

# **PROPOSAL FOR A COMPACT NEUTRON GENERATOR BASED ON A NEGATIVE DEUTERIUM ION BEAM**

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Kouichi Jimbo, Toshiyuki Shirai  
*National Institutes for Quantum Science and Technology,  
Accelerator and Medical Physics, Chiba, 263-8555, Japan*

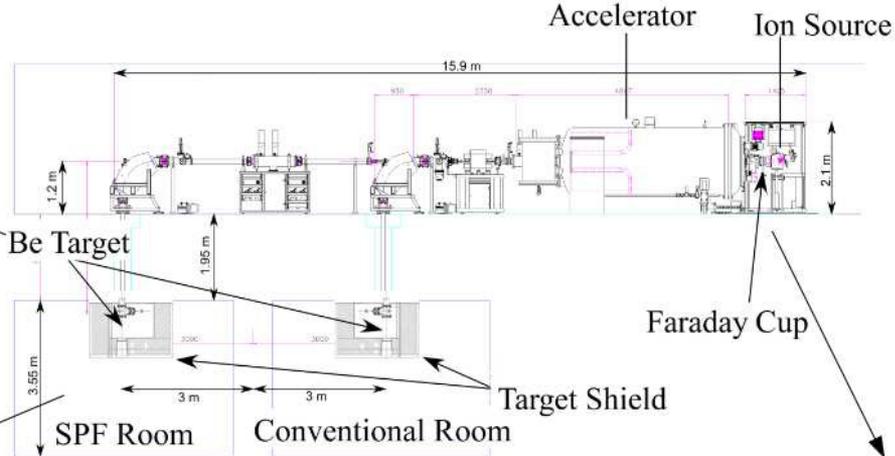
Ka-Ngo Leung, Karl van Bibber  
*Department of Nuclear Engineering, University of California Berkeley,  
Berkeley CA 94720, U.S.A.*

# NASBEE

(the neutron exposure accelerator system for biological effect experiments)



Be Target +  
Cooling Water Jacket



## Biological Effects of Fast Neutron Radiation Research



In SPF  
Experimental Room



Irradiation Stage



Mice Holder on  
Irradiation Stage



2-MV Tandatron  
Accelerator

# Need of widely available neutrons

Neutron radiation effect studies on integrated circuits, geochronology, medical isotope studies, nuclear data for reactor design, etc are necessary.

A compact neutron generator that could be affordably acquired, and occupy an ordinary size laboratory room of a university or a private company, is demanded.

# Neutron generators with Accelerators

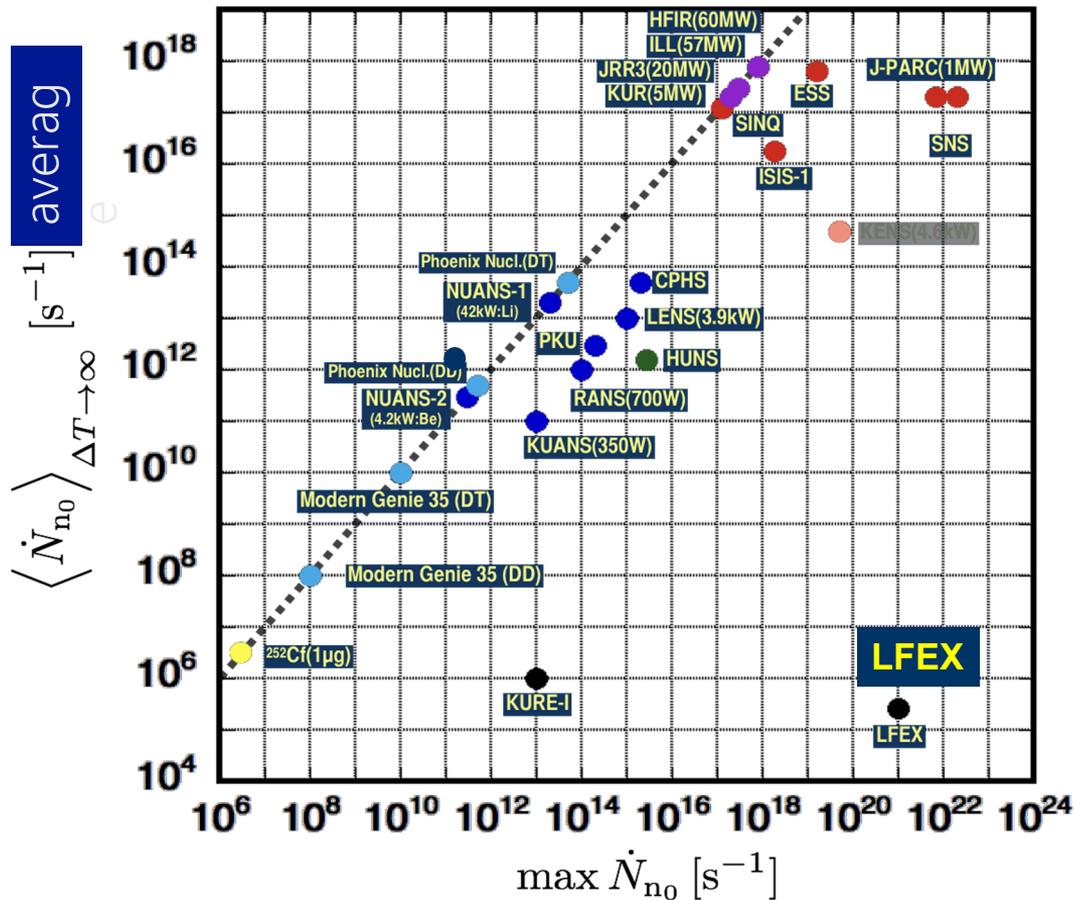
- Nuclear (d, n) and (p, n) process
- bombarding particles energy is large ( $\geq 1\text{MeV}$ )
- the generator is large



