-film?</u>

- base material is Fe
- What we should find is FeOOH, Fe_2O_3, Fe_3O_4
- Painting contains lot of H,

→It is impossible for X-ray to distinguish

al Fe

Using neutrons can we distinguish corrosion?

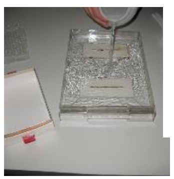
RANS imaging time~5~20 min.

Success of moisture reduction for hours

Dr.Taketani

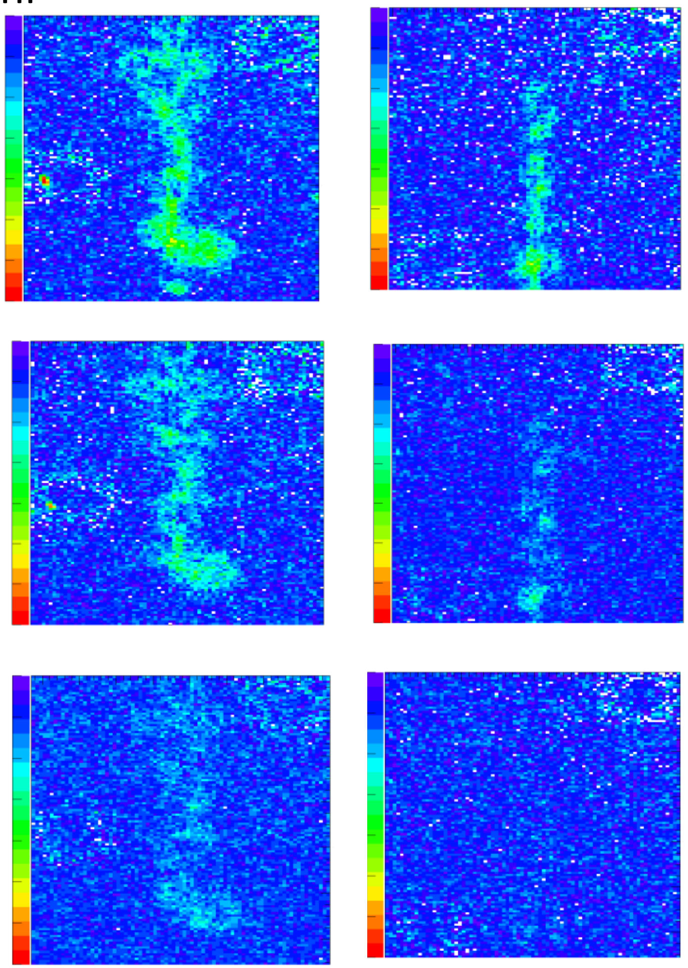
Steel alloy

wet



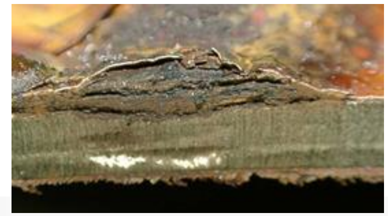
1 hour

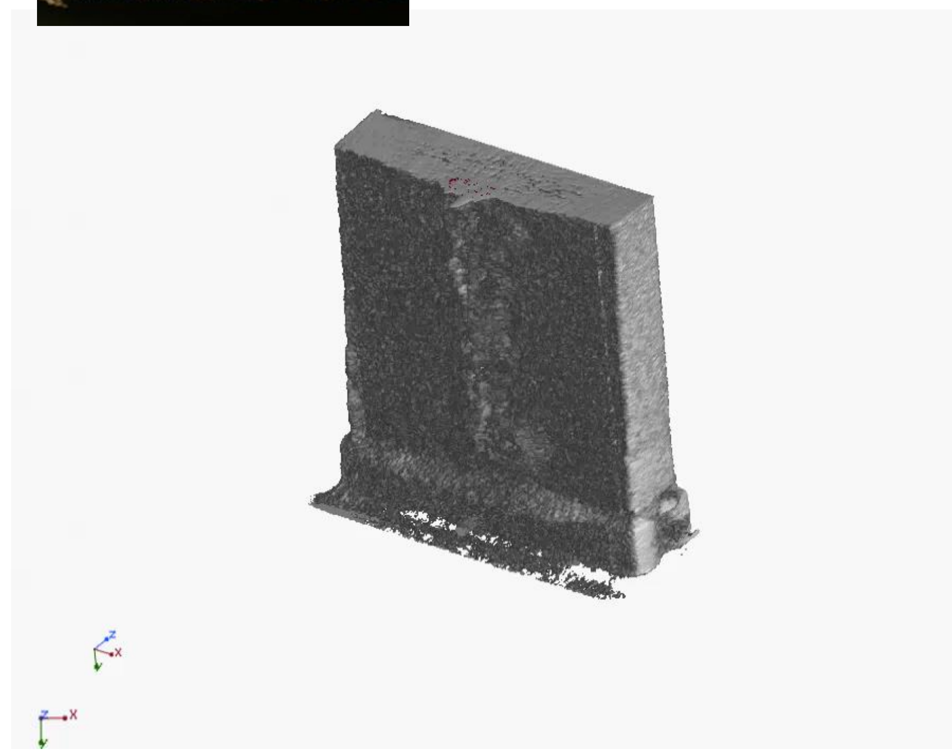
2 hours



3D information of the corrosion in the steel under-film

Corrosion with water





RANS explosure time~5 min per one shot.

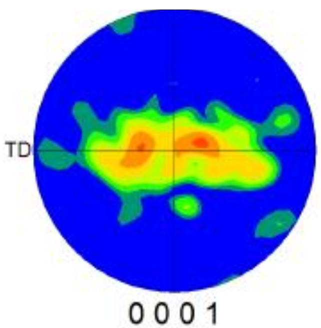
2.Metallographic observation, plastic forming process

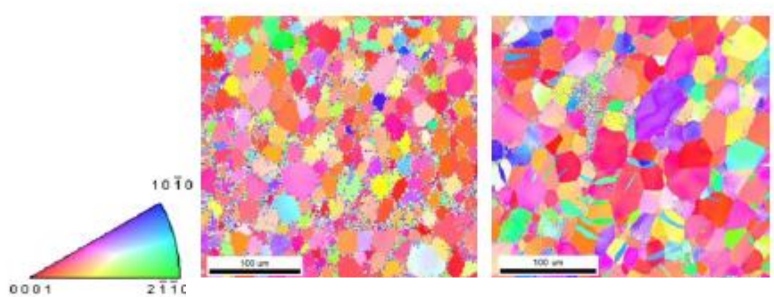
on 13th Y.Ikeda has presented

How about neutron diffraction with <u>compact neutron source</u>??

Pulsed neutron TOF measurement

Electron Back Scattering Diffraction Only surface information Pure Titanium (together with Prof. T.Hama Kyoto Univ)



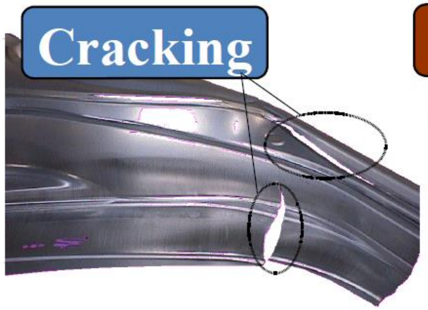


as received   After compression

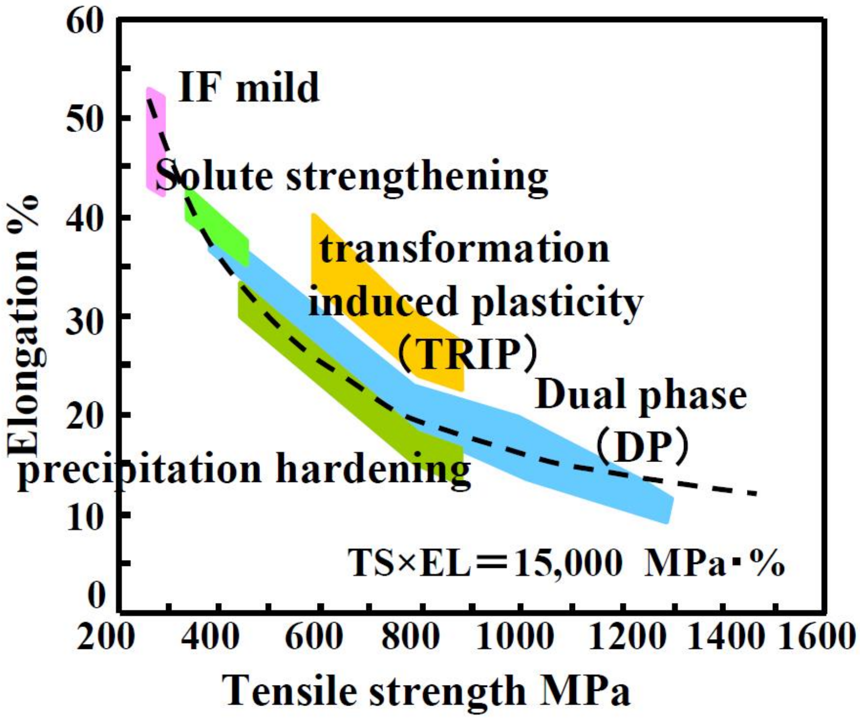
Lightweight solution of the materials with low cost are needed for the reduction of CO2, or energy problems…

Strength and Formability

- High-strength steel has a poor formability
  - Low forming limit or spring back in stamping operation



