A Plan of compact neutron source for industrial application at RIKEN

Advanced Manufacturing Metrology Laboratory, RIKEN

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Overview

- We are planning to construct a compact neutron source based on proton linac for the purpose of industrial and academic use.
- Outline
  - Current status at RIKEN
  - Neutron Imaging for industrial applications
  - Neutron scattering instrument for industrial and academic

Current status at RIKEN

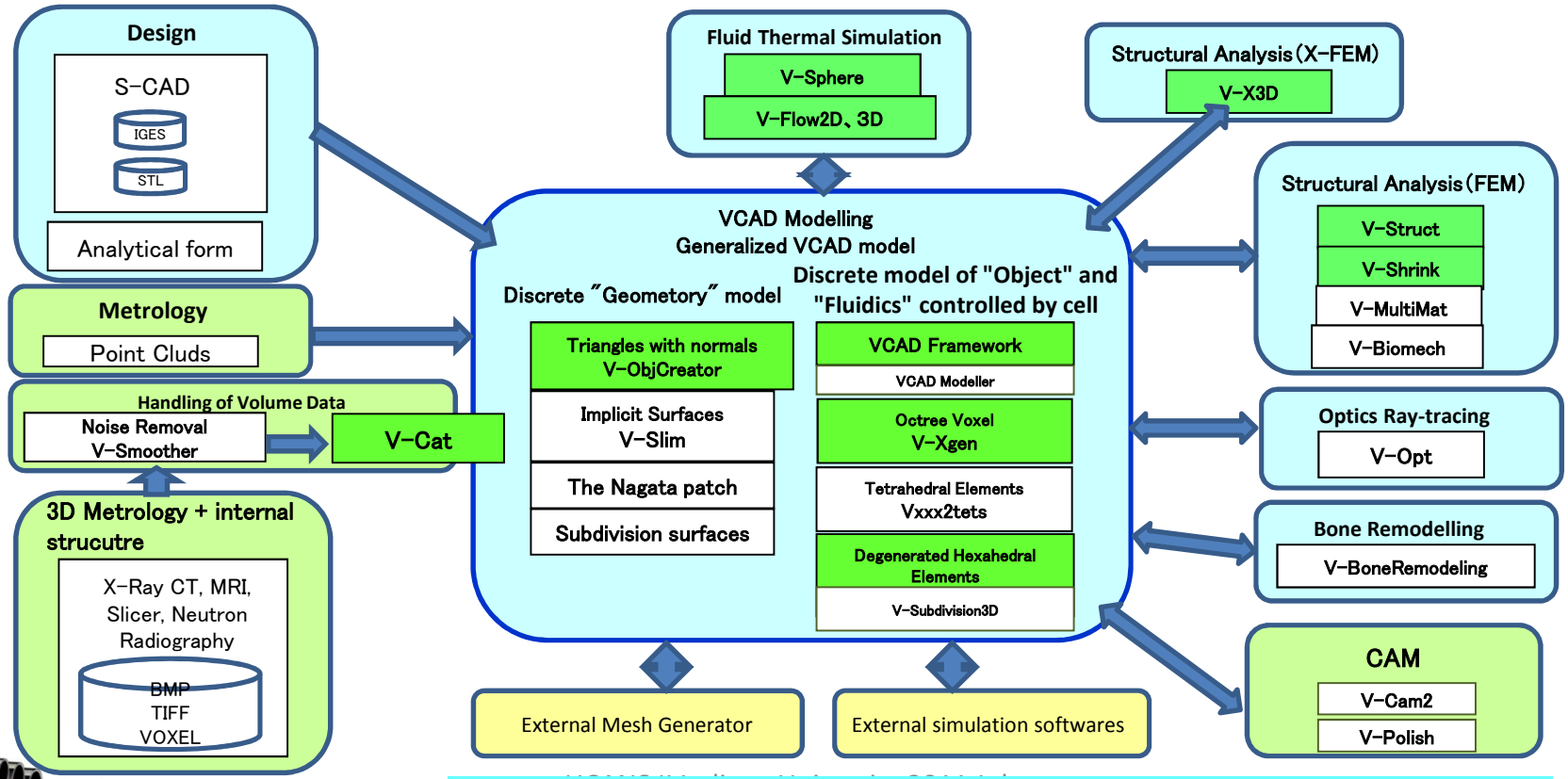
- The former VCAD System Research program has come to an end and a new team dedicated for neutron imaging was formed.
- The aim of the new team “Advanced Manufacturing Metrology Laboratory” is aiming for:
  - Neutron Imaging for industrial applications
    - Radiography of industrial components at relatively weak neutron beam ports
    - Development of new imaging technique (Phase contract imaging)
    - Development of detectors and instrumentation devices
  - Preparation for the construction of accelerator based compact neutron source
    - Neutronic design of target/moderator station
    - Thermal/mechanical design of target
    - Construction of simple target/moderator station using small proton linac
  - Obtain necessary funding !

Demands for non-destructive testing in industries

- Recent problems in production technology in Japan
  - Lower cost, energy efficient, recycled material, high quality, product liability
  - Slim, lean but sufficient design for optimum cost/performance
- Utilization of computer simulation in the design process is keen
  - Optimize hydrodynamic form
  - Minimize car body weight
  - Simple and sufficient design of engines, motors and batteries
- Computer simulation (Structural, CFD/thermal, molding...) are not always accurate without metrological data
  - Methodology to "measure" real physical phenomena become important
  - Fluid visualization, stress measurement, temperature, magnetic/electric field, chemical reaction and so on
- Significance of Non-destructive testing goes up
  - Product liability, quality control

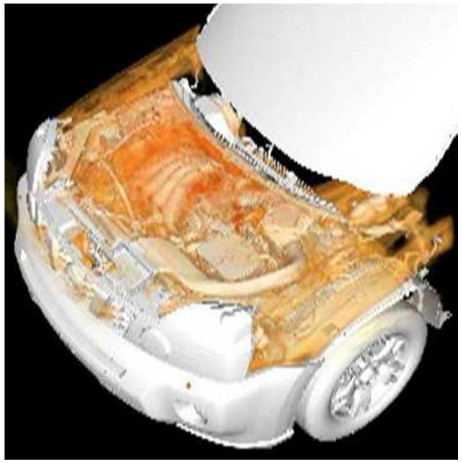
VCAD System Research Program

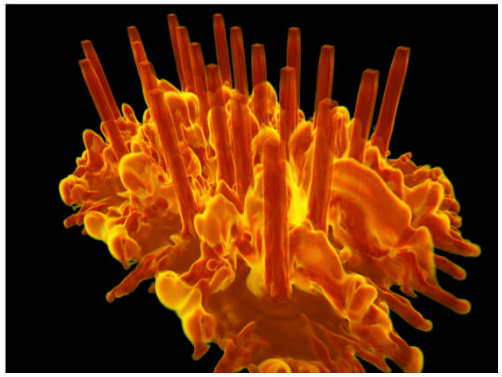
- VCAD System (Volume CAD) can realize computer model based on "real" object - VCAD model
- Based on VCAD model, various computational simulations can be carried out (CFD, Structural, molding, optical ...)
- These simulations are far realistic than those based on CAD models

