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

The 13th International Particle Accelerator Conference (IPAC’22)
IMPACT Exhibition and Convention Center,
Muang Thong Thani, Bangkok, Thailand
tentatively scheduled on 15-JUN-22)

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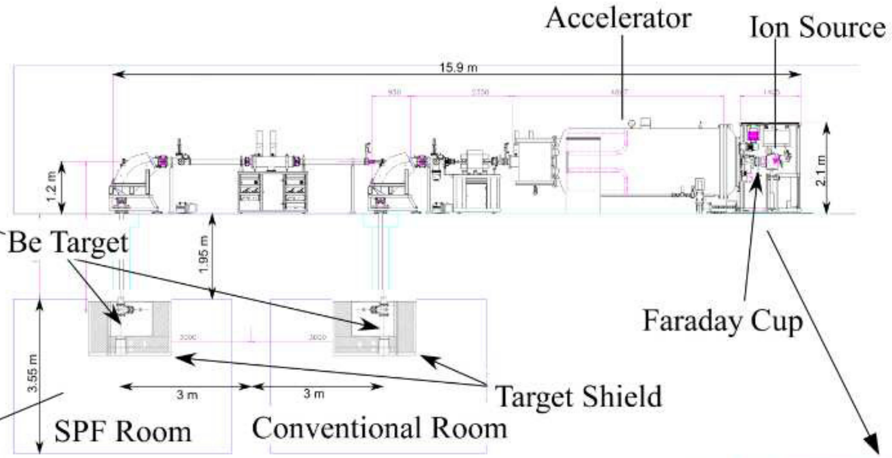
NASBEE

(the neutron exposure accelerator system for biological effect experiments)

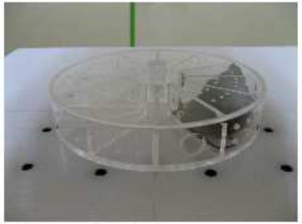
Be Target +
Cooling Water Jacket



Biological Effects of Fast Neutron Radiation Research

In SPF
Experimental Room

Irradiation Stage



Mice Holder on
Irradiation Stage

2-MV Tandetron
Accelerator

National Institutes for Quantum Science and Technology,
Accelerator and Medical Physics

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 (≥ 1MeV)**

→ **the generator is large**

$$ {}^{9}\mathrm{Be} + {}^{2}\mathrm{D} \rightarrow {}^{10}\mathrm{B} + {}^{1}\mathrm{n} + 4.36\mathrm{MeV} \qquad \mathrm{D-Be\ reaction} $$

$$ {}^{7}\mathrm{Li} + {}^{2}\mathrm{D} \rightarrow {}^{8}\mathrm{Be} + {}^{1}\mathrm{n} + 15.0\mathrm{MeV} \qquad \mathrm{D-Li\ reaction} $$