Formability and strength is in the inverse relationship



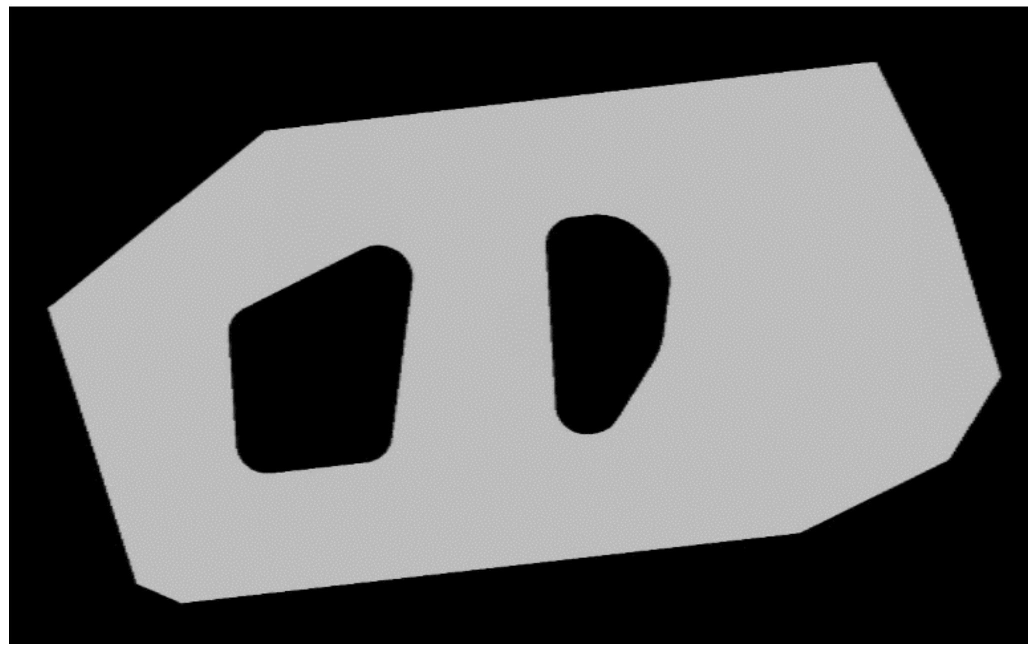
JSTP250th Dr. Ushio

Formability of metal;

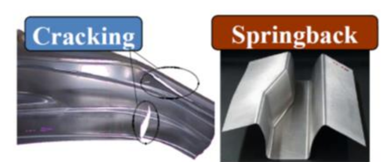
VCAD project
RIKEN 2001-2011
A. Makinouchi
M.Takamura,
H.Sunaga

RIKEN has the special Simulation technique : Body Side Outer Sheet metal forming simulation the largest parts

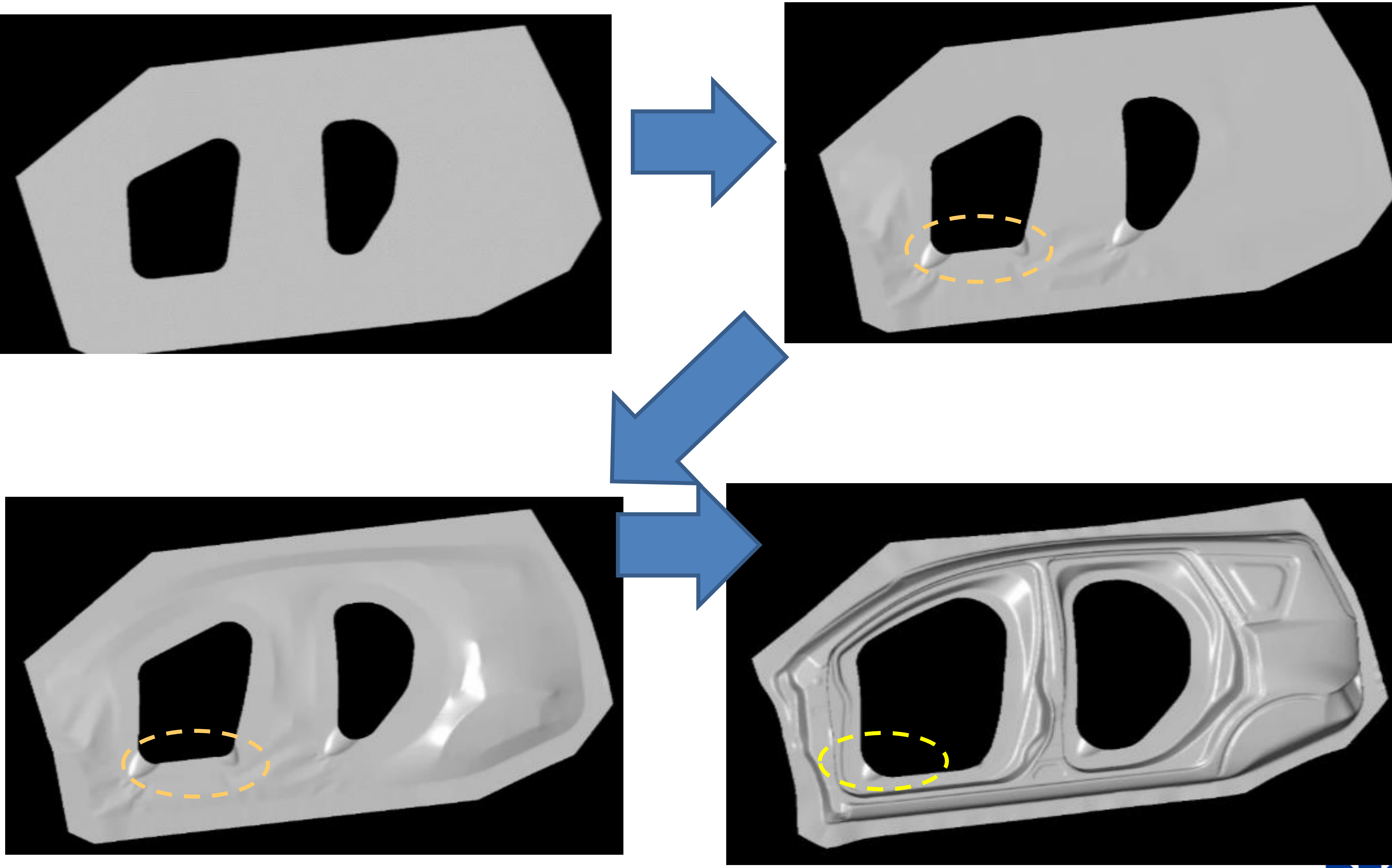
Body Side Outer



Plastic deformation under press process, to prevent racks, wrinkles, FEM analysis is useful tool.