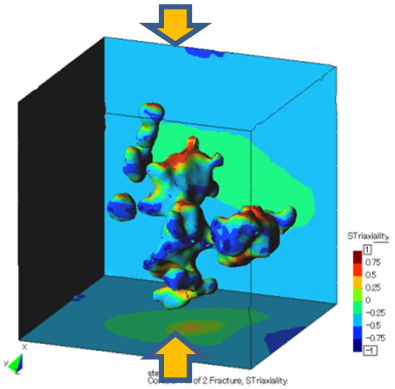


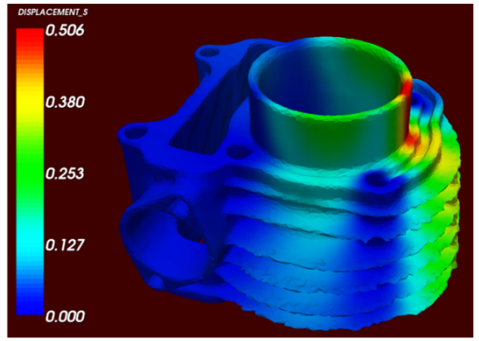
V-Sphere **Software in public release**

type "VCAD" at Google to see VCAD Website http://vcad-hpsv.riken.jp/en/





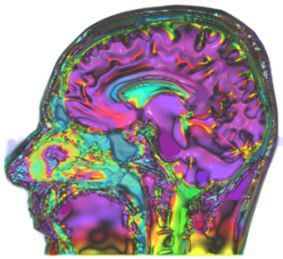


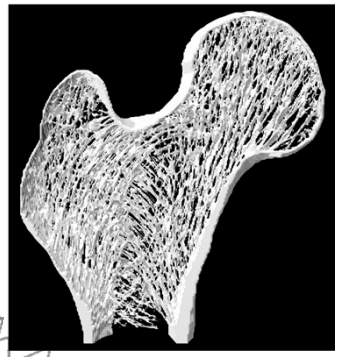


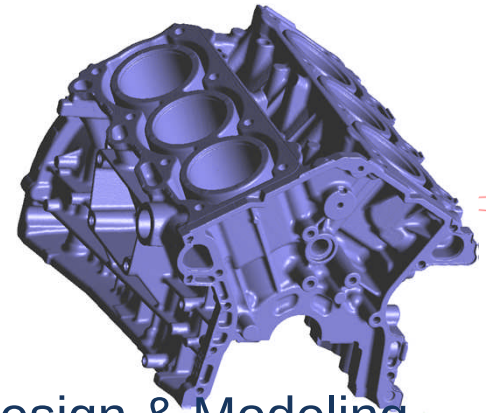
Fluid Dynamics

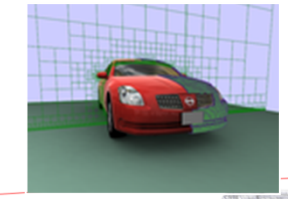
Structural Analysis

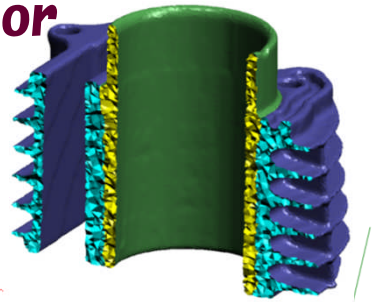
VCAD: Integrated CAD/CAM/CAE/CAT for Multi-Material Volumetric Objects

