The Union for Compact Accelerator-driven Neutron Sources: Past, Present, and Prospects

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Günter S. Bauer (1941-2013)

photo courtesy of Jack Carpenter

Overview given by Jack Carpenter

Low-Energy Nuclear Reactions to be Optimized for CANS

Table 1 Neutron production from low-energy nuclear reactions

Reaction types	Examples	Neutron yield per event	Heat Deposit (MeV)	Residual Products & radiation
(p/d, xn)	^{7}Li(p,n)^{7}Be ^{9}Be(p,n)^{9}B ^{9}Be(d,n)^{10}B	~10^{-3}-10^{-2} n/p or n/d	~2000	Mostly γ, possibly t and accumulation of hydrogen
Fusion	^{2}H(d,n)^{3}He ^{3}H(d,n)^{4}He	~10^{-5} n/d	>3000	Mainly γ
Photonuclear	35 MeV e^- on a W target	~10^{-2} n/e	~2000	Mainly γ

Table 2 The neutron producing reactions considered by Drosg *et al*. [2002] as candidates for monoenergetic neutron sources.

Reaction types	Examples
(p,n)	^{3}H(p,n)^{3}He, ^{6}Li(p,n)^{6}Be, ^{7}Li(p,n)^{7}Be, ^{9}Be(p,n)^{9}B, ^{10}Be(p,n)^{10}B, ^{10}B(p,n)^{10}C, ^{11}B(p,n)^{11}C, ^{12}C(p,n)^{12}N, ^{13}C(p,n)^{13}N, ^{14}C(p,n)^{14}N, ^{15}N(p,n)^{15}O, ^{18}O(p,n)^{18}F, ^{36}Cl(p,n)^{36}Ar, ^{39}Ar(p,n)^{39}K, ^{59}Co(p,n)^{59}Ni
(d,n)	^{2}H(d,n)^{3}He, ^{3}H(d,n)^{4}He, ^{7}Li(d,n)^{8}Be, ^{9}Be(d,n)^{10}B, ^{11}B(d,n)^{12}C, ^{13}C(d,n)^{14}N, ^{1}4N(d,n)^{15}O, ^{15}N(d,n)^{16}O, ^{18}O(d,n)^{19}F, ^{20}Ne(d,n)^{21}Na, ^{24}Mg(d,n)^{25}Al, ^{28}Si(d,n)^{29}P, ^{32}S(d,n)^{33}Cl
(t,n)	^{1}H(t,n)^{3}He
(α,n)	^{3}H(α,n)^{6}Li, ^{7}Li(α,n)^{10}B, ^{11}B(α,n)^{14}N, ^{13}C(α,n)^{16}O, ^{22}Ne(α,n)^{25}Mg