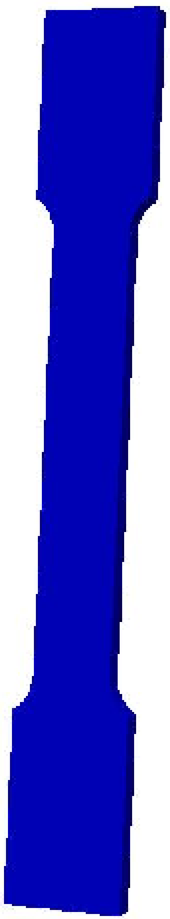


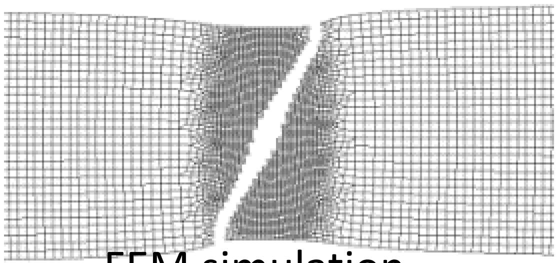
FEM simulation



Press forming process involves elongation and compression

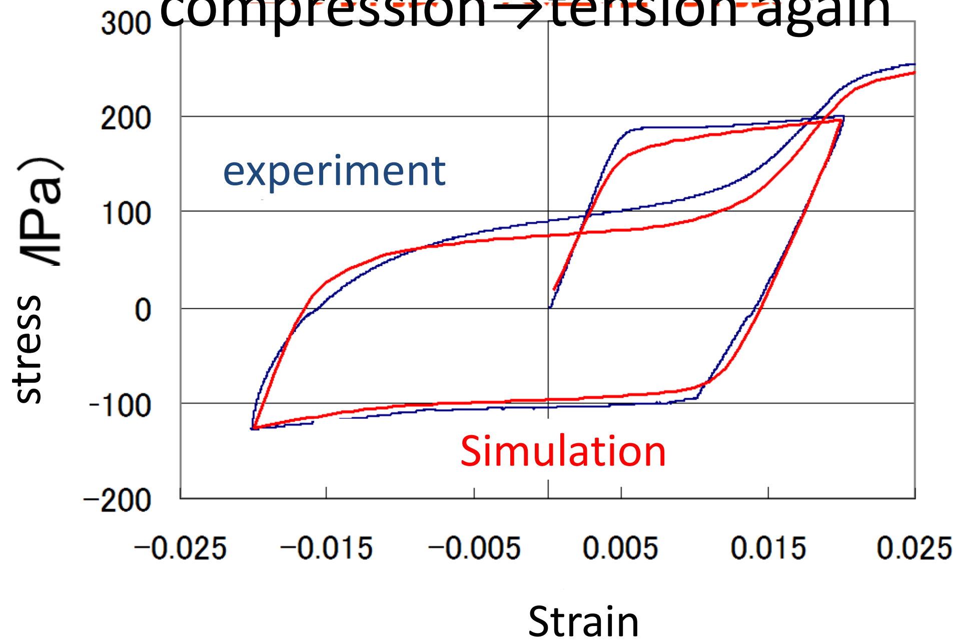
elongation, tensile test, stress-strain

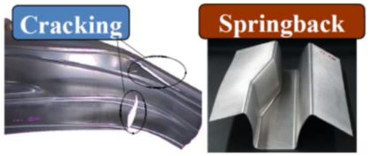




FEM simulation

2% tension→-4% compression→tension again





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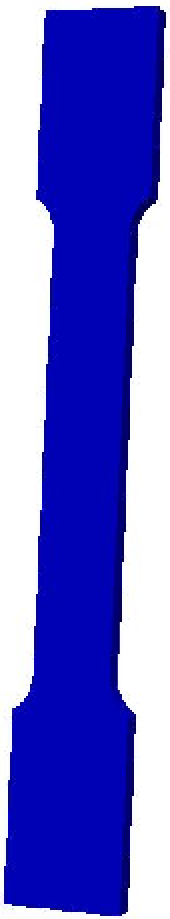
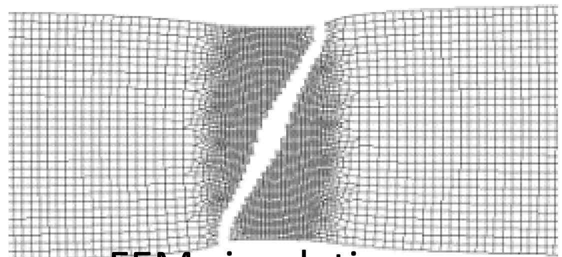
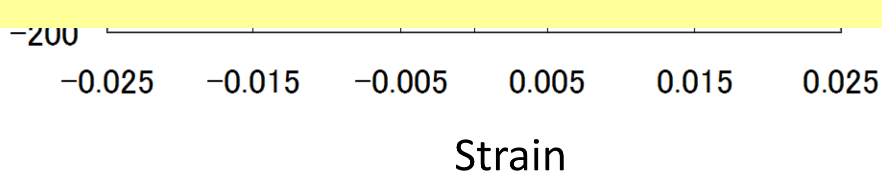




FEM simulation

Until now, we only introduce macroscopic mechanics in the simulation, to reach more realistic results, we need the mesoscopic information.

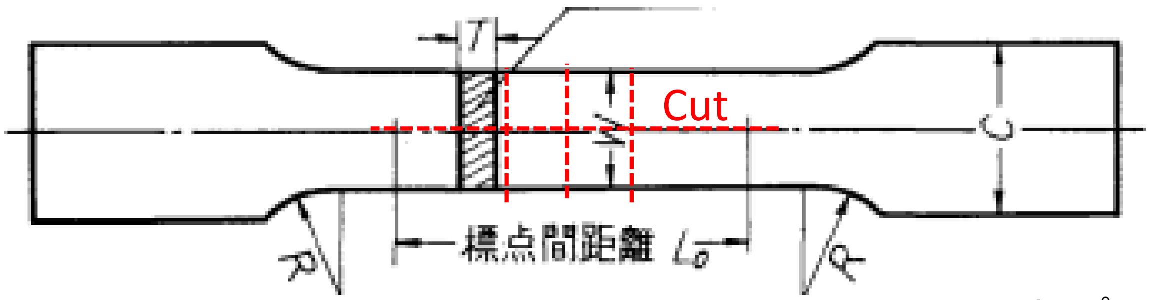
Bulk metal observation on site should be possible only with neutron beam



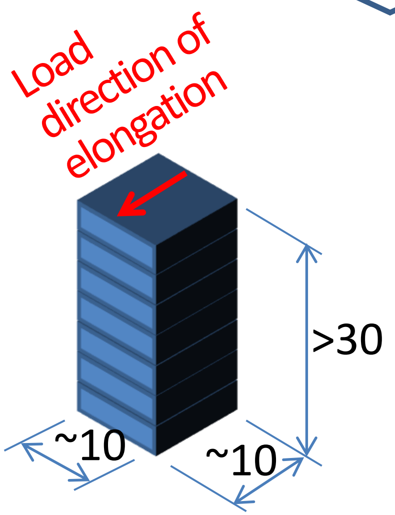
First trial experiment at RANS was done 30 31 July 2014