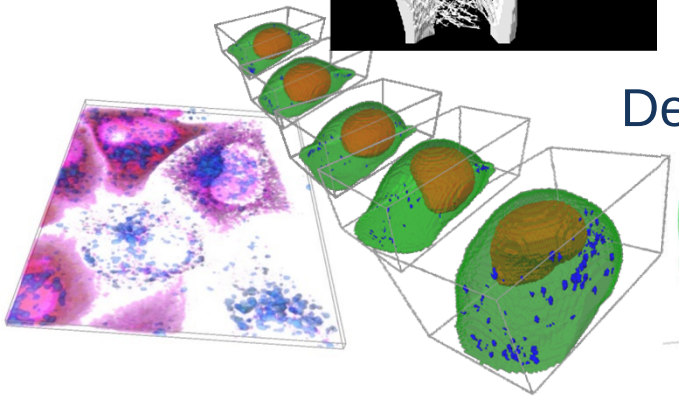


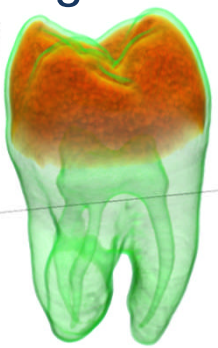


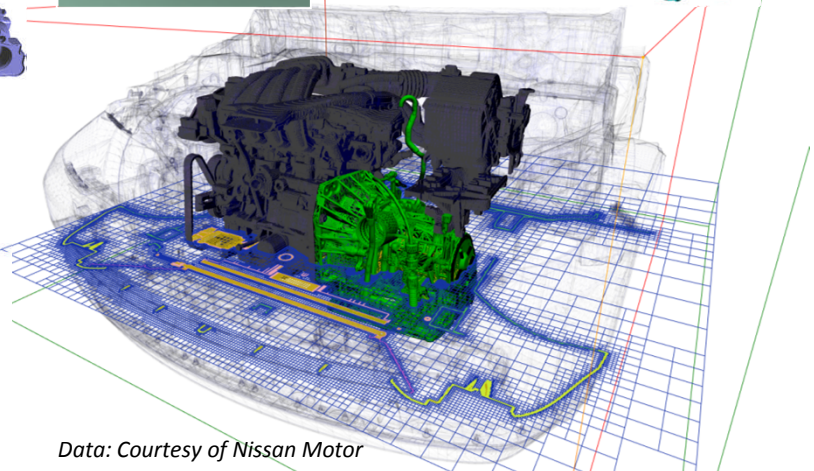












Design & Modeling

Bio-Medical Application

Data: Courtesy of Nissan Motor

Meshing & Grid Generation

©RIKEN, 2009

UCANS-II

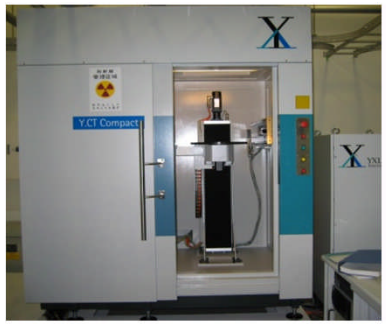
VCAD

3D Volume data input method to VCAD System

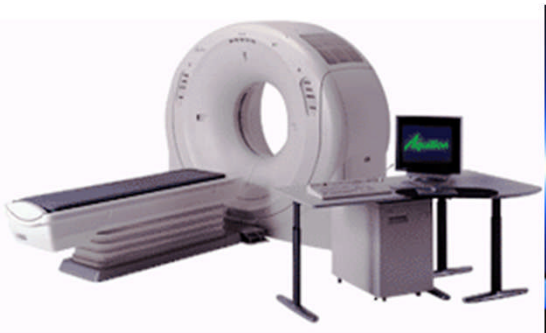
Metrology of volume 3D data of real "objects"

INPUT to VCAD

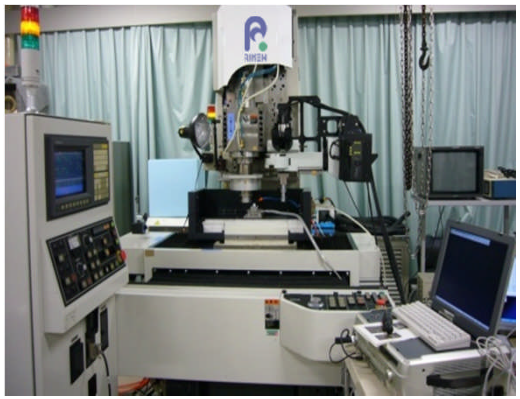
- CAD Design data
- Surface metrology
- volume 3D data



X-ray CT fo industrial and medical



Confocal laser microscopy

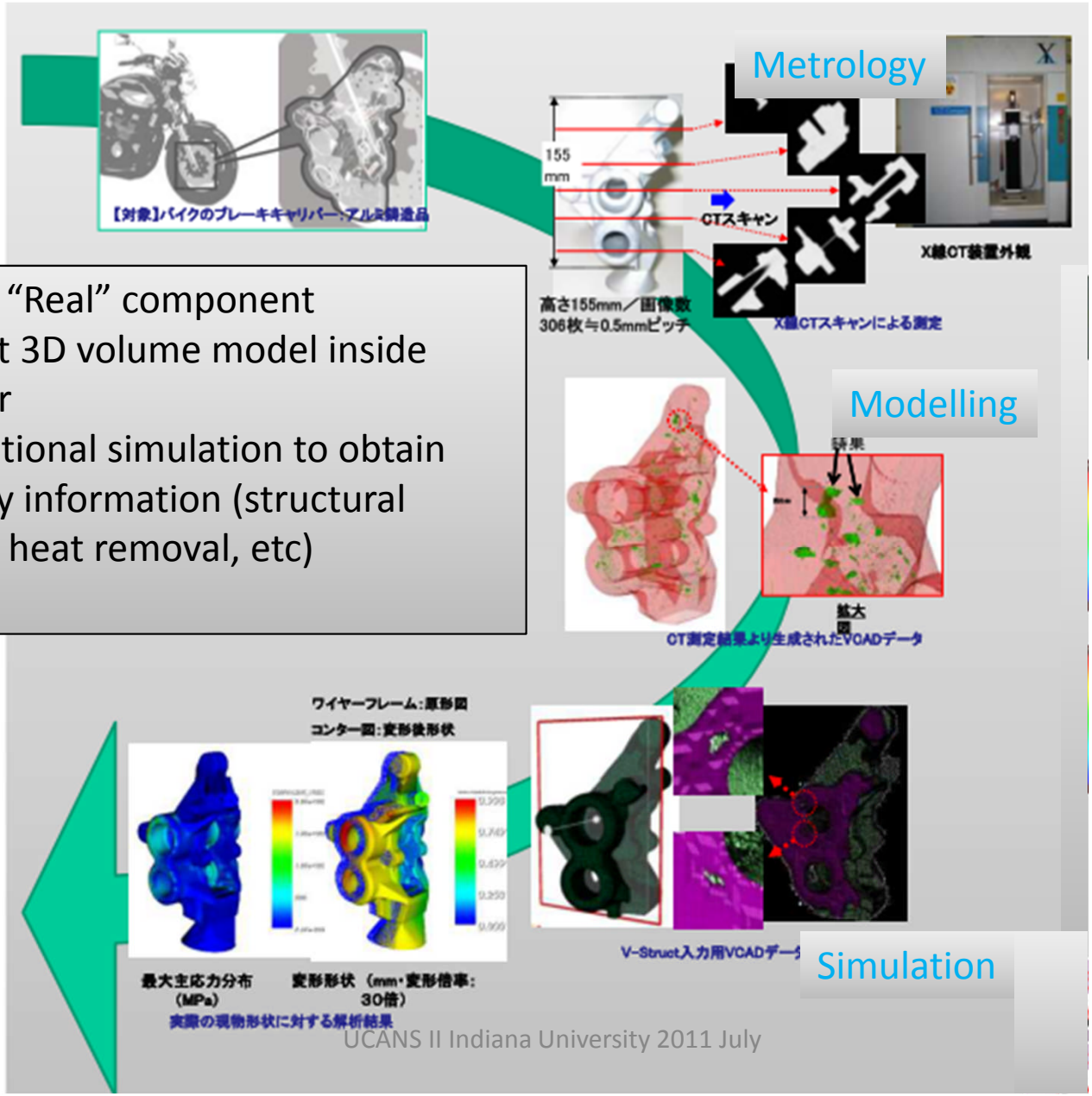


3D internal structure microscopy (Slicer)

Neutron Radiography (JRR-3)

Example of imaging and simulation for the industry using X-ray

1. Measure “Real” component
2. Construct 3D volume model inside computer
3. Computational simulation to obtain necessary information (structural strength, heat removal, etc)