Most popular neutron generators in Japan

# Neutron Production Rate

By the courtesy of  
Prof Shimizu,  
Nagoya Univ.

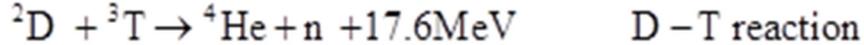


Proprietary :  
Fundamenta  
ls Working  
Group,

Japanese  
Society for  
Neutron  
Science

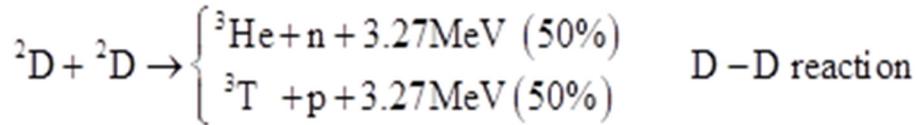
# Compact Neutron Generators without Accelerator

- Nuclear fusion (d, t) and (d, d) processes
- bombarding particles energy is small ( $< 1\text{MeV}$ )
- the generator is small



The carry off energy of neutrons is  $14.1\text{MeV}$ ,  
while the Q-value is  $17.6\text{MeV}$ .

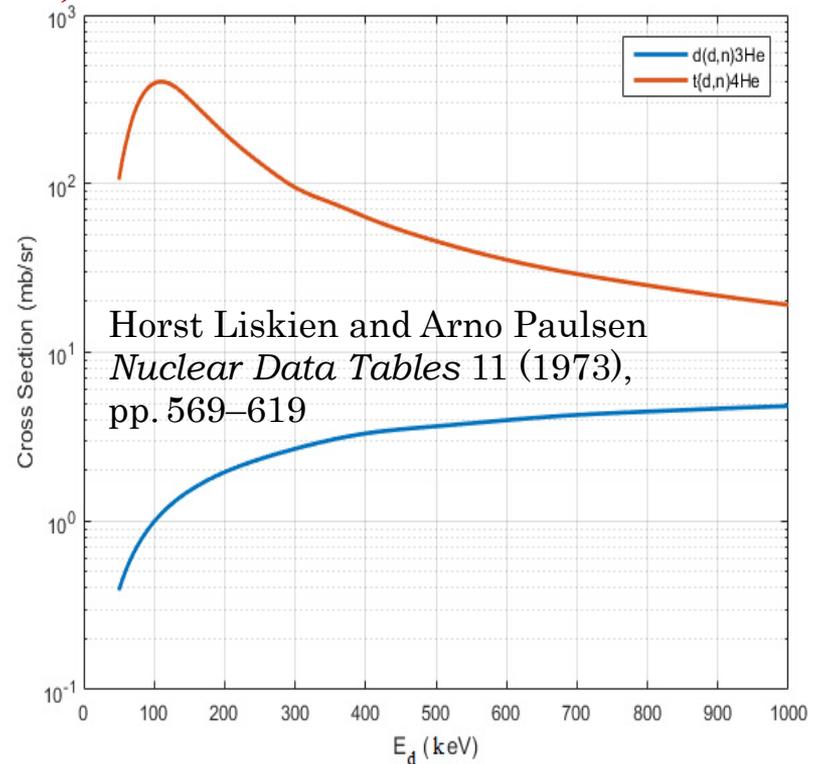
→ A lot of difficulties in handling