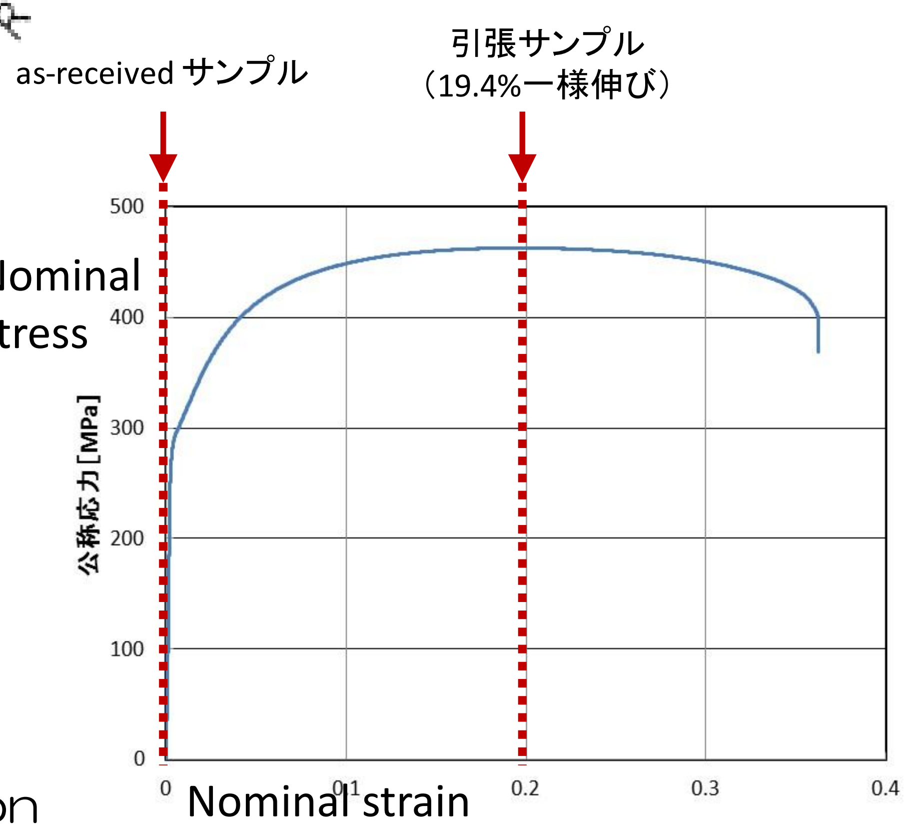
Sample with 19.4% elongation

引張試験片 JSC440W



W=30mm、t=1.2mm



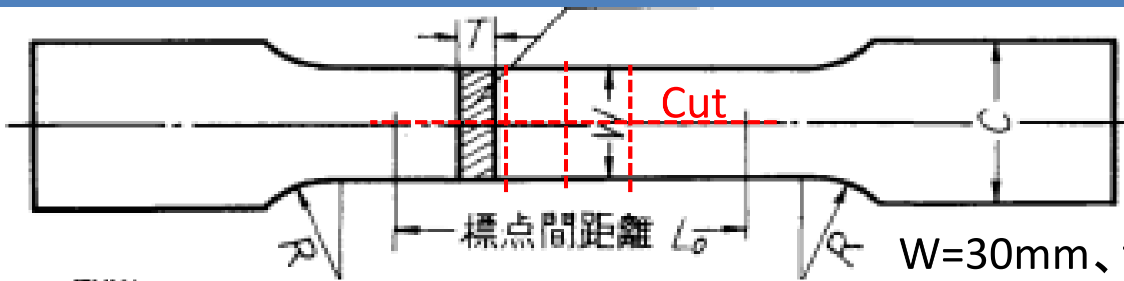


30 plates with the same direction

Stress-strain curve

Diffraction results by RANS： elongation

JAEA H.Suzuki,
RIKEN Takamura, Y.IKEDA

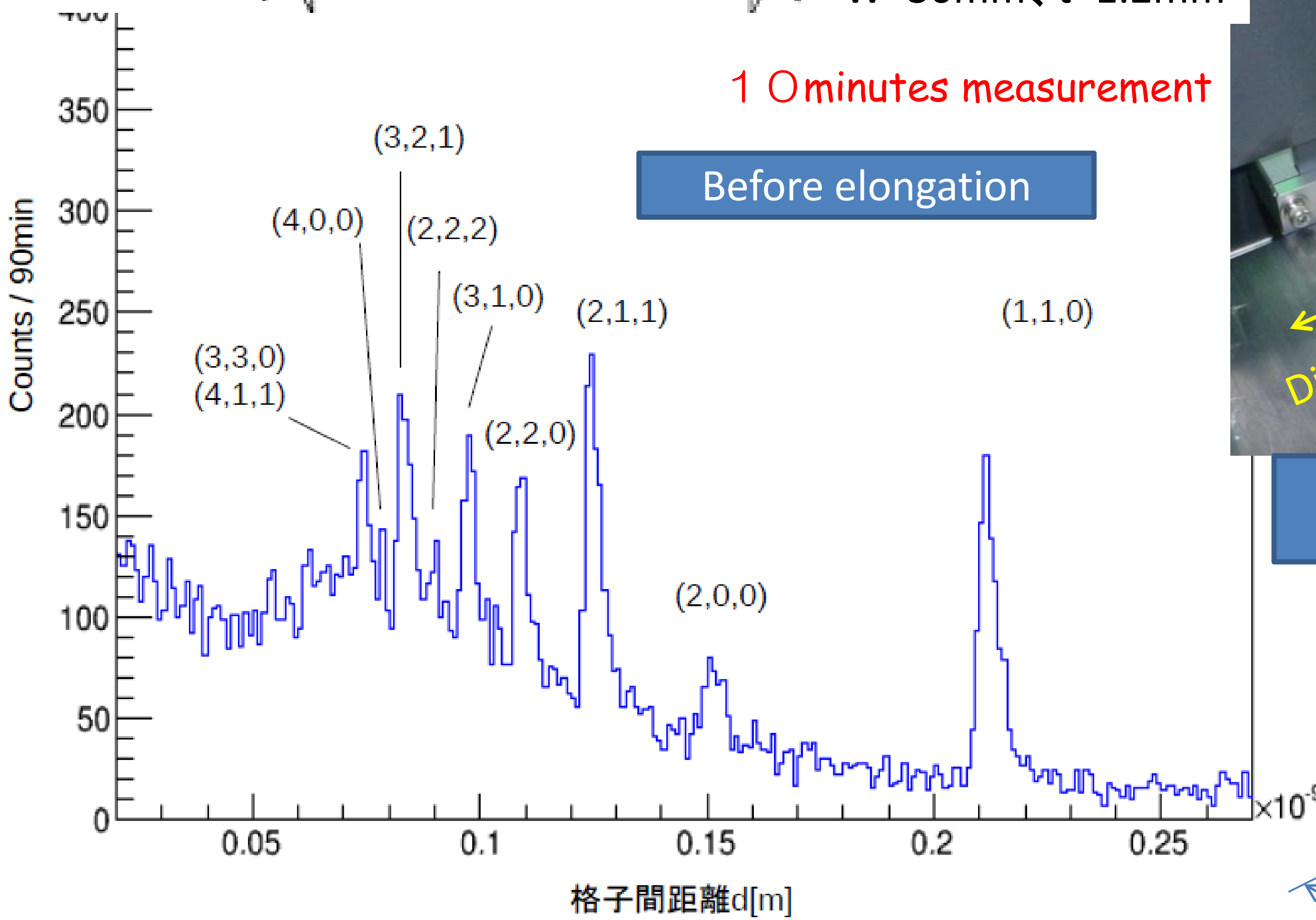


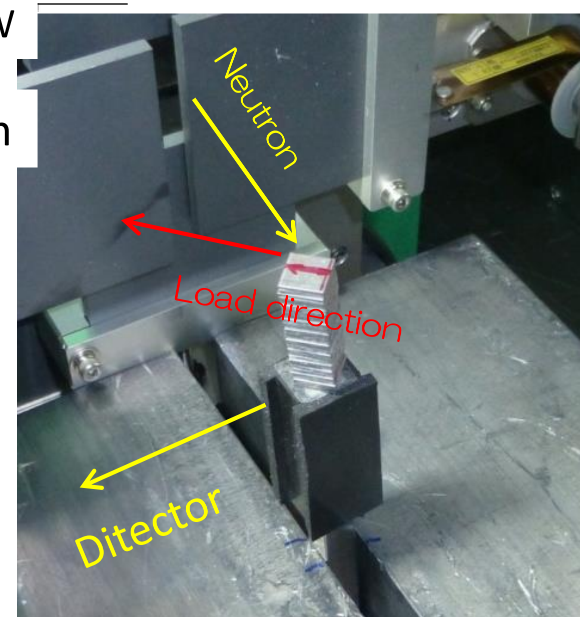
JSC440W

W=30mm、t=1.2mm

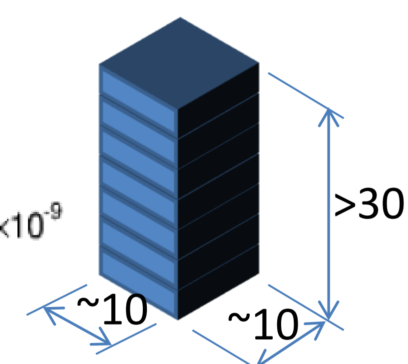
１０minutes measurement

Before elongation





BCC steel sample
JSC440W

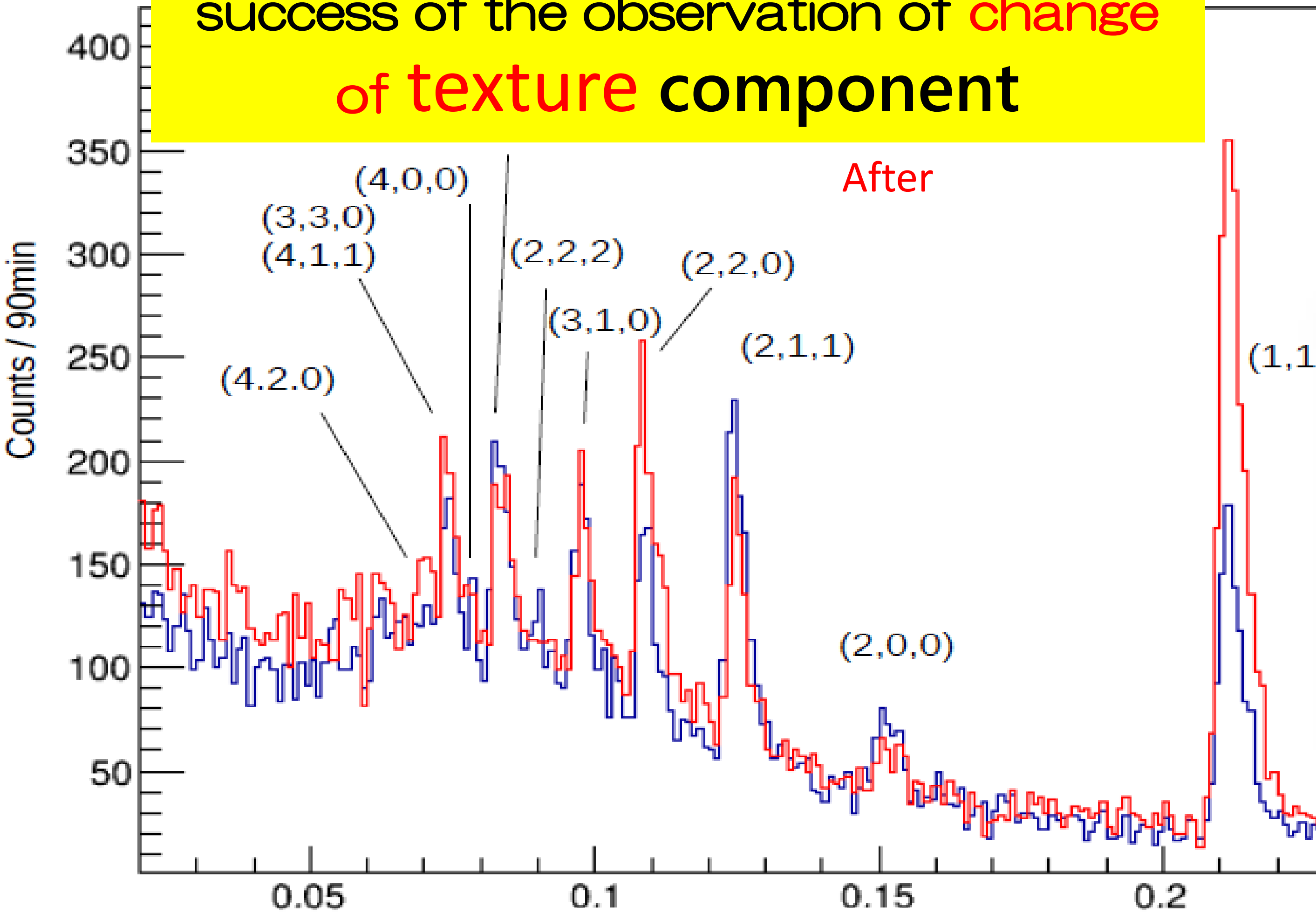


Success of the observation of texture @ RANS

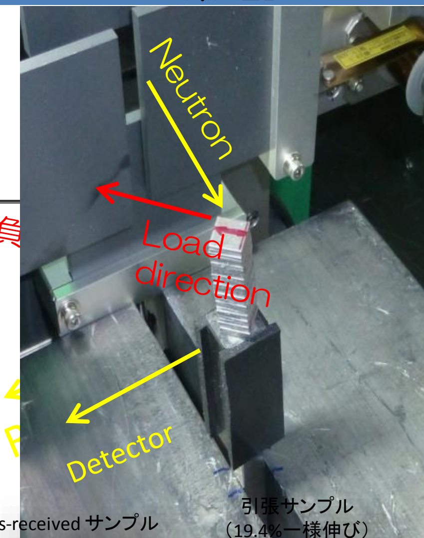
JAEA H. Suzuki,
RIKEN Takamura,
Y.IKEDA

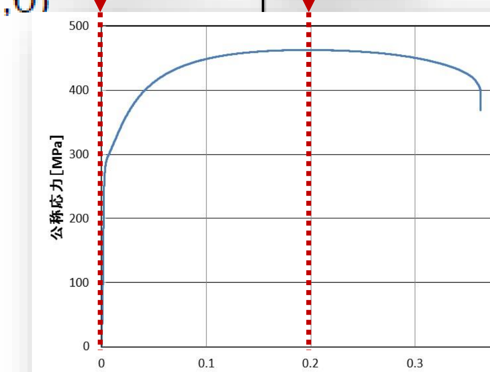
- As-receive（0%）rather strong orientation along (110)
- Under elongation along 110 orientation

success of the observation of change of texture component



Lattice constant [nm]