What the industry needs from neutron imaging

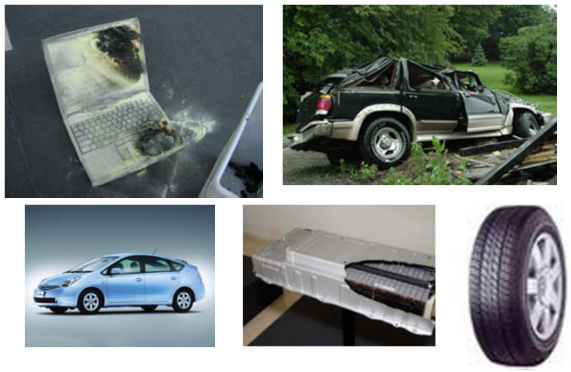
- There are a number of components that cannot be measured by X-ray with sufficient information. (Steel components, metal/plastic composite, bonding material, plastic parts, CFRP etc..)
- It is very important for industries to produce interpreted result rather than just an radiography image!
- It is also important that neutron imaging facility can be easily accessed. Beam time of several times per year is not convenient enough for industrial use.

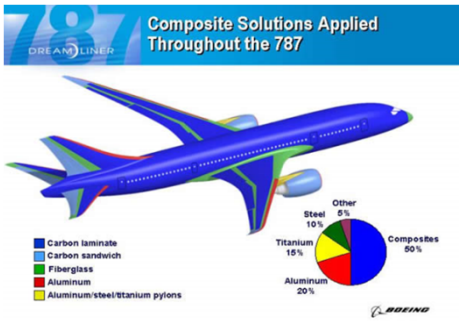
Easy to access, convenient neutron imaging by compact neutron source is important

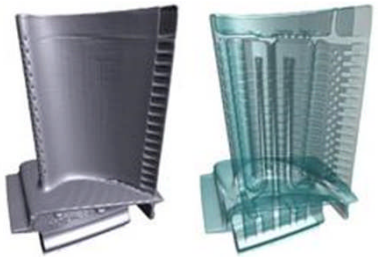
Neutron imaging for the industries

Neutron imaging for industries

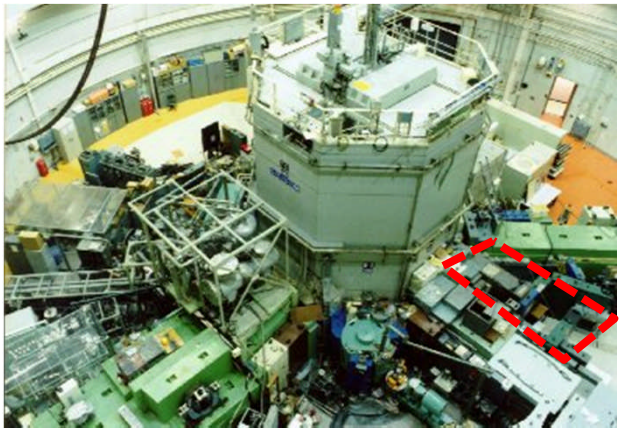
- Automobile industries
  - Batteries (liquid motion, safety tests)
  - Structural components (residual stress)
  - Plastic/metal composite components (cables, tires)
- Aerospace industries
  - CFRPs(carbon fiber reinforced plastics)
  - Turbine blades (mold removal)
  - Metal bonded components (bonding material distribution)
  - Metal-plastic composite components







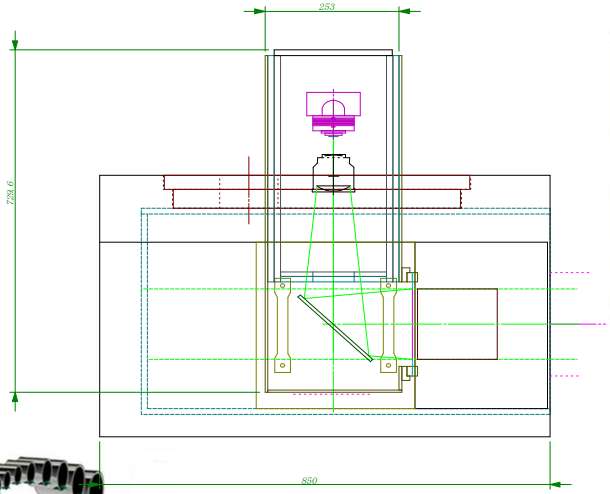
Neutron radiography at relatively low intensity source



Kyoto University Research Reactor (KUR)

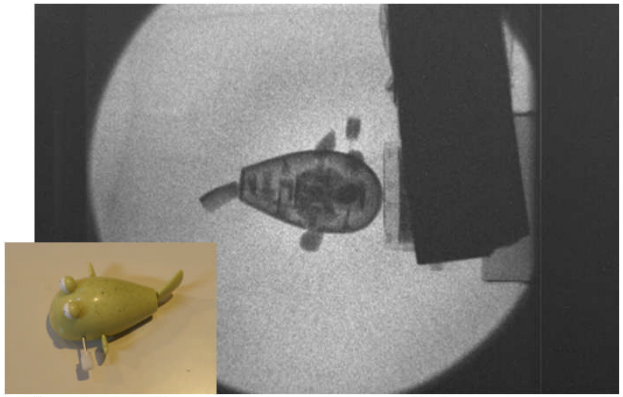
- Neutron radiography is conducted at KUR E-2 port to verify the possibility of imaging at relatively low neutron flux.

Specification of E-2 port
Neutron flux: 8×10^4 n/cm^2/sec @1MW
4×10^5 n/cm^2/sec@1MW
L/D= 100
Beam diameter = ϕ15cm

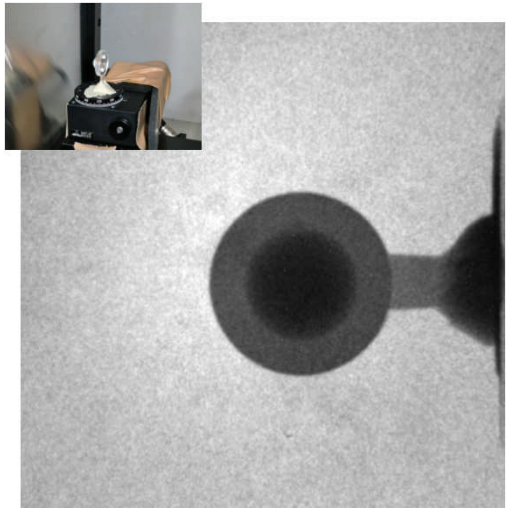


Imaging camera with ^{6}LiF+ZnS(Ag) scintillator
Cooled CCD Camera 11 Million pixel(4008x2764)
Resolution ～50μm
Imaging area: 150mmx150mm