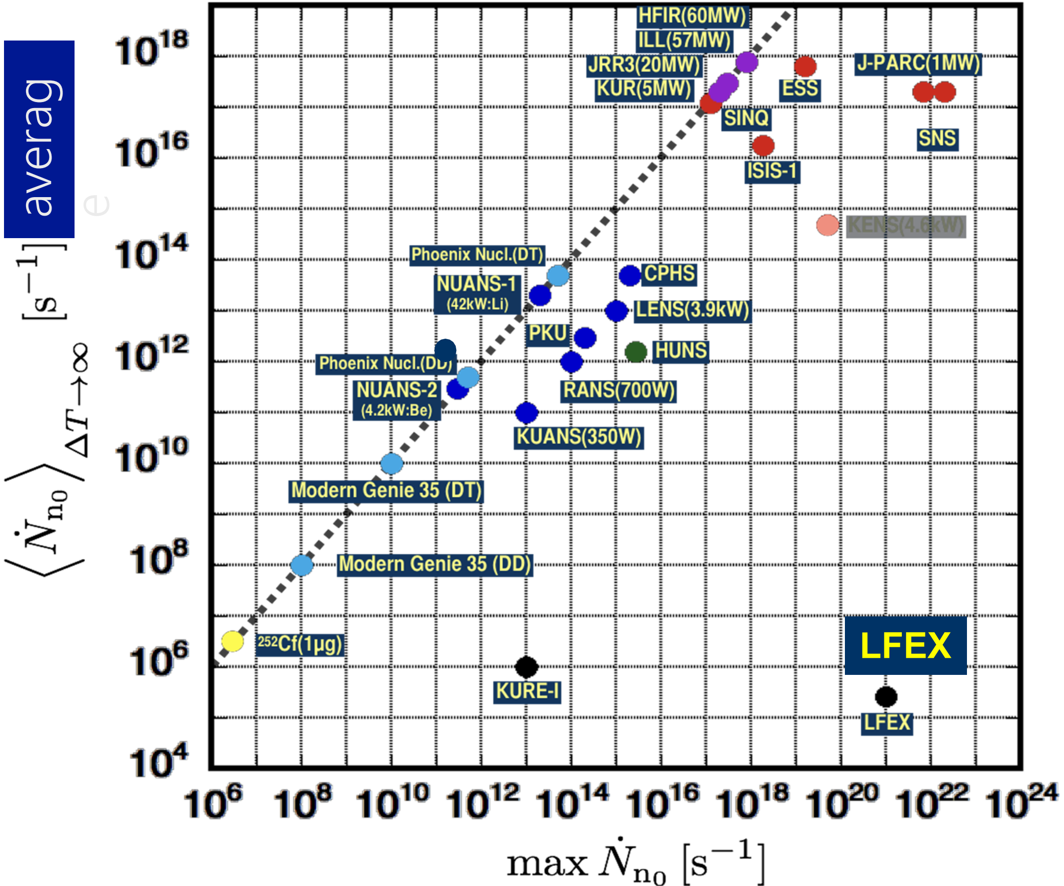
$$ {}^{7}\mathrm{Li} + {}^{1}\mathrm{H} \rightarrow {}^{7}\mathrm{Be} + {}^{1}\mathrm{n} - 1.64\mathrm{MeV} \qquad \mathrm{H-Li\ reaction} $$

$$ {}^{9}\mathrm{Be} + {}^{1}\mathrm{H} \rightarrow {}^{9}\mathrm{B} + {}^{1}\mathrm{n} - 1.85\mathrm{MeV} \qquad \mathrm{H-Be\ reaction} $$

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

peak

Compact Neutron Generators without Accelerator

→Nuclear fusion (d, t) and (d, d) processes
→ bombarding particles energy is small (< 1MeV)
→ the generator is small

$$^{2}D + {}^{3}T \rightarrow {}^{4}He + n + 17.6\mathrm{MeV} \qquad D-T \text{ reaction}$$

The carry off energy of neutrons is 14.1MeV,
while the Q-value is 17.6 MeV.

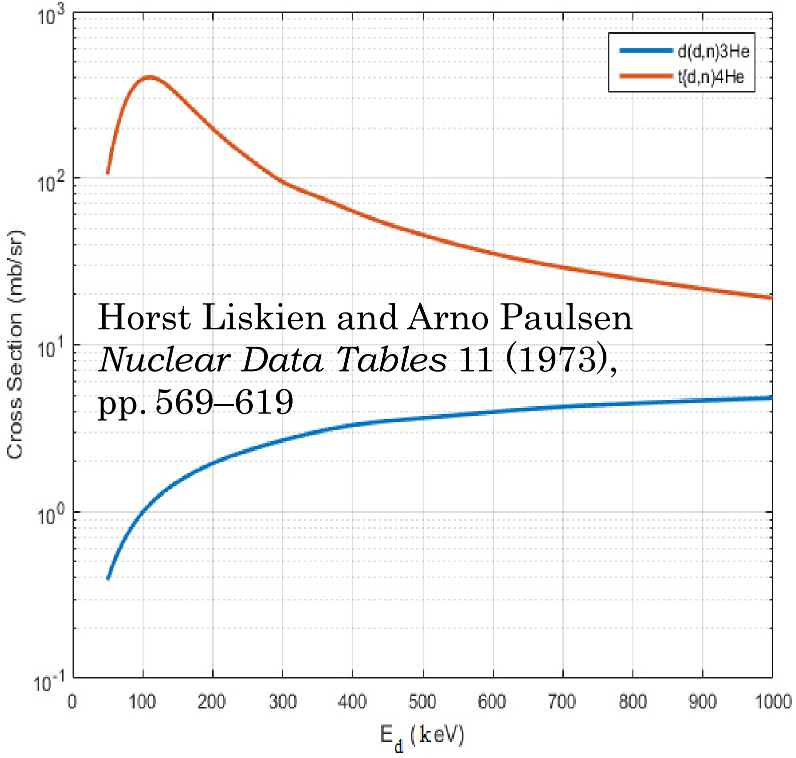
→ A lot of difficulties in handling

$$^{2}D + {}^{2}D \rightarrow \begin{cases} {}^{3}He + n + 3.27\mathrm{MeV}\ (50\%) \\ {}^{3}T\ + p + 3.27\mathrm{MeV}\ (50\%) \end{cases} \qquad D-D \text{ reaction}$$