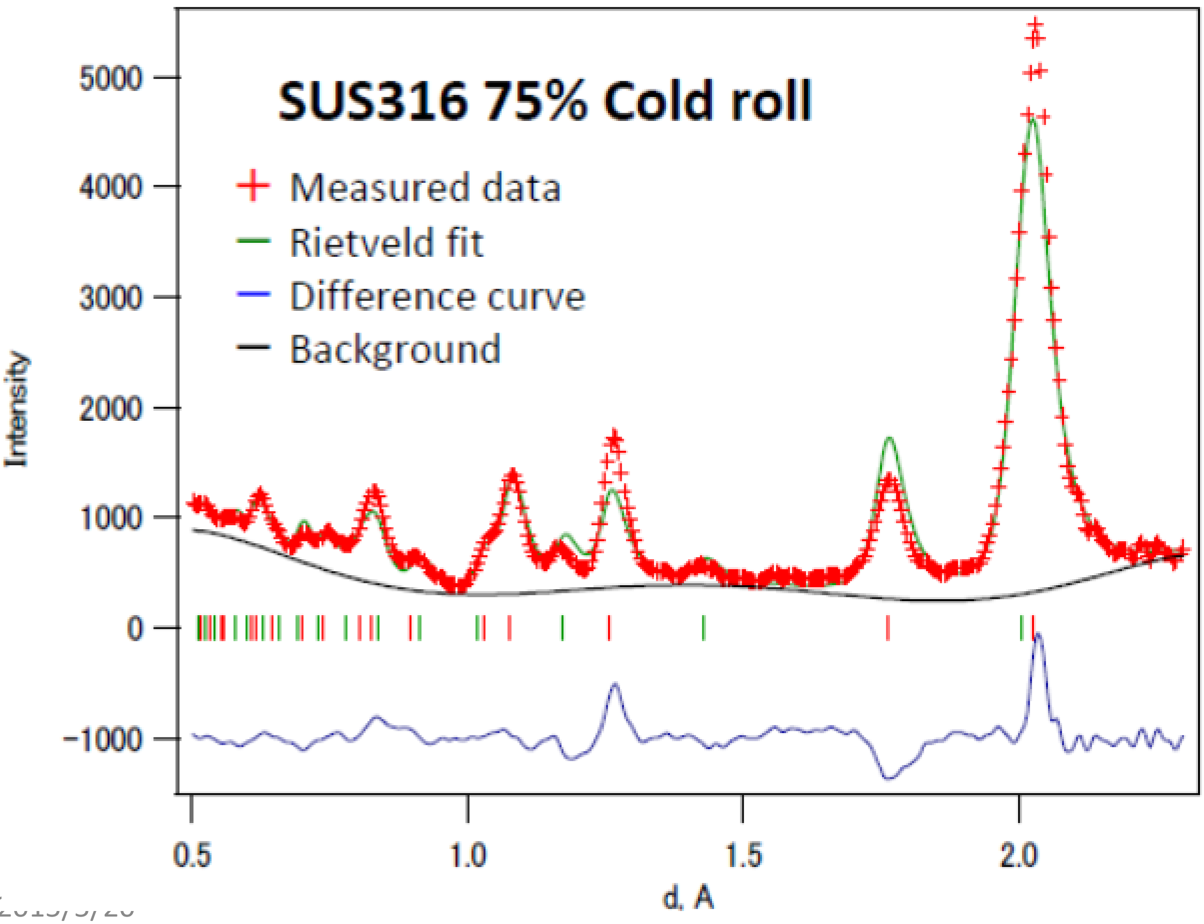


Stress-strain curve

Strength of metal;

DUAL PHASE STEEL Neutron diffraction:

→Whether the residual austenite / martensite phase can be observed with compact neutron source?



strong request from steel companies

1st trial experiment has done SUS316 75% cold roll

Martensitic phase: bcc

26%

Austenite phase: fcc

Fast neutron imaging system for nondestructive inspection of large-scale concrete structures

Y. Seki[1], A. Taketani[1], T. Hashiguchi[1], H. Ota[1], S. Tanaka[2], K. Kino[3], K. Hirota[4], H. Baba[1], S. Wang[1,4], Y. Yamagata[1], Y. Otake[1]

RIKEN[1], KEK[2], Hokkaido Univ.[3], Nagoya Univ.[4], Xi'an Jiaotong Univ.[5]

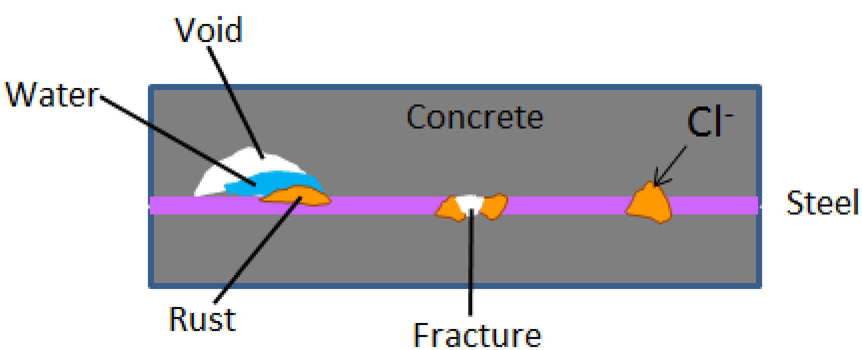
Background

- Aging deterioration of large-scale concrete structures
  - Lifespan of concrete ~ 60 years → peak in 2025 in Japan
    → Lifetime expiration 42,000 bridges
  - New construction of bridges/highways is impossible

    → Diagnosis, preventive maintenance, life extension

Collapse of the Ynys-y-Gwas brg.
(UK, 1985)

- Assessment of concrete deterioration



- Width of Steel bar
- Void
- Water
- Fracture of steel bar

→Required resolution ~ 3 cm

Deteriorated concrete

Fast neutron transmission imaging

as on-site nondestructive inspection technique

High penetration power

Sensitivity to water

Transportable compact neutron system

- Prestressed bridge,

we cannot know without pealing the concrete slab

- Steel bridges

steel bridge
corrosion

After disassemble joint part・・・

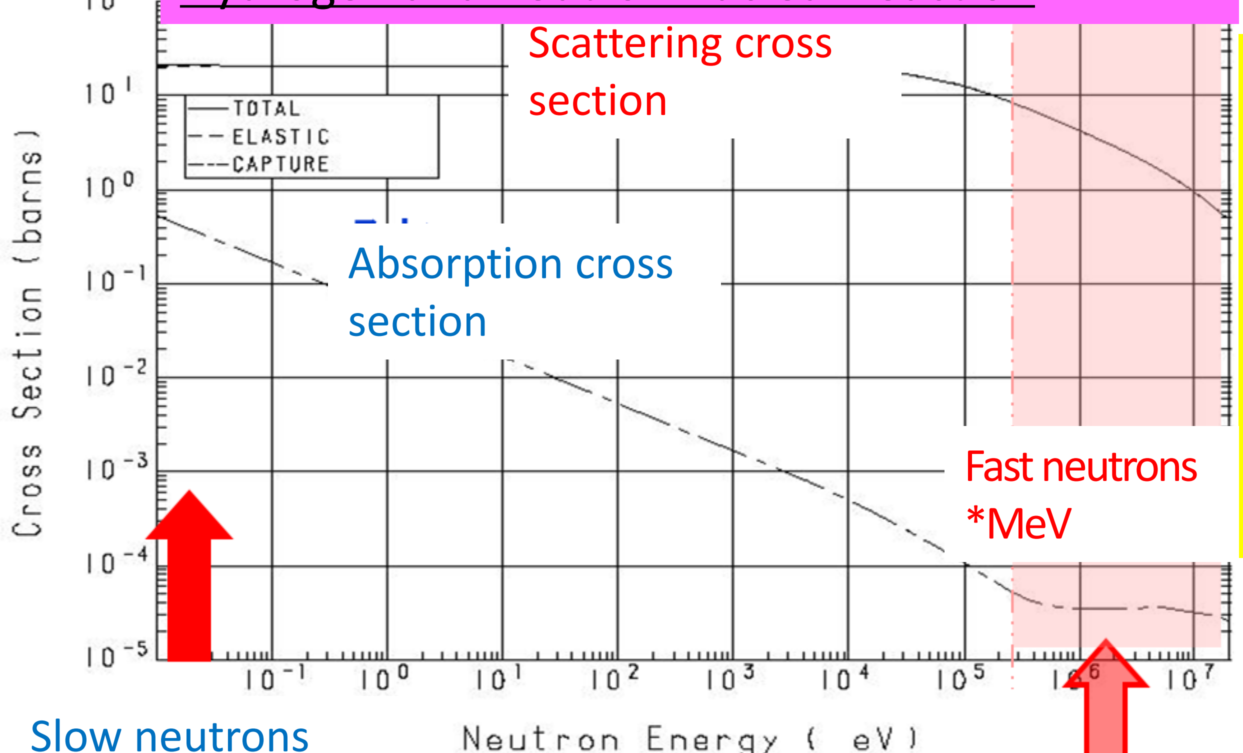
Non-destructive inspection, use fast neutron beam (~MeV)

Fast neutron (some MeV) : concrete slab with~50cm thickness

Fast neutrons Slow neutrons)