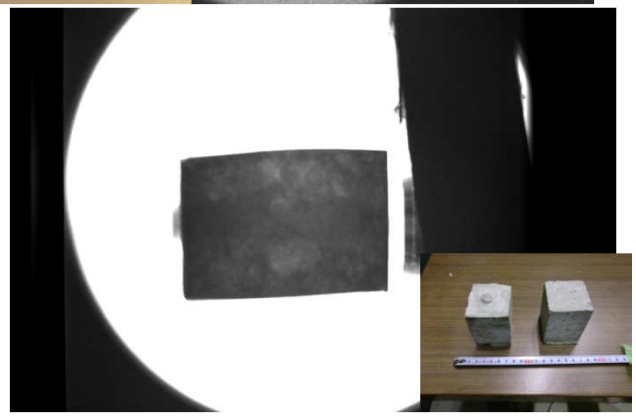
Some examples of imaging at KUR



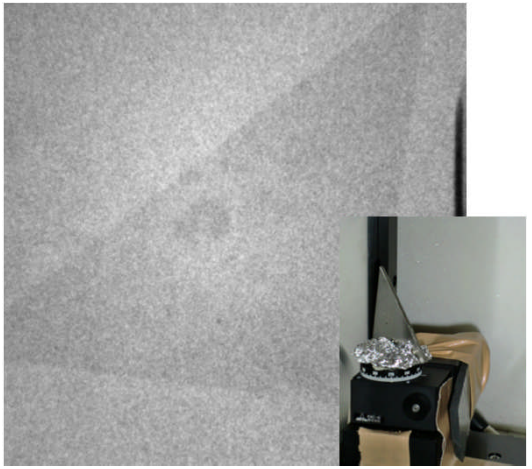
Bath toy (plastic-metal composite sample)
1min at 1MW



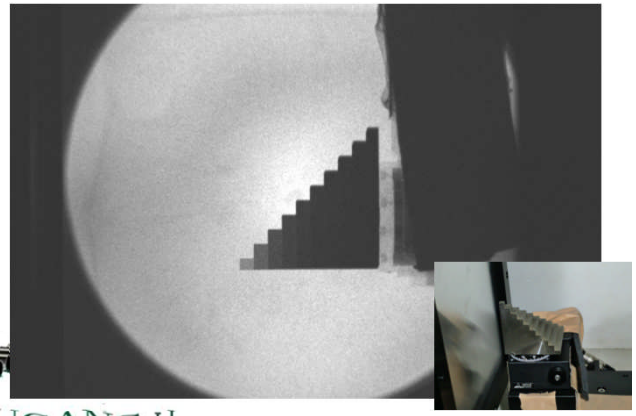
Plastic Lens
20sec @5MW



Concrete sample w/steel reinforcement
20min@1MW



Nb sample with micro defects
1min @ 5MW

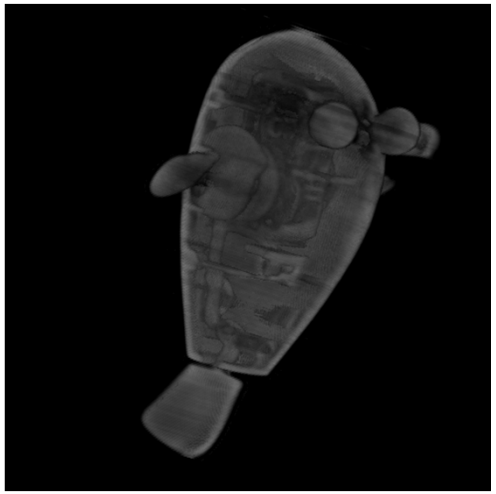


Steel pyramid(5cm)
1min @1MW

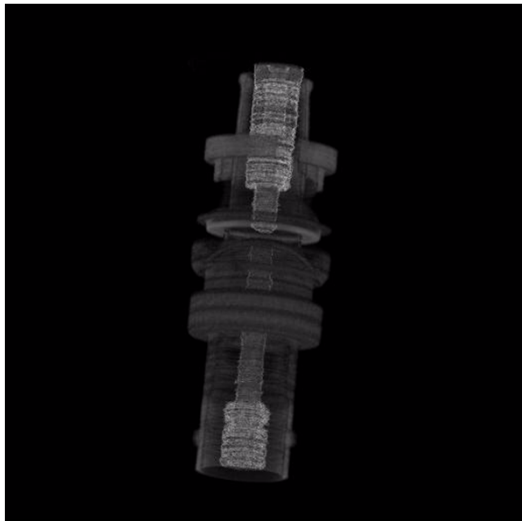
Practical images can be captured by 1 min exposure in most cases at 1MW

CT reconstruction and movie

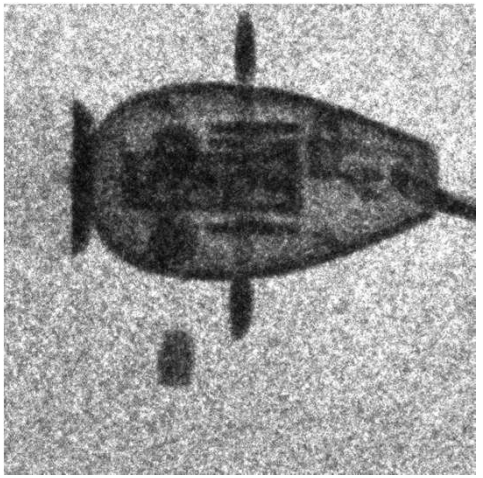
- CT reconstruction is also possible with several hours of imaging



Volume rendered image of bath toy
CT capture 60sec x 500 images
1002x668 10 hours
Resolution 160um



Volume rendered image of connector
CT capture a B-4 port



Simple movie (512x512)
By EMCCD 8fps at E-2 5MW

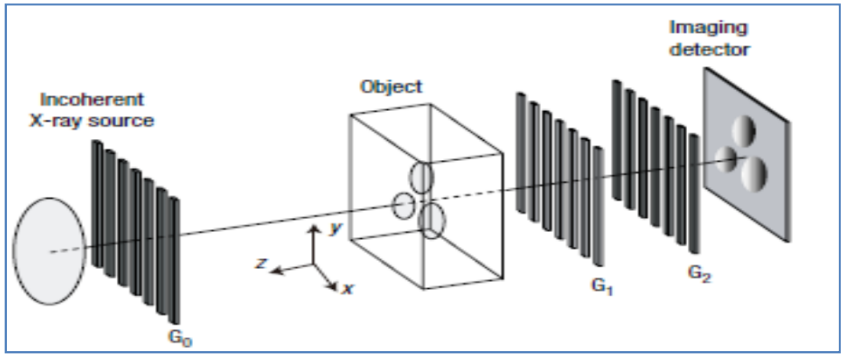
By using latest CCD camera with very high sensitivity, a small movie can be captured.