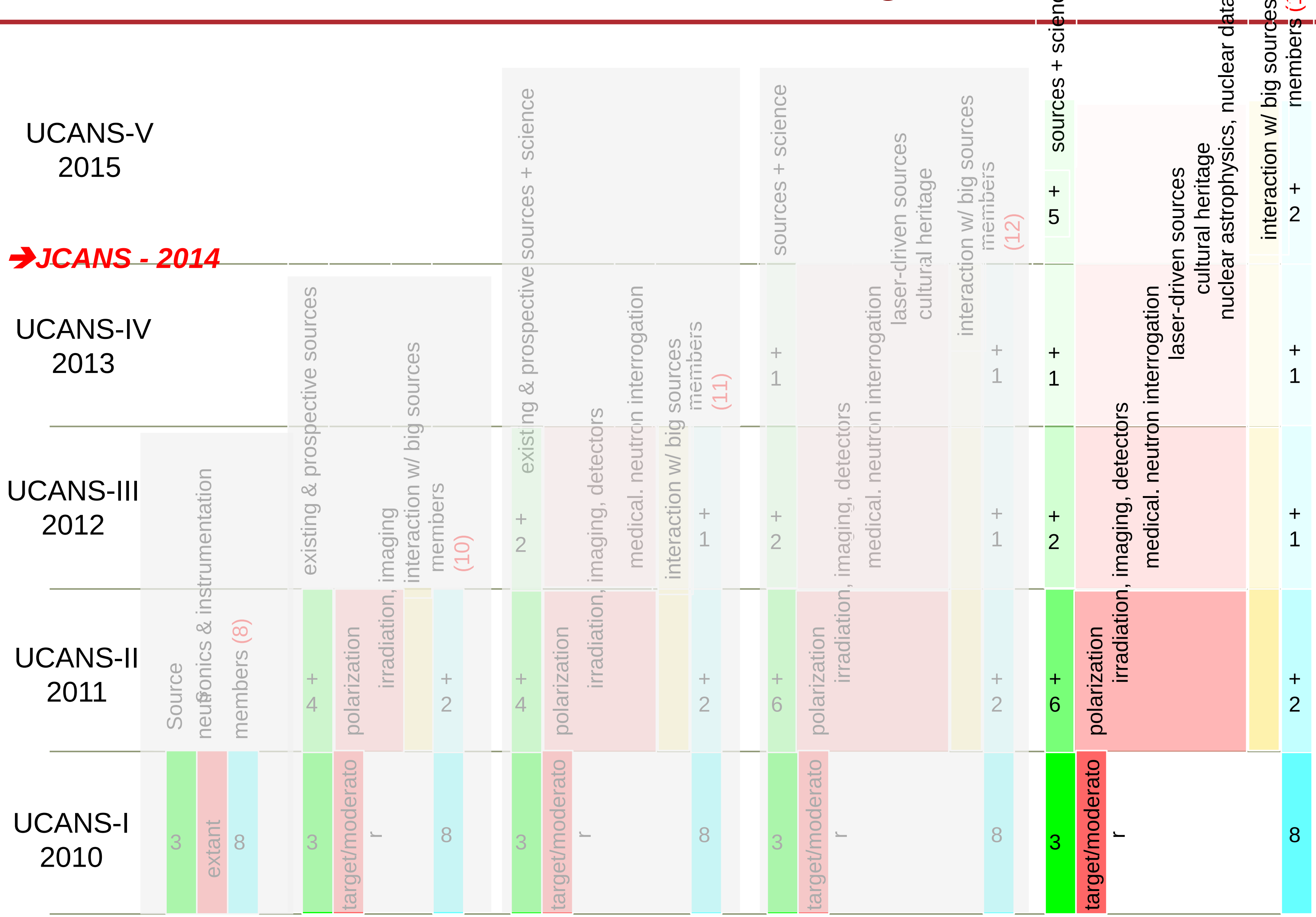
Cross-disciplinary applications each requires tailored configuration

Table 3. Preferred characteristics of CANS applications. The underlined items represent the preferred configurations.

Applications	Neutron-matter reactions		Accelerator systems	Neutronics & energies	Remarks
Interrogation of materials/structures	(n,γ)	PGNAA	P, CW	cold, thermal	Compact, rugged, transportable (portable for landmine detection & well logging), minimal innate γ background & large, scannable beams
		DGNAA	P, CW	cold, thermal	
		NRCA	P, CW	epithermal	
		FNAA	P, CW	fast	
		APT	P (ns)	$D(T,\alpha)n$, E_n=14MeV	
Radiography & imaging	(n,γ)	+ PGNAA	P, CW	cold, thermal	Combined tomographic and activation analysis techniques, neutron polarization analysis of magnetic materials
		+ NRCA	P, CW	epithermal	
		+ FNAA	P, CW	fast	
		RITS	P	thermal	
		polarization	P, CW	cold, polarized	
Irradiation effects on electronics	Neutron-induced soft errors (SEU)		<u>P</u>, CW	fast, selective	High flux to speed up testing/certifying processes, matching test and environmental spectra
Neutron capture therapy	BNCT		P, CW	epithermal	Compact and suitable for operation in hospitals, good flux and clean beam, development of boron-bearing pharmaceuticals
Isotope production	$^{N}X(n,\gamma)X^{N+1*}$		CW	selective	Compact, prevalently located near isotope processing and generation facilities
Nuclear data & cross section measurements	reaction & scattering		<u>P</u>, CW	all	Flexible and multi-purpose beamline and endstations
Nuclear astrophysics	n-capture, β-decay, (n,γ) decay rate, calorimetry		<u>P</u>, CW	fast	High-intensity beams needed for microgram samples
ADS science & technology	subcritical fission, transmutation		P	thermal to epithermal (?)	Intense beams & reliable operation

Andreani et al. (2015)