E Energy	10^6eV	10^3eV	25meV	1meV	0.01meV	10^{-7}eV
Temperature	10^{10}K		300K	10K	0.1K	10^{-5}K
Velocity	10^7m/s		2200m/s		1m/s	
Wave length	10^{-12}m		0.18nm	1nm		1µm

Hydrogen and neutron nuclear reaction

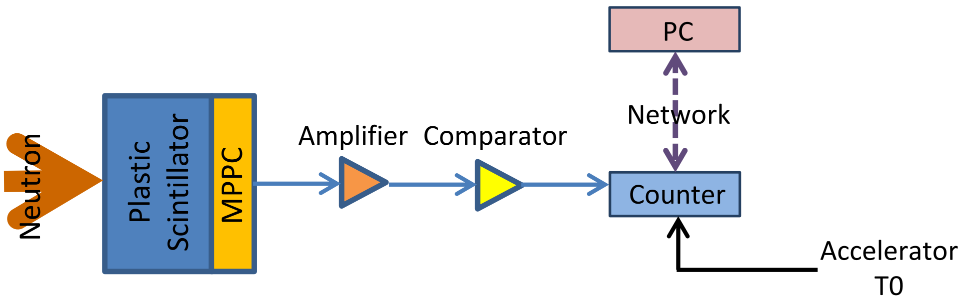


Slow neutrons (25 meV)

E~1MeV,
Low absorption for almost all elements,
But still high scattering cross section for H atom
↓
Detection of Water in the concrete (~50cm)

Fast neutron detector for concrete inspection

- Detector design
  - Outdoor use
  - Mobile use
  - Mass production

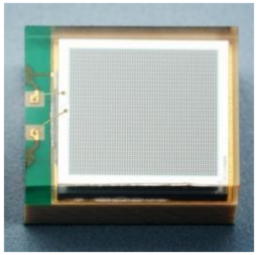


Plastic scintillator

BC-408

3 cm(H) x 3 cm(W) x 5 cm(D)

Multi-Pixel Photon Counter (MPPC)



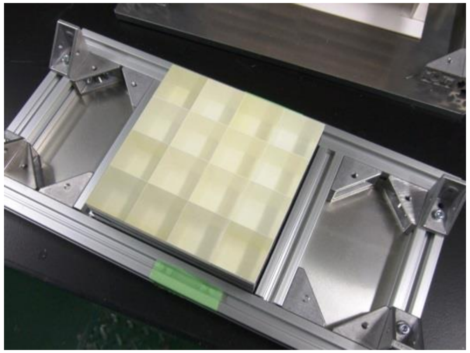
HAMAMATSU S10931-050P

Effective area: 3 mm x 3 mm

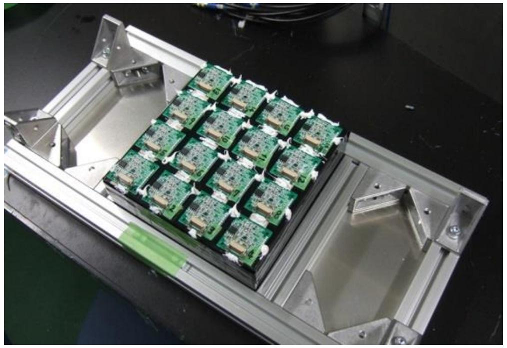
Counting ability: 3 mV/p.e.

Time resolution: 500-600 ps

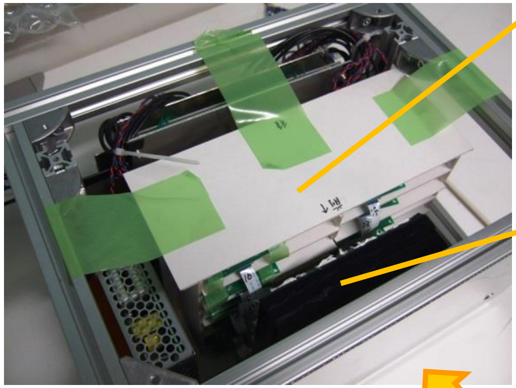
- Prototype 4 x 4 ch (12 cm x 12 cm) detector



Scintillators



Scintillators + MPPCs



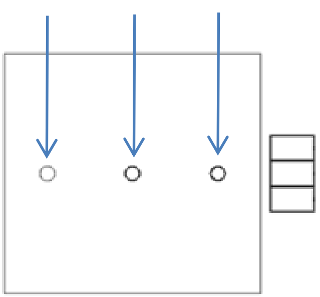
Readout circuit

Scintillators + MPPCs

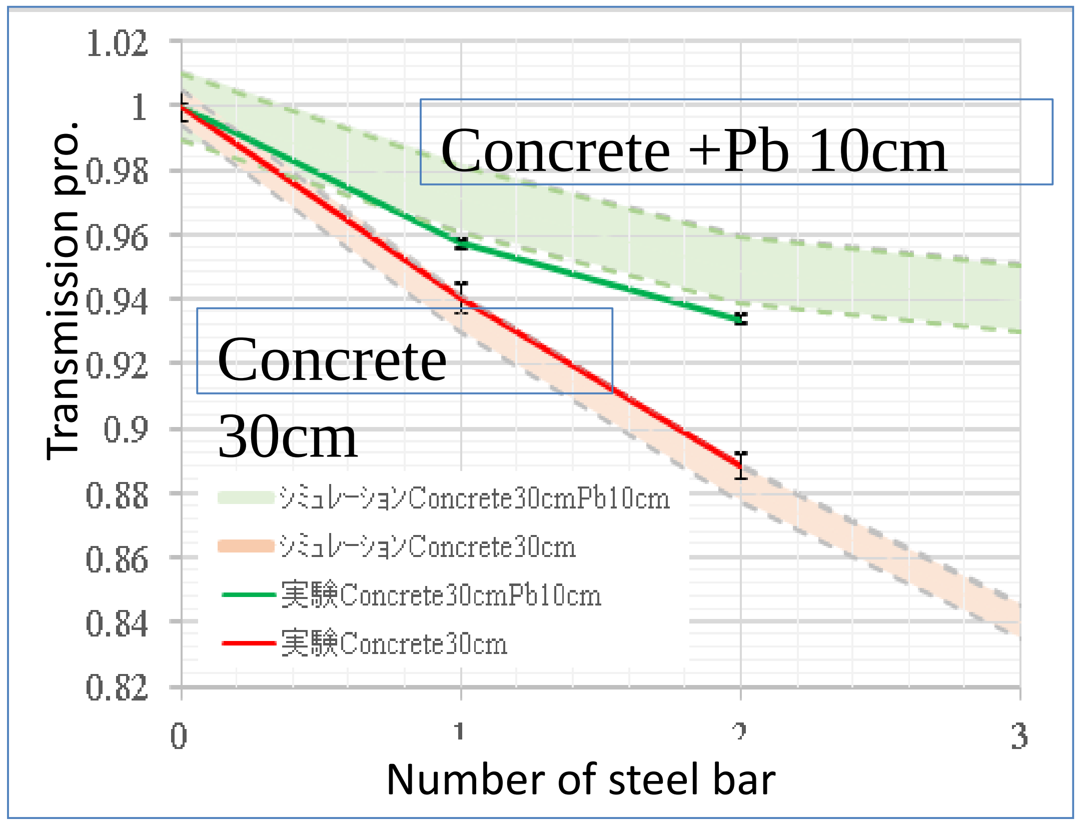
Neutron beam

Success of observation difference of steel bar in the concrete

Insert ion bars
into concrete
0, 1, 2, 3

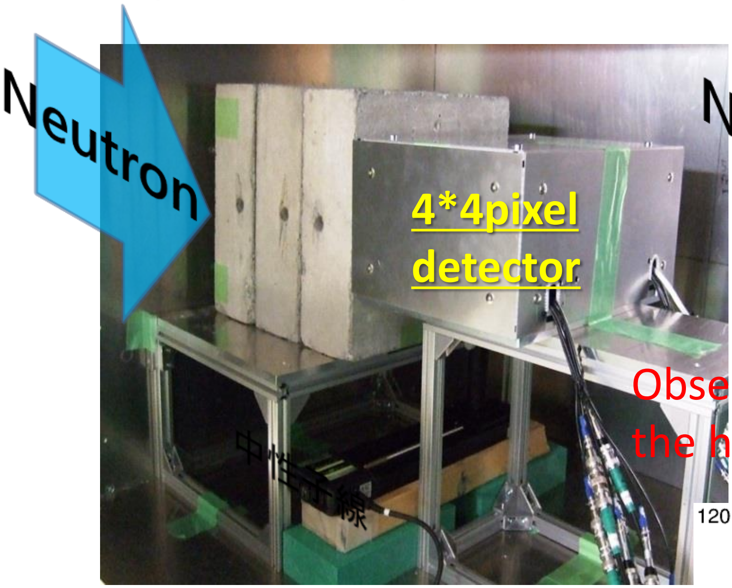


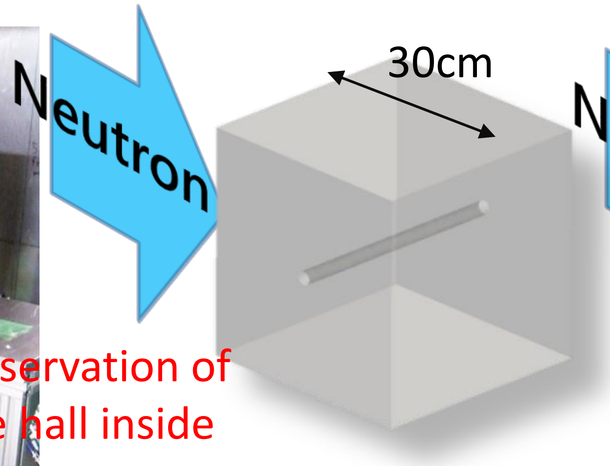
・comparison with the experimental results and simulation by GEANT4.