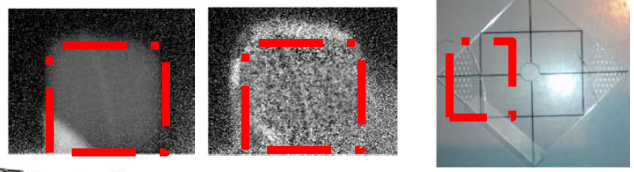
Possibility of relatively low neutron flux for practical radiography

Neutron interferometry imaging (Phase contract)

- Neutron radiography(absorption) gives better contrast over X-ray to plastic and CFRP(Carbon fiber reinforced plastics)
- Interferometry imaging gives even better recognition of organic materials, which may be possible to distinguish water, PMMA, epoxy and CFRP.
- This imaging technology is crucial to components where light-weight is very important.

Talbot-Lau Interferometer using three diffraction gratings

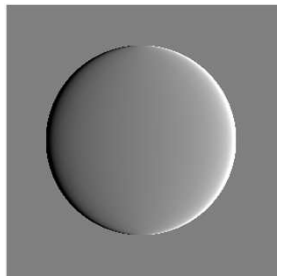




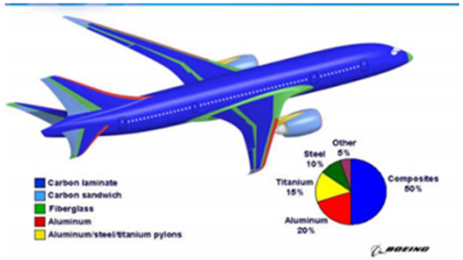
Interference image at JRR3 ULS

Epoxy resin in water (Simulation)

Absorption based image



Phase contract image



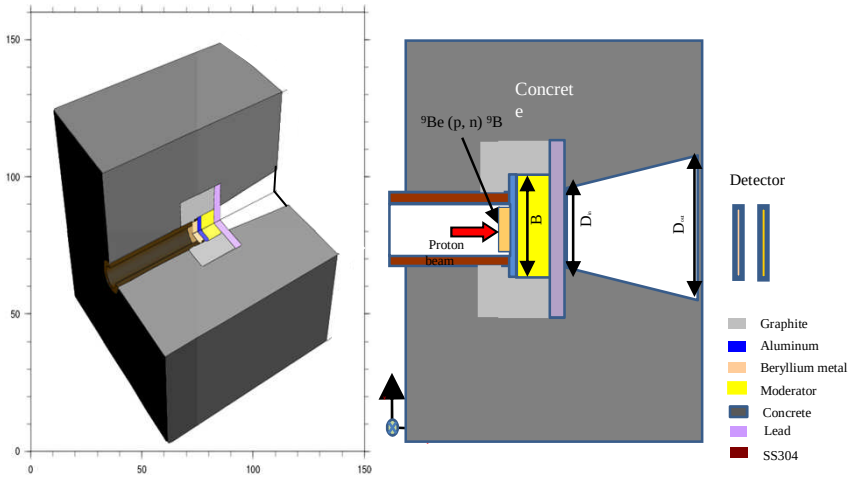
Combined with compact neutron source, there is a possibility of non-destructive testing of aircraft components

Design and research toward compact neutron source

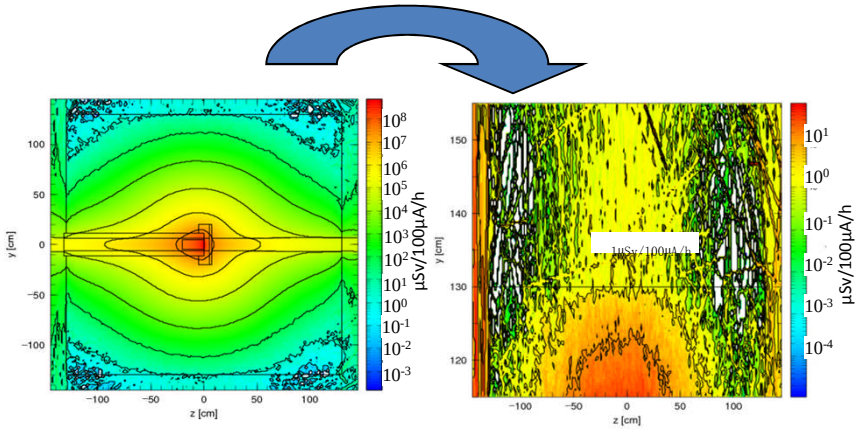
- Simulation and design of target-moderator station by PHITS code [poster: S.Wang]
- Thermal and Mechanical design of target[poster: J.Ju]
- Imaging detector development[poster: K.Hirota]

Simulation and design of target-moderator station by PHITS code

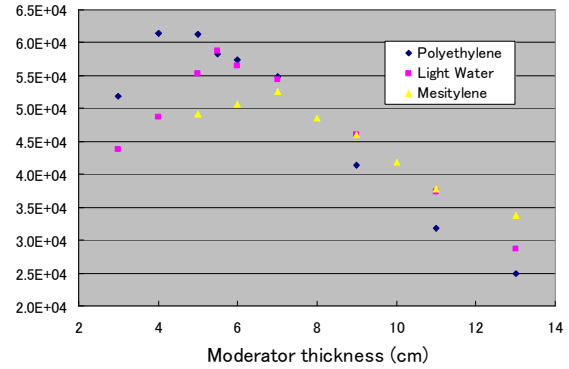
For the small proton linac (3.5MeV, 100uA) at Faculty of Science at Kyoto University, we are designing target/moderator/shielding for thermal neutron radiography