The carry off energy of neutrons is  $2.45\text{MeV}$ .  
while the Q-value is  $3.27\text{MeV}$ ,

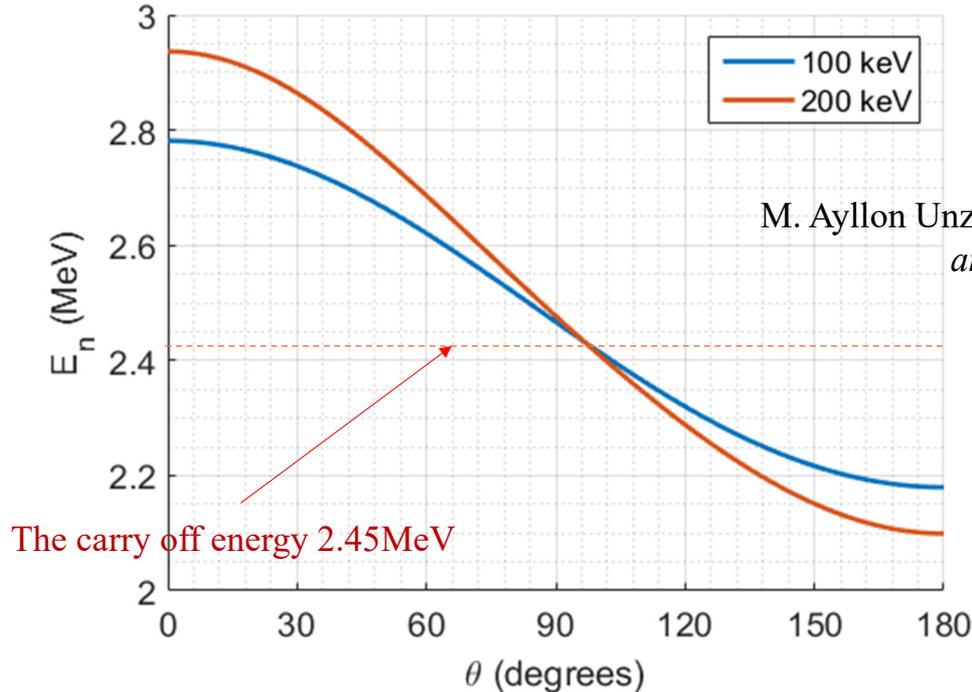
→ Accelerating voltage of D ion should  
be large or a large current is necessary.

Laboratory reference frame cross section  
with a neutron in the exit channel



# Direction dependent mono-energetic neutrons

Isotopically produced fusion neutrons,  
their energy depends on their directions on the laboratory frame.



M. Ayllon Unzueta et al., *Nucl. Instrum. and Meth. Phys. Res. A*, 903, 193 (2018)

Neutron energy  $E_n$  at different lab emission angles  $\theta$  for 100 and 200 keV deuterium energies for D-D fusion reactions in the lab reference frame.