The carry off energy of neutrons is 2.45MeV.
while the Q-value is 3.27 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

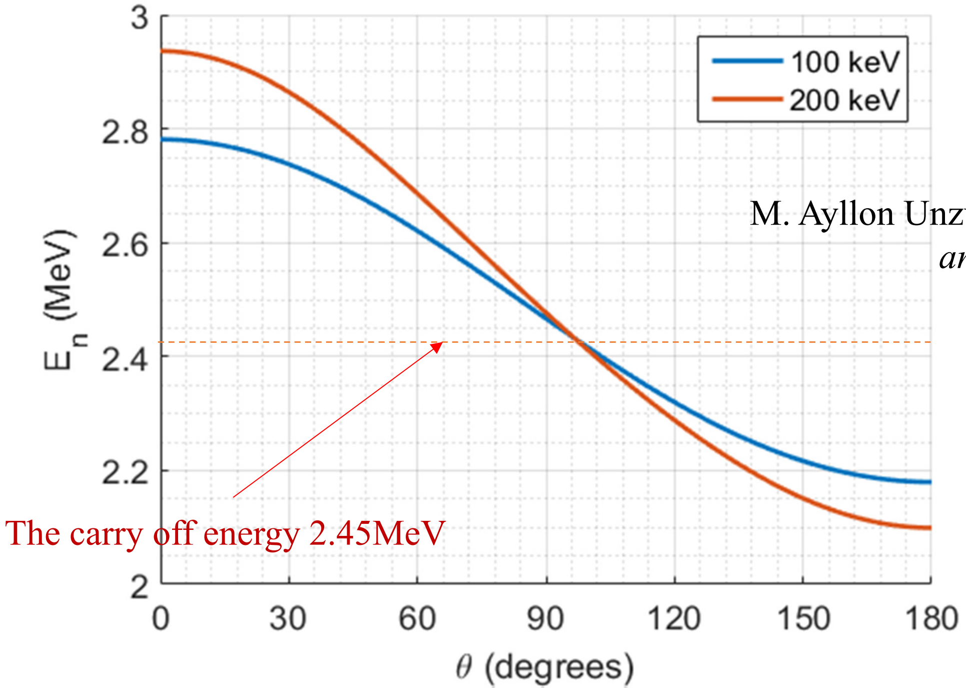


Horst Liskien and Arno Paulsen
Nuclear Data Tables 11 (1973),
pp. 569–619

Direction dependent mono-energic 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 En at different lab emission angles θ for 100 and 200 keV deuterium energies for D-D fusion reactions in the lab reference frame.

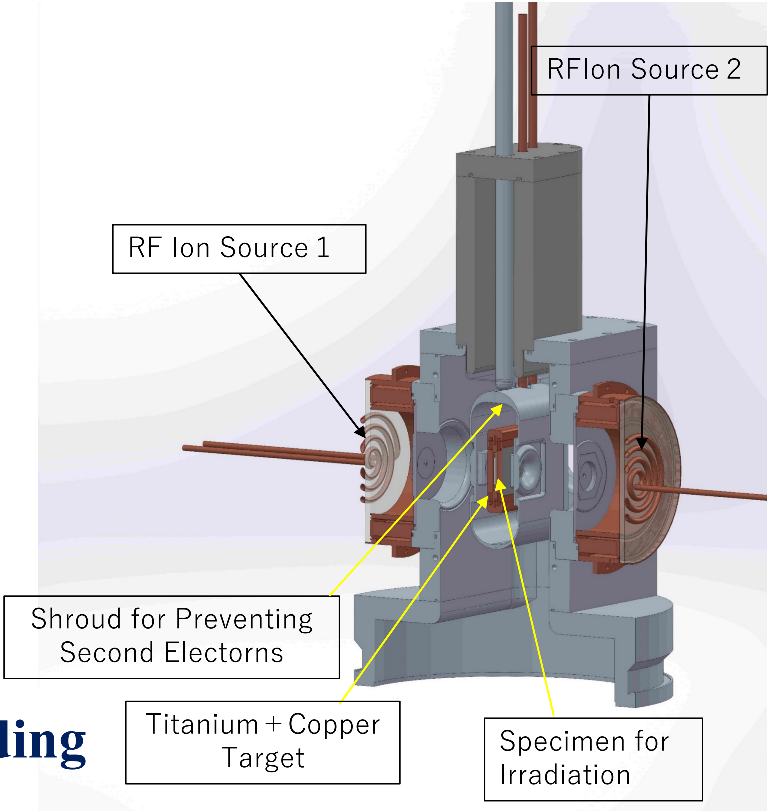
D-D fusion based Neutron Generator High Flux Neutron Generator (HFNG)