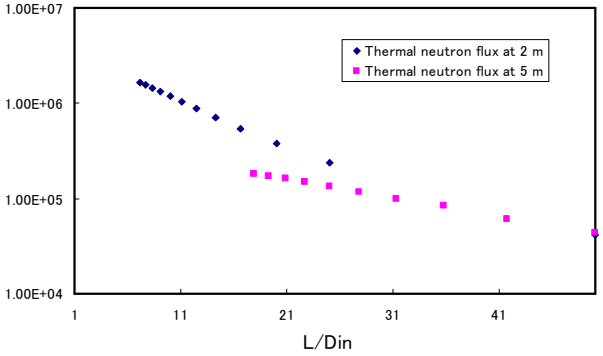
Design of “simple” target moderator



Shielding calculation for neutron & photon



Moderator optimization

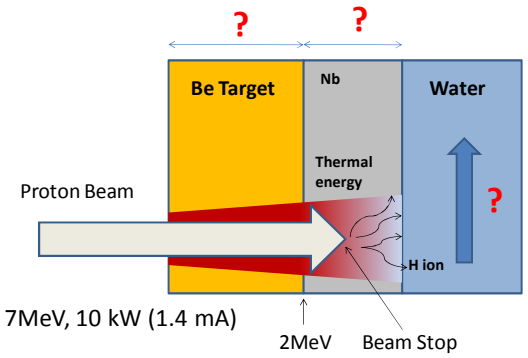


Thermal neutron flux vs L/D

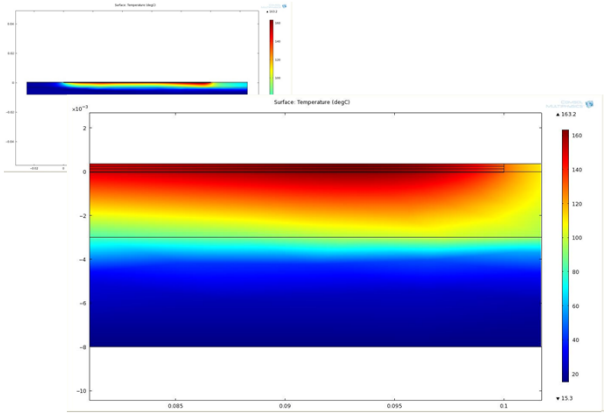
4.4E+3 n/cm^2/100uA (5m L/D=50)

Thermal and Mechanical design of target

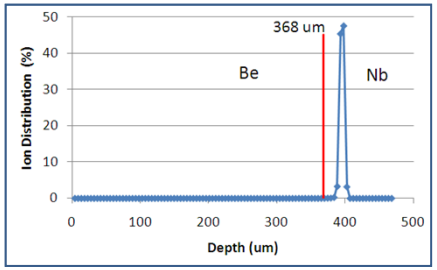
- Heat removal and structural strength is the most important factor for stable operation of compact neutron source. Thermal propoerties are simulated using FEM code by fluid-thermal combined analysis. Hydrogen damage caused by proton beam is considered in terms of hydrogen diffusion in metals and hydrogen embrittlement effect to avoid blistering.



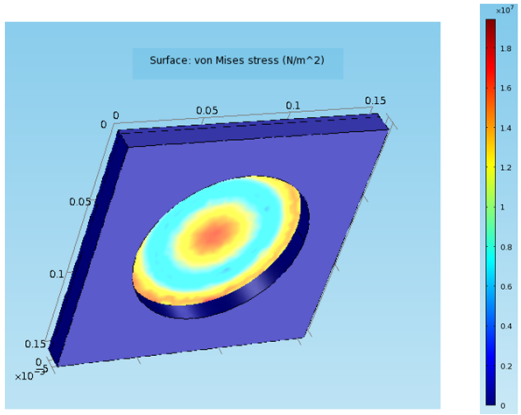
Basic design concept



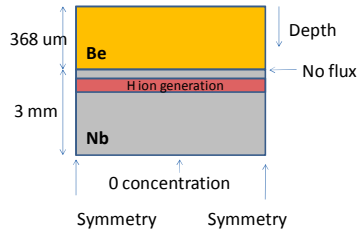
Heat removal by water cooling

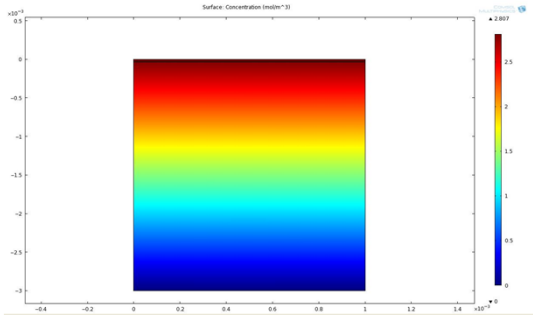


Hydrogen distribution by SLIM



Mechanical strength consideration





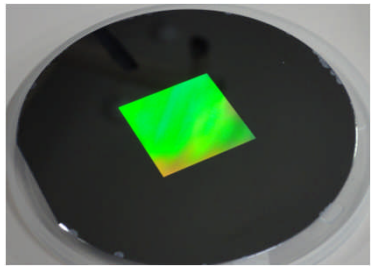
Hydrogen diffuse model analysis

Neutron detectors and optics development at RIKEN

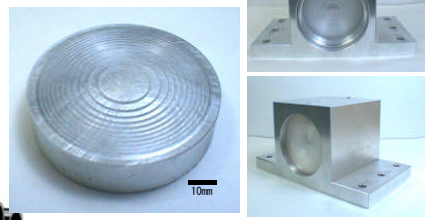
- Neutron optics

Ellipsoidal neutron mirror
Ultra High Precision machined mirror with multilayer coating (used in mf-SANS)

Neutron diffraction gratings

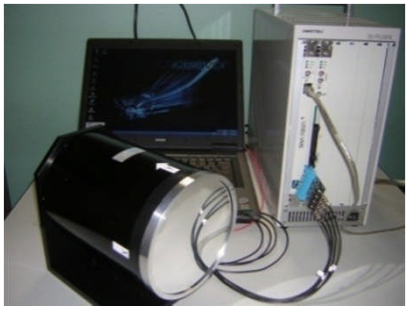


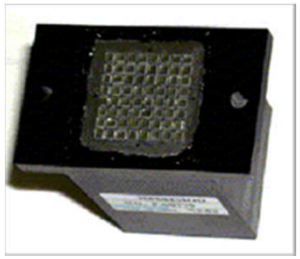
Neutron Lens



Neutron Detectors

RPMT
Register netowork PhotoMutiplying Tube type detector. 2D Position sensitive and counting mode. Capble of doing pulse neutron spectrometry.