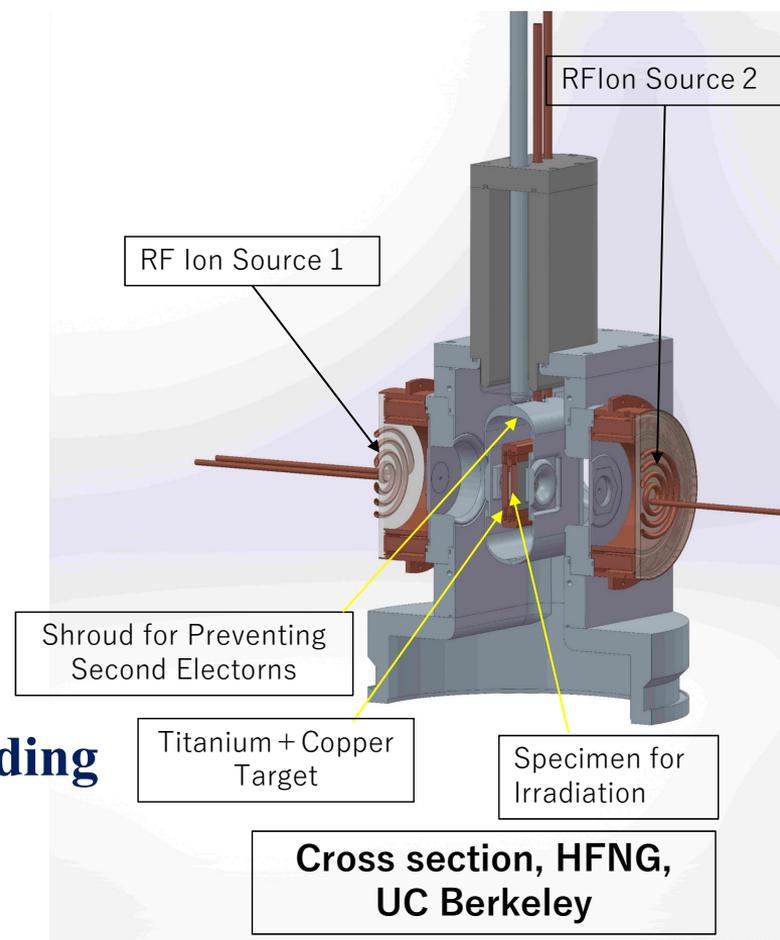
# D-D fusion based Neutron Generator High Flux Neutron Generator (HFNG)

Ka-Ngo Leung, Karl van Bibber  
Nuclear Engineering, UC Berkeley

Two symmetrically located RF D<sup>+</sup> ion sources (19cm in diameter and 1m width)  
In their middle, a specimen is irradiated.

D atoms in the titanium target are **self-loading**

D<sup>+</sup> ions are accelerated to 125keV,  
and the neutron energy is 2.8MeV.



M. Ayllon Unzueta et al., *Nucl. Instrum. and Meth. Phys. Res. A*, 903, 193 (2018);

## Good point of HFNG

RF multi-cusp ion source

→ RF antenna locates outside the vacuum chamber and maintenance is easy.

## Problem of HFNG

Since Titanium target located 6~9 cm away is irradiated by 125keV D<sup>+</sup> ion beam, a lot of **secondary emission electrons**, which impede the beam irradiation and damaging the ion source, are produced.

Since titanium has low thermal conductivity, titanium target, in which titanium is bonded on the water-cooled copper plate, is easily destroyed.

# How beat these difficulties ?

To suppress the secondary emission electrons.

→ **D<sup>-</sup> (Negative ion) source should be introduced .**

To obtain a reliable target to produce neutrons,  
stable titanium bounding conditions have to be preserved.

→ **Copper target should be introduced.**

# Neutron production reference data by $D^-$ ion beam

In JT60U (Upgrade) NNBI (negative neutral beam injector) experiment 25 years ago at JAERI Naka site, Fig.1 shows neutron production yields near the water cooled copper made beam dump.

Red circles shows  
 $3 \times 10^{12}$  neutron/sec  
under 410keV 10A  $D^-$  ion beam