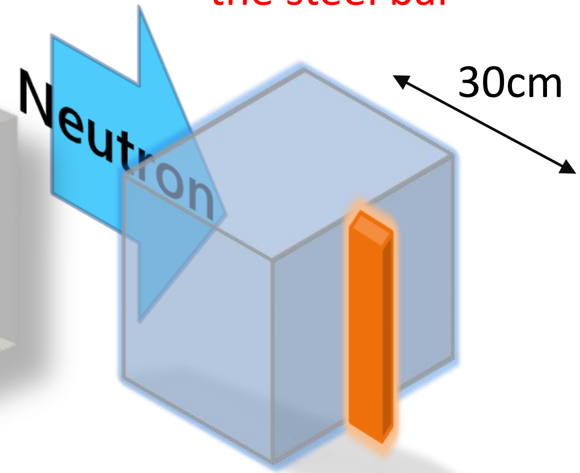
Fast neutron imaging through 30cm concrete block

(>1MeV) Non-destructive inspection

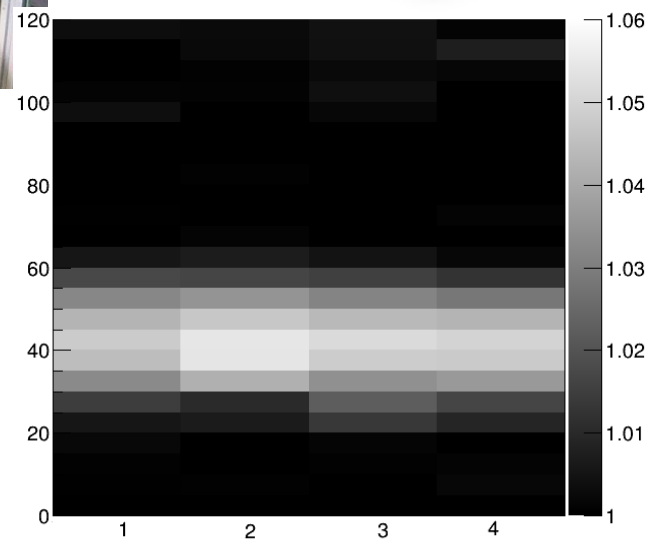


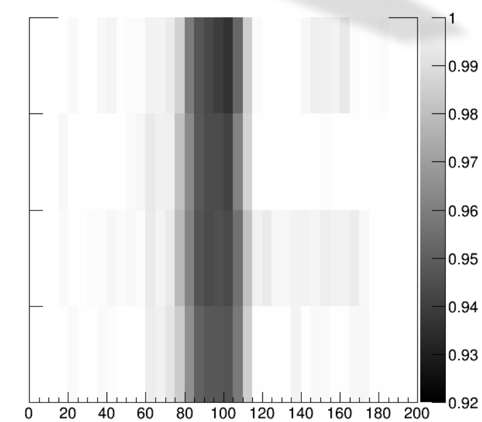


Observation of the hall inside



Observation of the steel bar





Proton linac

Proton energy: 7 MeV
Beam current: 11 μA (avg.)
Rep. rate: 20 Hz
Pulse width: 100 μs

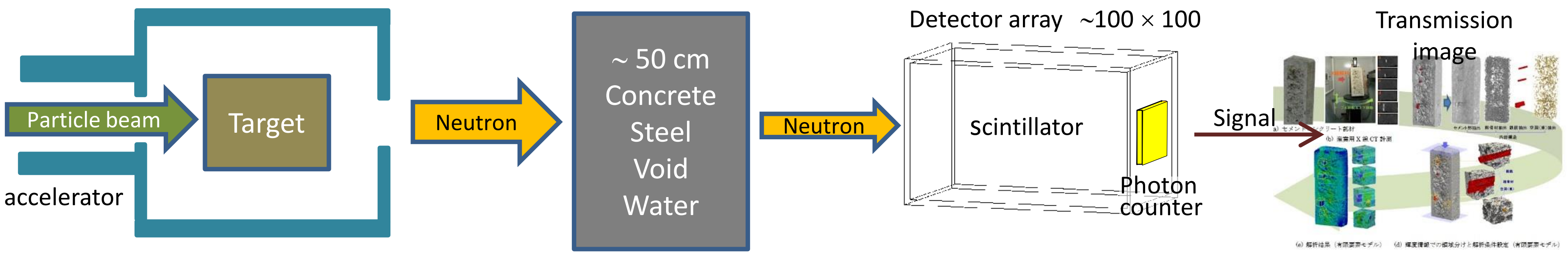
Success of the observation of steels, void

- New fast neutron imaging detector development
- 1pixel = 30 mm x 30 mm
  10 mm x 10 mm steel
  Φ18 mm void (air hole)

<u>1m*1m 1024 channner large area fast neutron imaging detector is now being tested with real bridge</u>

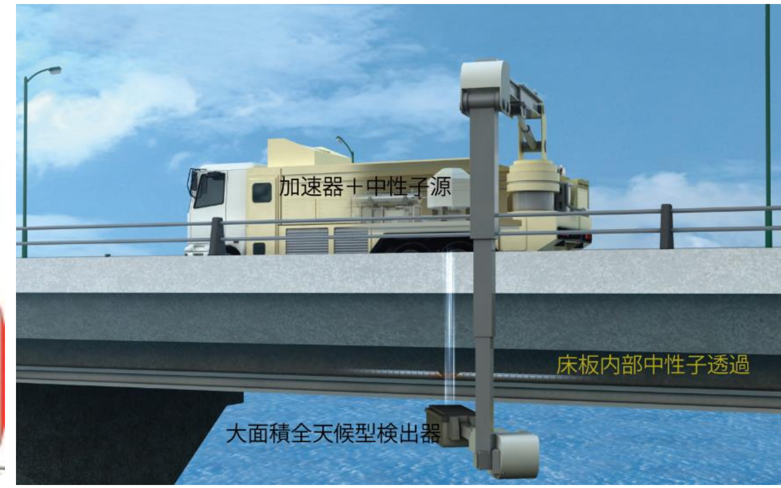
1平米
橋梁用1024チャンネル検出器
[32 x 8 ピクセル (1ピクセル = 20 mm x 20 mm)]

Fast neutron imaging system



	Compact neutron source	Fast neutron detector	Software (analysis/simulation)
Components	• Accelerator • Target • Shielding	• Scintillator • Photon counter • Readout circuit	• Image processing • CT • FEM
Study items	• Neutron producing reaction • Neutron flux • Energy spectrum • Beam divergence	• Dimension of detectors • Photon number threshold • Demonstration of concrete imaging	• Noise reduction • Blur correcting • Predictive and diagnostics simulation
Existing techniques	• RIKEN RANS • Ion source	• Radiation detection • PHITS/GEANT4 code simulation	• RIKEN VCAD system (FEM)

Trans portable compact neutron system in a truck will be realized in some years.



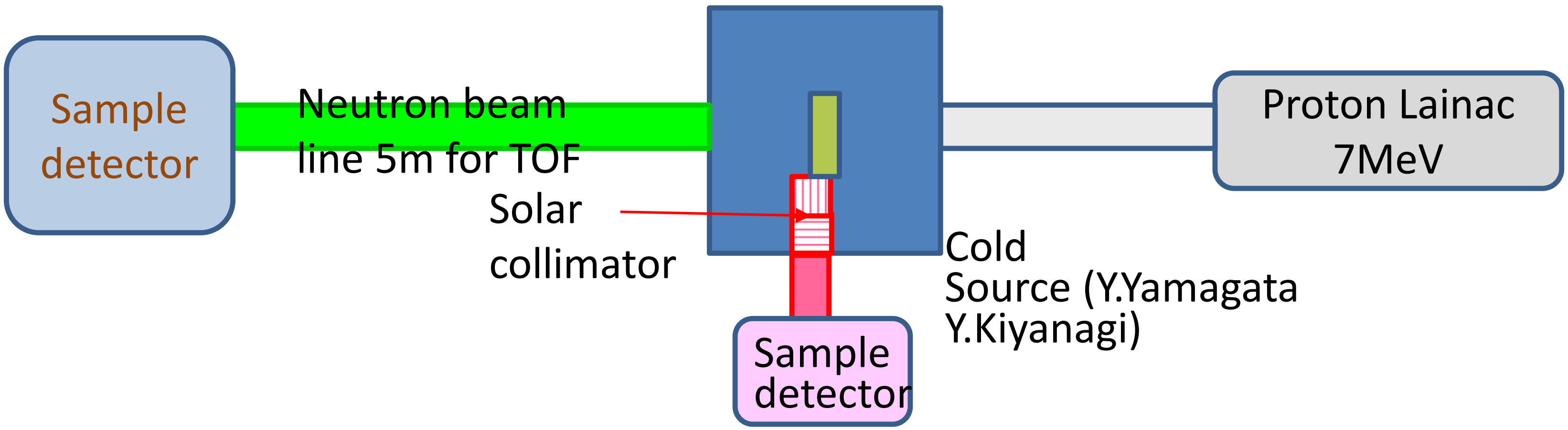
The radiation level 3m far from the center of the target will be 0.6μSv/h by GEANT4 simulation.