Collaboration: UCANS' Endeavoring Roles

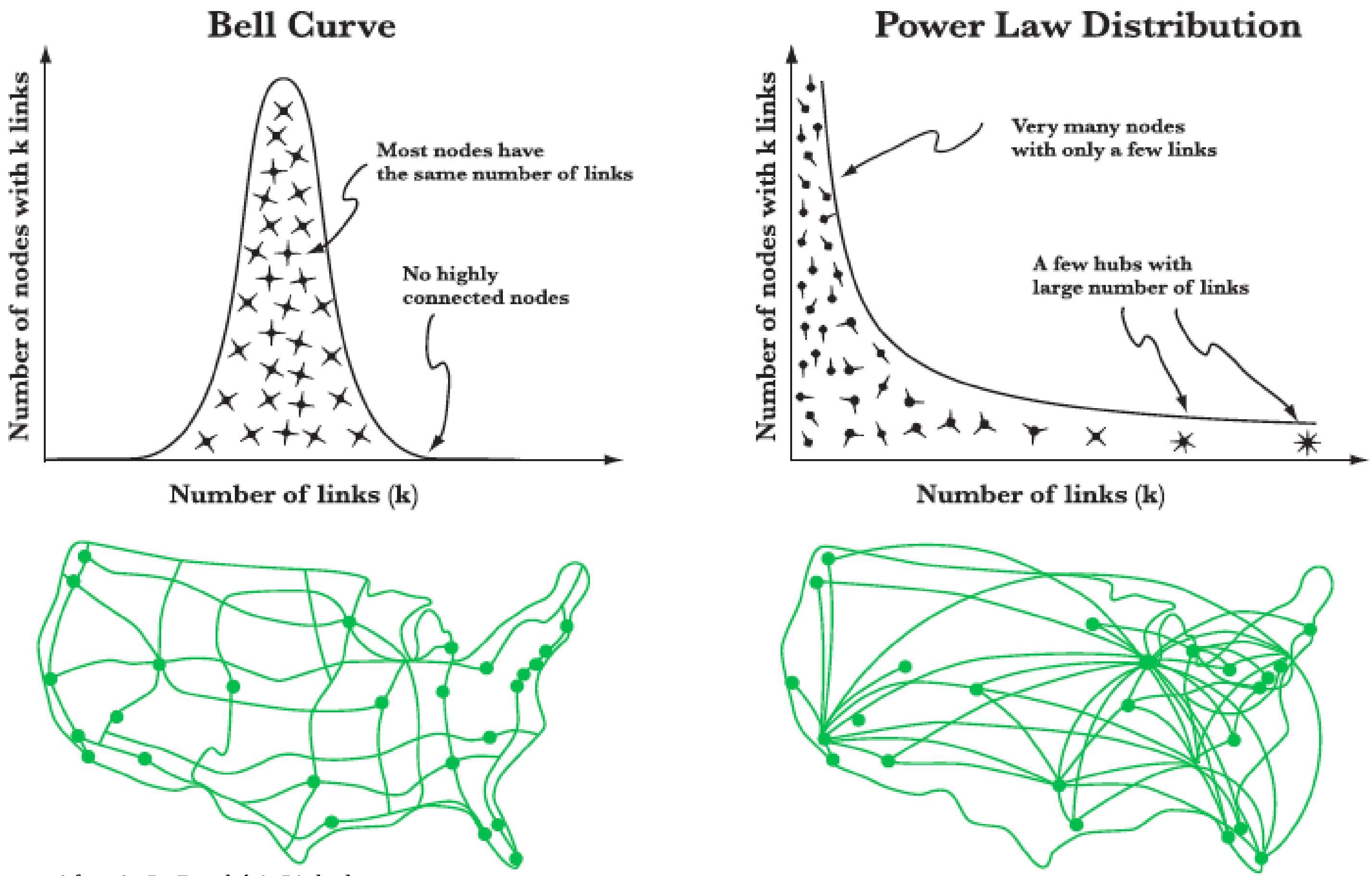


This slide needs to be checked and brought up to date

A. Maintain connectivity & momentum between meetings

1. Upkeep of a master mailing list
2. Tending an attractive & informative website
   http://ucans.org/ by Hiro Shimizu (Nagoya U.)
3. Posting all the presentations for download
4. Expedite proceedings publication
   Gianfranco Prete (INFN), editor
5. Report of UCANS progress (a set of thematic papers) in The European Physical Journal EJP Plus
   1st session: Carla Andreani (U Rome), G. Prete, C. Loong, guest editors
6. …