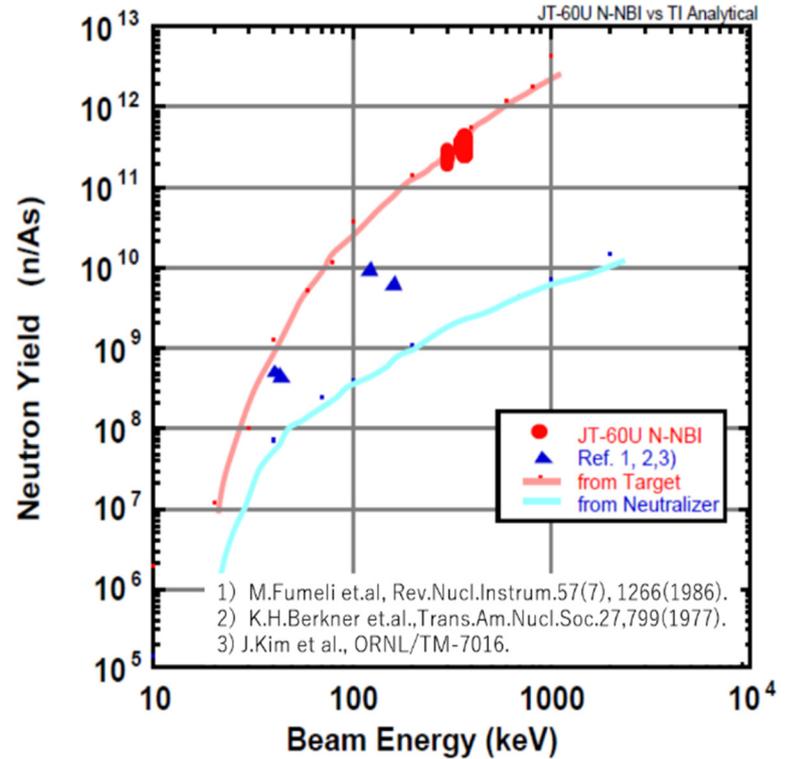
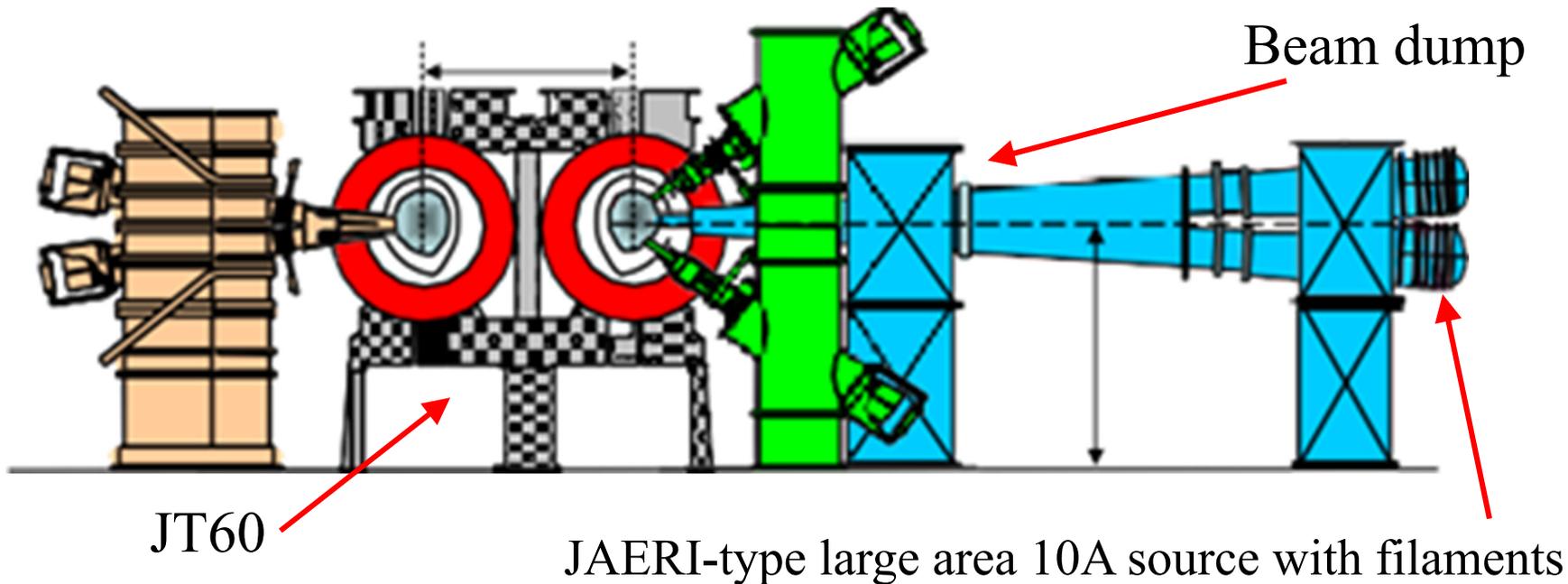


Fig.1 : DD neutron generation from beam-solid interaction based on J.Kim's model.