- **放射線障害等防止法第10条　および　関連規定（平成17年7月改定）**Japanese regulation 4MeV>linac
  - 橋梁等の非破壊検査に用いる**直線加速器で4メガ電子ボルト**以上のエネルギーを有する放射線を発生しないものは、放射線発生装置の使用の場所の変更を都度許可を得る必要がなく届出で足りることとする。（ただし、設備については、事前に原子力規制委員会原子力規制庁の届け出許可が必要。）

Collaboration and the support from JCANS (Prof. Kiyanagi), and

In 2 years,

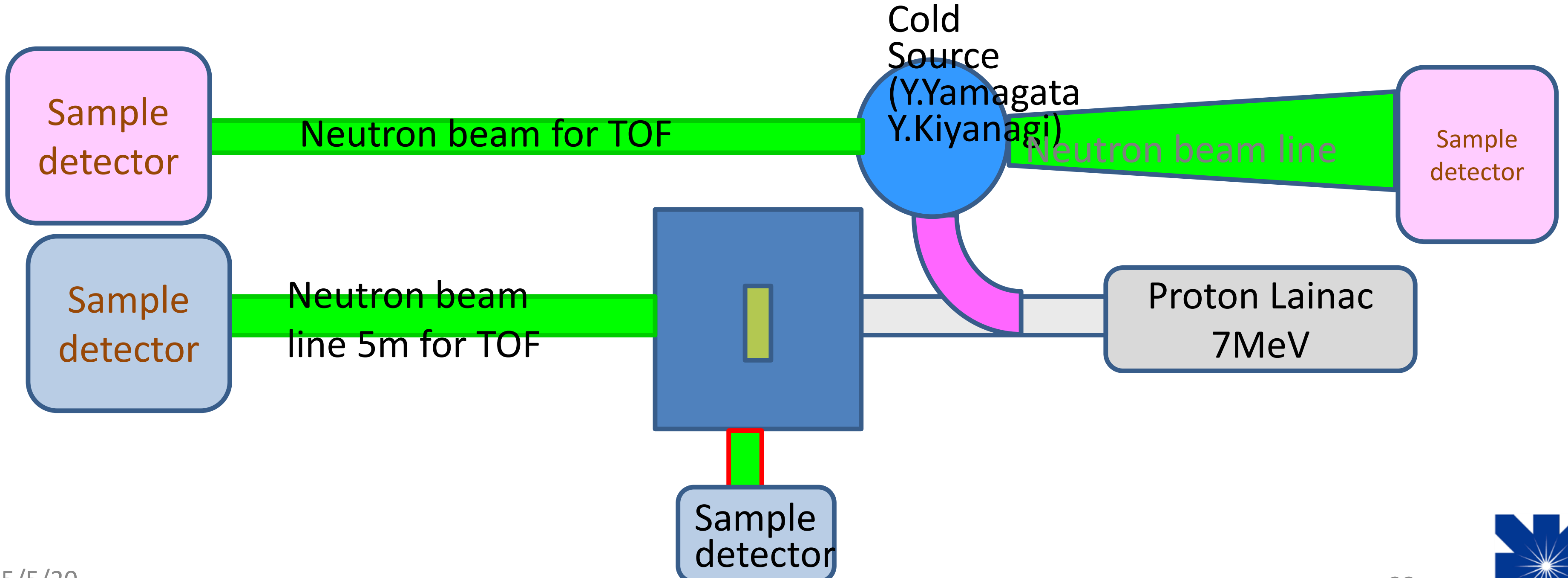
- One <u>more beam-line for imaging </u>with thermal neutron in 2015 with changing the moderator with Polyethylene,



In 2 years,

- One <u>more beam-line for imaging </u>with thermal neutron in 2015 with changing the moderator with Polyethylene,

- Cold source construction in 2016 with the switching magnet for the proton beam

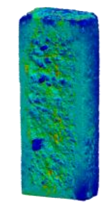


Summary RANS, towards practical use

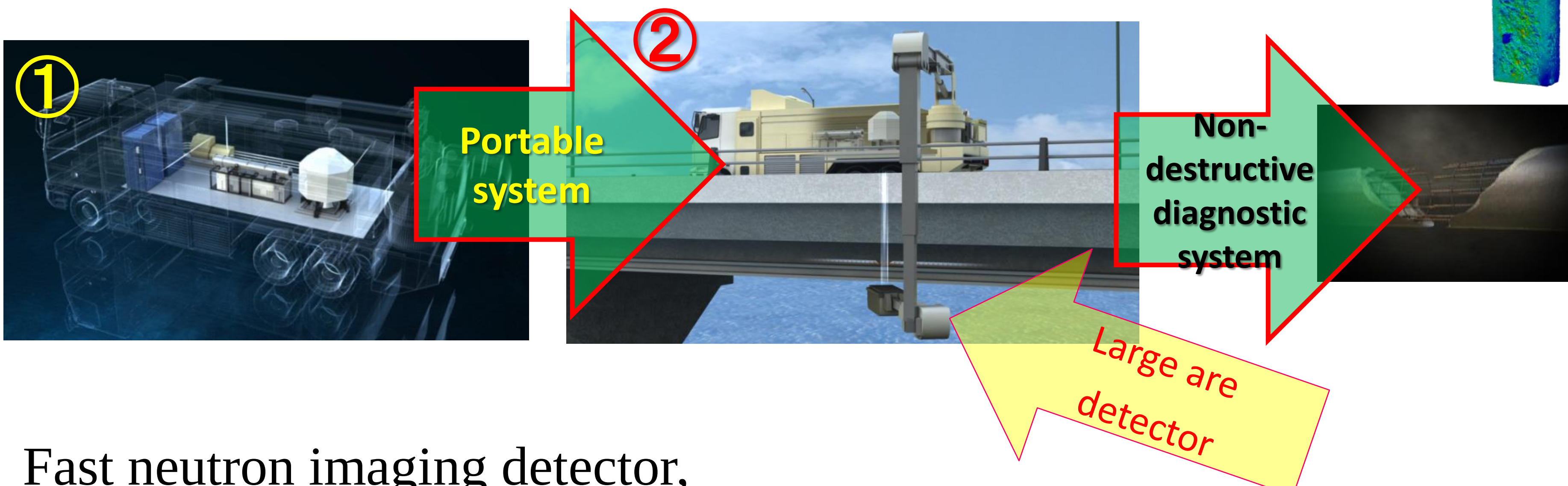
- Compact neutron source for industrial use floor-standing type

- 3D neutron imaging (3D)
- Neutron diffraction for metal deformation

Crystal texture, pole figure measurement



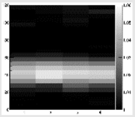
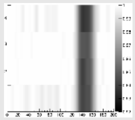
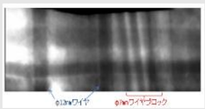
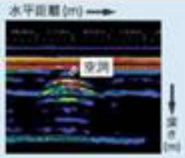
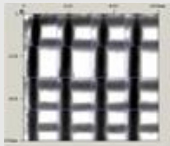
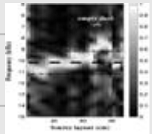
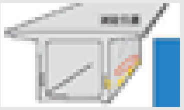
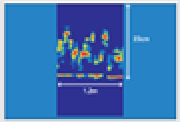
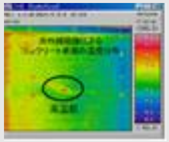
- Development for the transportable neutron system



Fast neutron imaging detector,
health diagnosis system development

Transportable X-ray instrument for bridges Prof.M.UESAKA (Univ.Tokyo)
3.95MeV X-band e-linac
Already it was tested outside.

Smaller, better for practical use (including shielding)
-> proton beam,
low energy, low current
Easy for maintenance (especially for the accelerator)

非破壊測定法	透過コンクリート厚	放射線遮蔽	用途	見えるもの	水の識別	2次元	イメージング	装置　大きさ 価格
中性子線（2ＭｅＶ，高速中性子）	1m以上	ホウ素化ポリエチレン（0.9トン）	橋梁等の大型構造物	空隙、水、鉄筋	良好	（分解能：2〜20mm程度）	 	加速器3〜4メートル 3〜6億円??
高エネルギーX線（MeV）	1m以下	鉛(3.3トン、屋外可搬不向き、高価)	橋梁等の大型構造物	空隙、鉄筋	困難		  （20cm~厚）	加速器1メートル以下 1~3億円程度？
電磁波レーダ	30cm程度	不要	橋梁、トンネル	空隙、鉄筋、水、(水セメント比）	不可	（分解能:MAX5mm(ｺﾝｸﾘ30cmでどの程度かは不明)；鉄筋ピッチ8cm以上の間隔必要）	 	数10センチ 数百万円程度
電磁誘導法	15cm	不要	橋梁、トンネル	鉄筋，さび	不可	（分解能:MAX5mm(ｺﾝｸﾘ15cm厚では不明)；鉄筋ピッチ8cm以上の間隔必要）		50センチ位 数百万円
超音波（波長：70〜180mm程度）	〜60cm	不要	橋梁、トンネル	空隙、鉄筋、(水セメント比)	不可	（分解能：70〜180mm程度） 波長を下げると分解能上がるが、吸収が激しくなり、表層しか見えない。		1メートル以下 数百万円以下
衝撃弾性波(ハンマー）	〜60cm	不要	橋梁、トンネル	弾性波速度、ひび割れ、空隙、コンクリート厚さ	不可	（分解能：MAX30mm程度）	 	1メートル以下 数百万円以下
赤外線カメラ	表層〜10cm	不要	橋梁	空隙、剥離	可	（分解能：〜0.2mm程度）	  	50センチ位 数百万円
レーザ	壁面表層	不要	トンネル	ひび割れ，水，ジャンカ	可	（分解能：〜0.1mm程度）