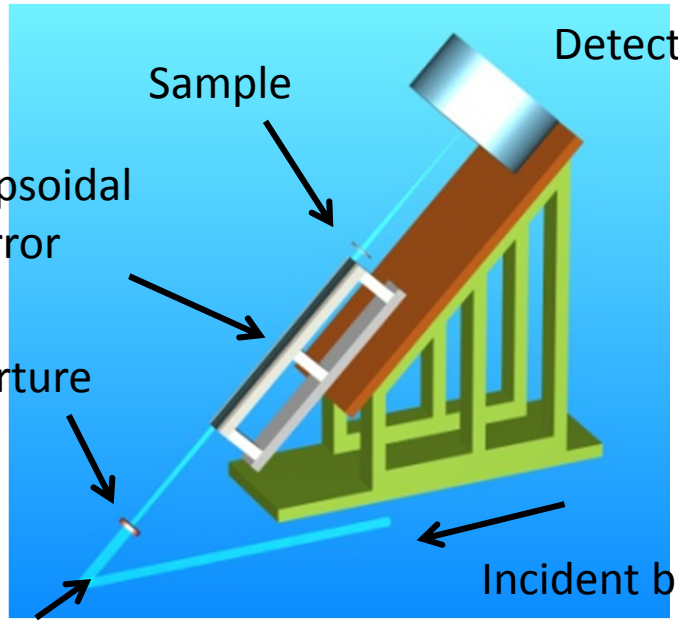
Pixel type detector
High speed pixel detector capable of counting mode. Used in pulse neutron imaging.

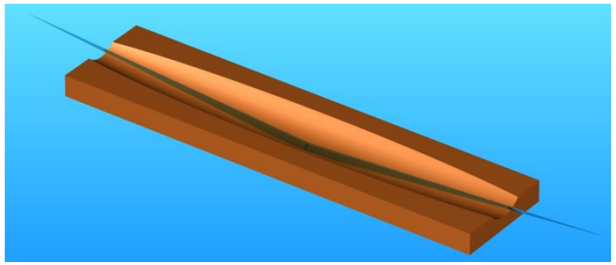
Imaging camera with CCD + Scintillator
6LiF+ZnS scintillator and cooled, intensified CCD

Scattering experiments using compact neutron source

- Unlike high-intensity spallation neutron source facilities, flux of compact neutron source is limited. So, effective method of scattering experiment is limited.

mf-SANS at JRR-3





Ellipsoidal mirror (0.9m) for mf-SANS

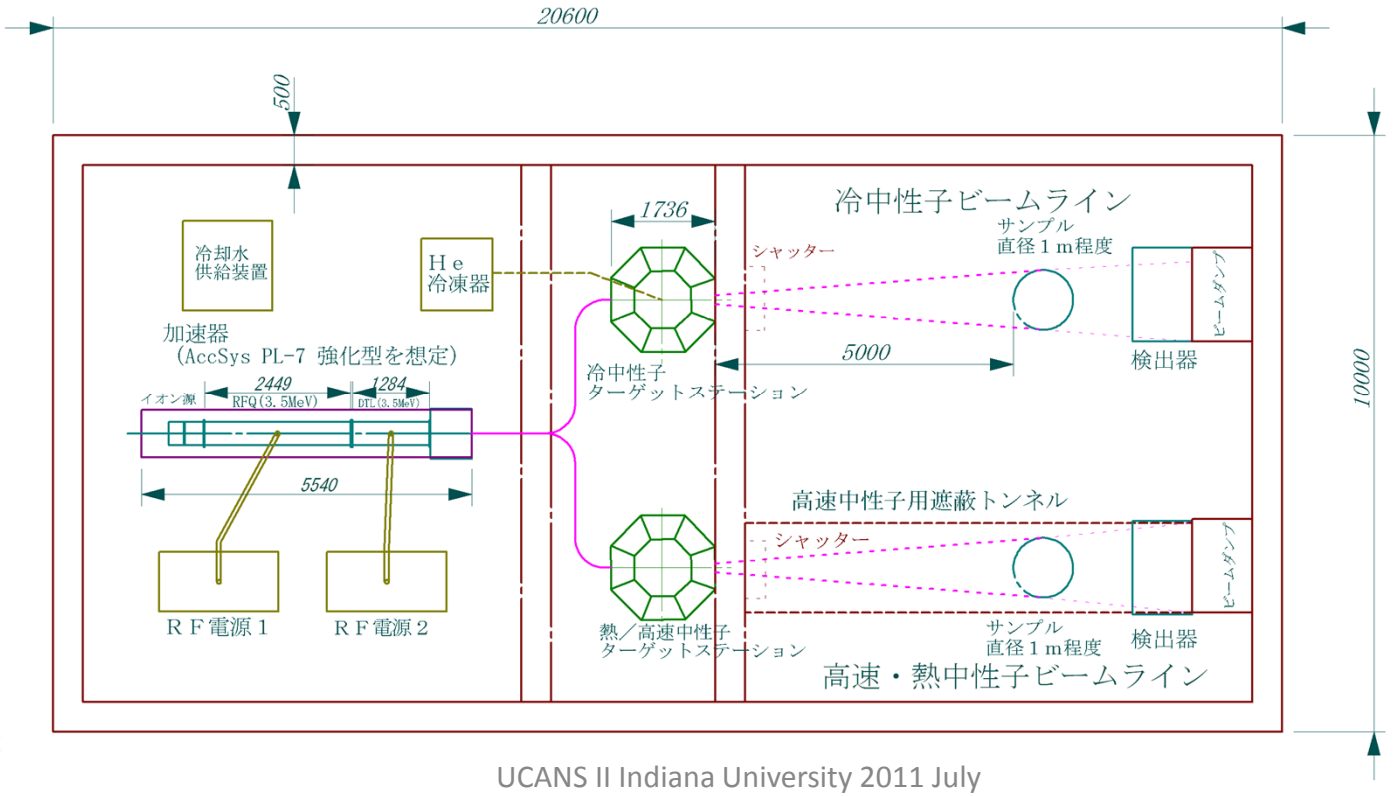
mf-SANS utilizes neutron optics to effectively increase the resolution with very small instrument size (~ 2m)

mf-SANS may be an effective way for scattering experiment at CNS

- mf-SANS may be able to obtain useful data with relatively low neutron flux
- small angle and middle angle scattering may be possible with same instrument

Expected plan of the facility

- Facility space of 10mx20m
- 7 to 10 MeV proton linac (start with current 100uA and upgrade to 3mA)
- Thermal and cold TMR
- Thermal beamline for neutron radipgraphy
- Cold beamline for mf-SANS and pulse imaging



Conclusion

- A plan for compact neutron source at RIKEN is in progress.
- Compact neutron source will be very important for industry users and may expand the users of neutrons.
- Design and plan of RIKEN-CNS is under way based on proton linac.

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