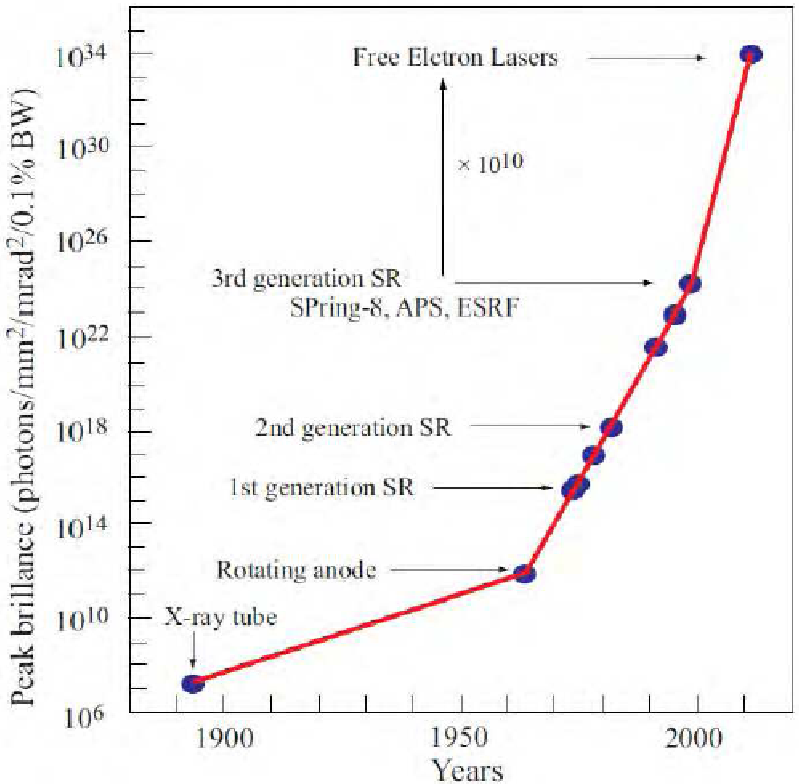
B. Networking

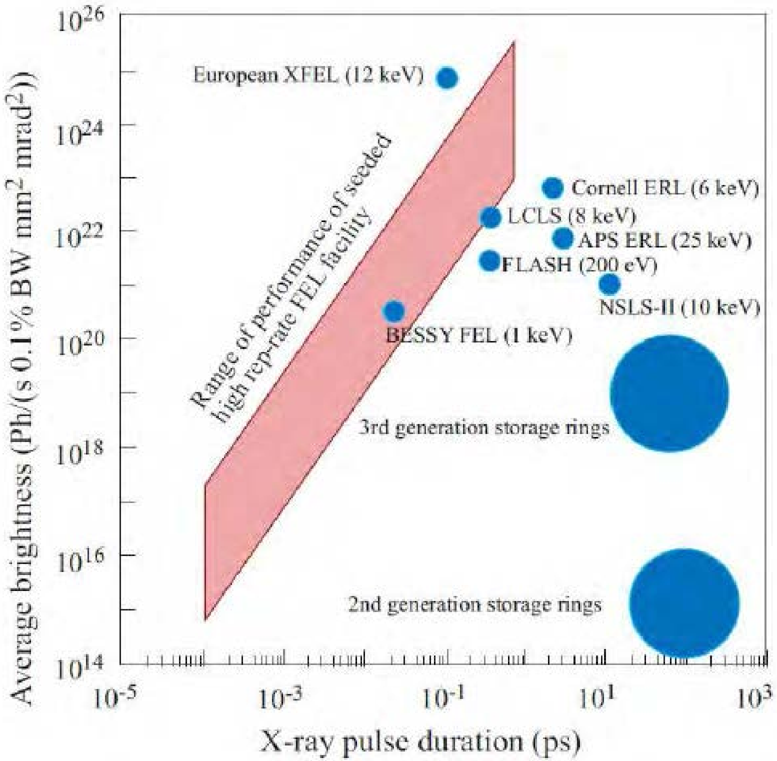


After A.-L. Barabási, *Linked*

Each UCANS member acts as a hub in a CANS Network; elects a correspondent to communicate highlights.