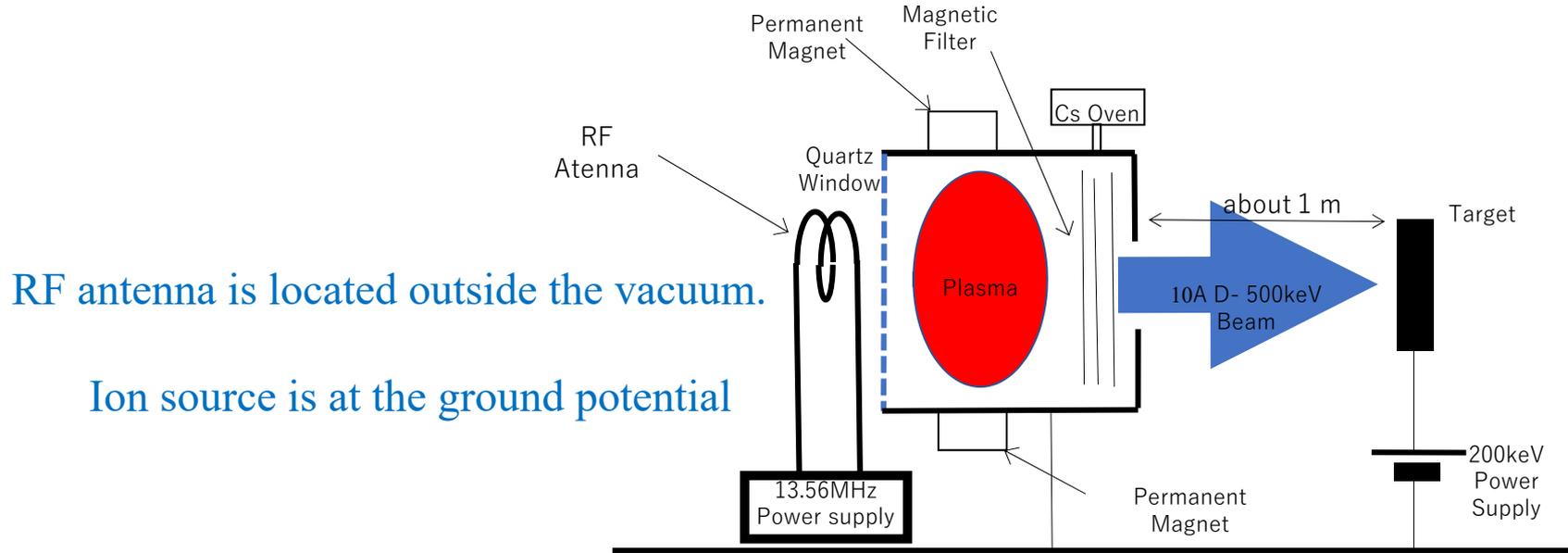
→ T.Inoue, IdoMS N53 DDD 26 98-06-12W

# JT60U and the copper beam dump of the negative neutral beam injection systems (NNBIs) of at QST, Naka.



→ M. Kuriyama et al., "Negative-ion based NBI system for JT-60U,"  
Proceedings of the 16th International Symposium on Fusion Engineering, 1995,  
pp 491-496 Vol.1, doi :10.1109/FUSION.1995.534267.

# Our proposal for a compact neutron generator



RF antenna is located outside the vacuum.

Ion source is at the ground potential

## Conceptual diagram of the compact neutron source with RF D<sup>-</sup> negative ion source

Using RF D<sup>-</sup> ion source and copper target,  
We can construct a reliable  $1.0 \times 10^{10}$  neutron/sec  
CW neutron generator by **100mA 200keV** D<sup>-</sup> beam.

# Conclusion

Considering the result of HFNG,

in the finite area near the target,

$1.0 \times 10^9$  neutrons /cm<sup>2</sup>secCW would be obtained stably.

We can construct

a compact mono-energetic neutron generator,  
in which energies depend on the direction.