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

Two symmetrically located RF D+ 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+ ions are accelerated to125keV, and the neutron energy is 2.8MeV.



Cross section, HFNG, UC Berkeley

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+ 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^- **(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 bean injector)experiment 25 years ago at JAERI Naka site, Fig.1 shows neutron production yields near the water cooled copper made beam dump.

Red cicles shows

$$3\times10^{12}\,\mathrm{neutron/sec}$$

under 410keV10A D^- ion beam

。

→ T.Inoue, IdoMS N53 DDD 26 98-06-12W

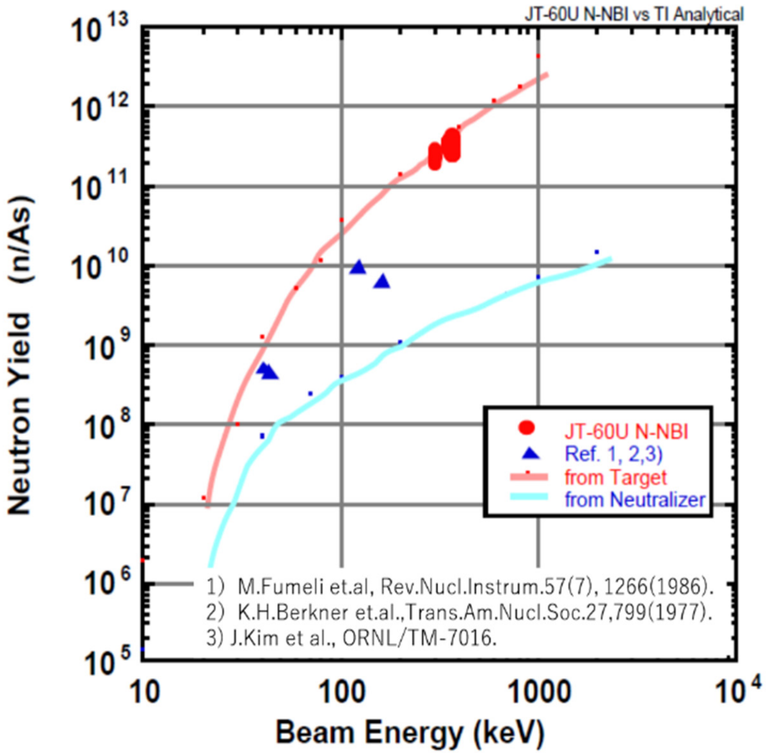
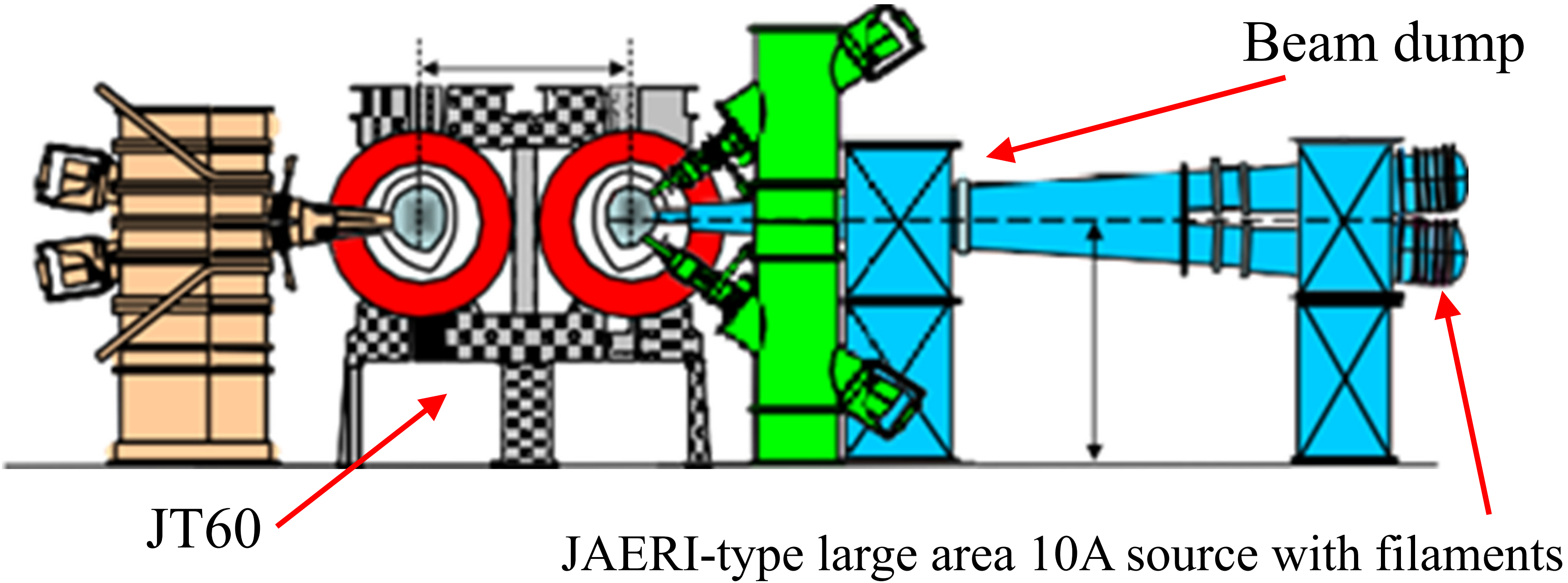