C. Challenges & Competitions





To inspire young talents, helping them to realize the unique advantage of neutrons and to empower the complementarity between neutrons and photons for the best science.

3 Books about CANS:

Neutron Scattering Applications and Techniques (Springer)

Series Editors: Ian Anderson, Alan Hurd, & Robert McGreevy

Upcoming volumes:

Compact Accelerator Driven Neutron Sources: Physics, Technology and Applications

Editors: David V. Baxter (Indiana U), Michihiro Furusaka (Hokkaido U), & Chun Loong

Neutron Experimental Methods in Cultural Research

Editors: Nikolay Kardjilov (Helmholtz-Zentrum Berlin) and Giulia Festa (U Rome)

E. Novel ultra-compact 'neutristors'

Novel Surface Mounted Neutron Generator (Neutristor)

- J. Elizondo-Decanini at Sandia National Laboratories in the U.S. has been developing a compact neutron source based on surface deposition and lithography
- Original development motivation is for cancer therapy
  - Introduce ^{10}B into cancer cell
  - $n + {}^{10}B \rightarrow {}^{4}He + {}^{7}Li + \gamma$
    - α and ^{7}Li cause local cell damage
- To prevent damage to healthy cells put the source as close as possible to target
- Goals:
  - Small
  - Inexepensive

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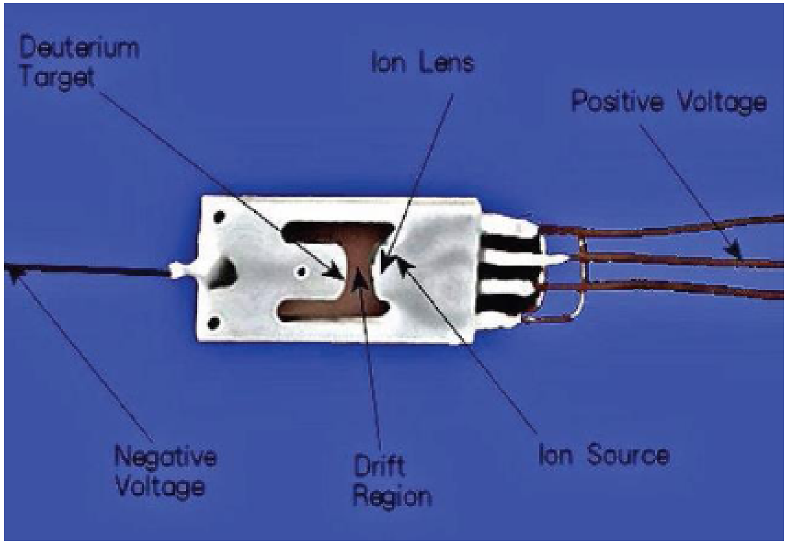
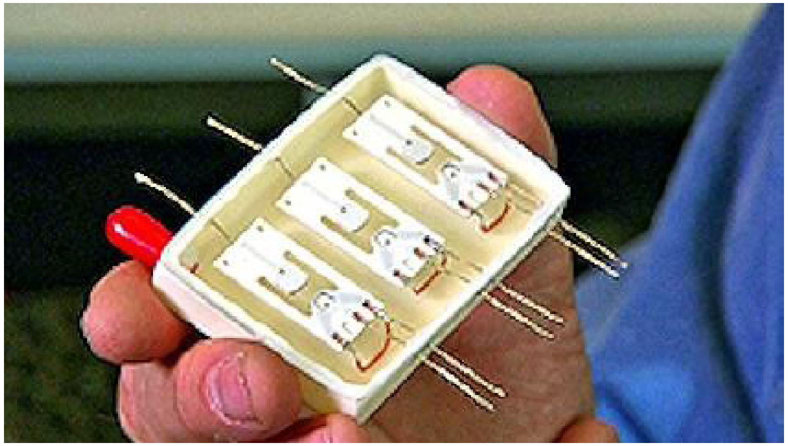
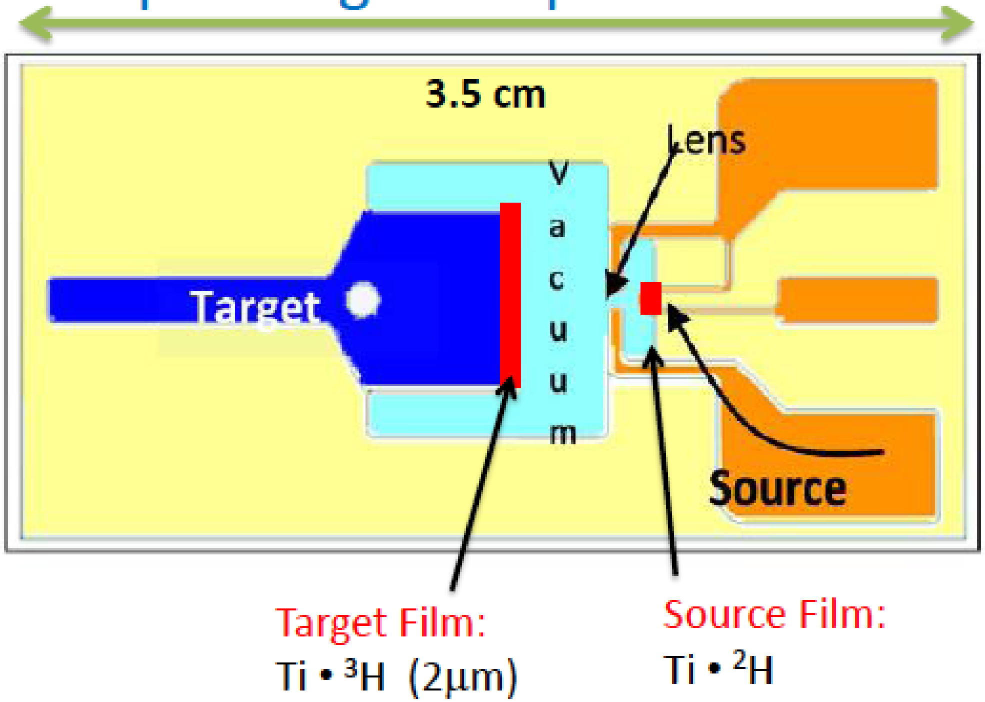




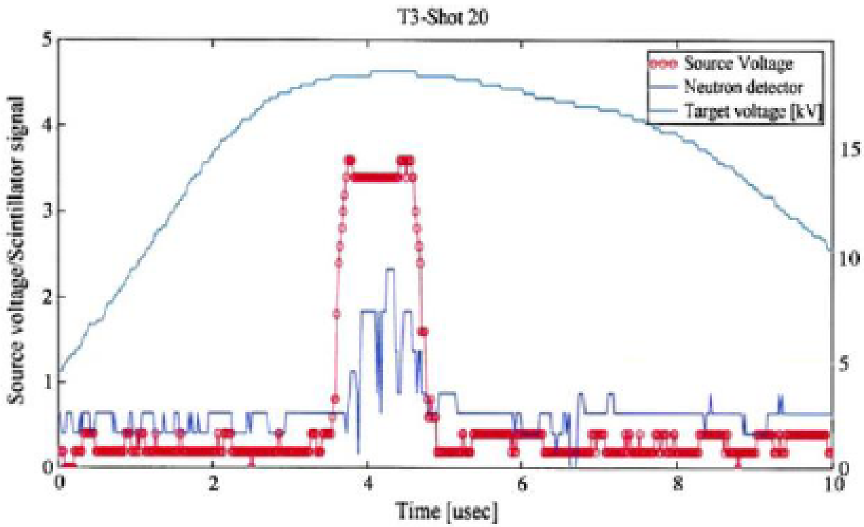
Roger Wendell, 2014

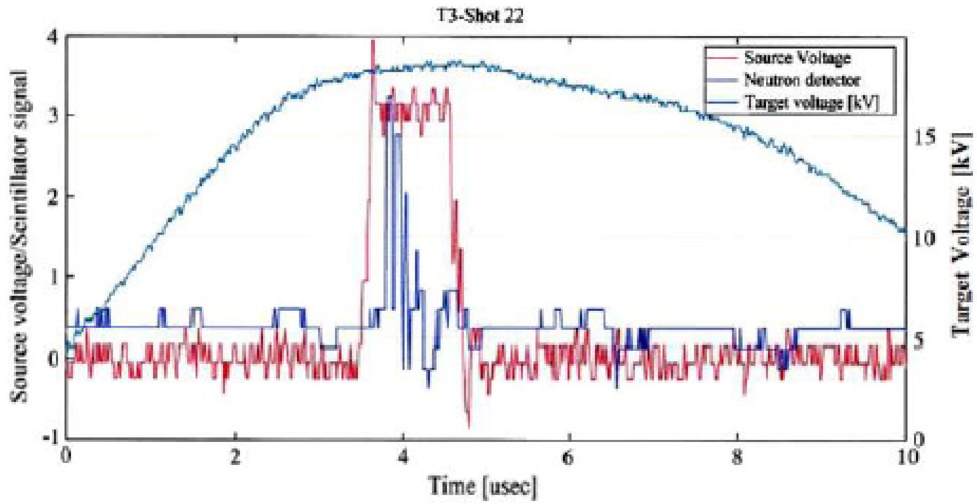
Neutristor : The Operating Principal



- Deuterium and Tritium thin films are deposited onto to the ion source and target elements
- Applying O(300)V at the source gap causes breakdown and the formation of an arc. The arc heats the source film releasing deuterium into the vacuum and ionizing it at the same time
- An accelerating voltage O(15)kV across the target is used to accelerate $^{2}H^{+}$ (etc.) ions onto the target film to induce D-T fusion