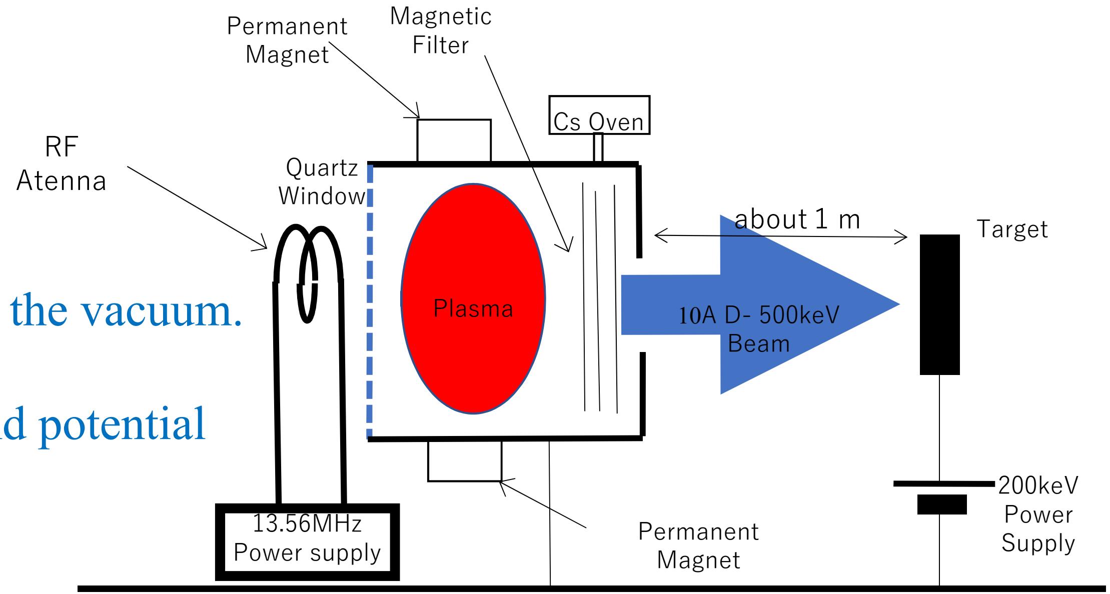
Fig.1：DD neutron generation from beam-solid interaction based on J.Kim's model.

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－negative ion source

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

Conclusion

Considering the result of HFNG,

in the finite area near the target,

1.0×10^9 neutrons /cm2secCW would be obtained stably.

We can construct

a compact mono-energetic neutron generator,

in which energies depend on the direction.