- An electrostatic lens is used to focus the ion flow to the target

Neutristor : Performance





- Several prototype devices have been built and operated successfully

- Source voltage 600 V (>150 kV/cm at ion source gap)
- Target (accelerating voltage) 20 kV trapezoid, 10µs in duration

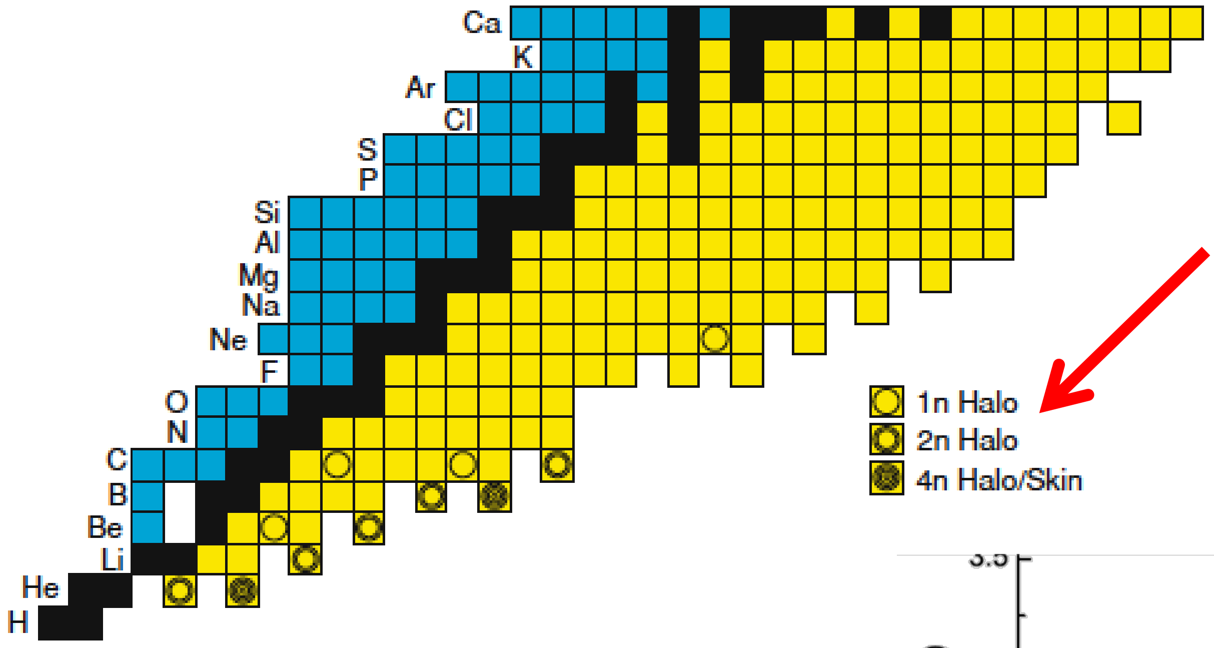
- Produces ~2000 n per pulse (10^9 n/s)
- Long rep time O(60) s to allow the device to cool

- Principal of operation is proven

F. Halo Nuclei

Borromean Rings – A coat of arms and symbol of the Renaissance Borromean Family in north Italy. If one ring is removed, all rings fall apart.

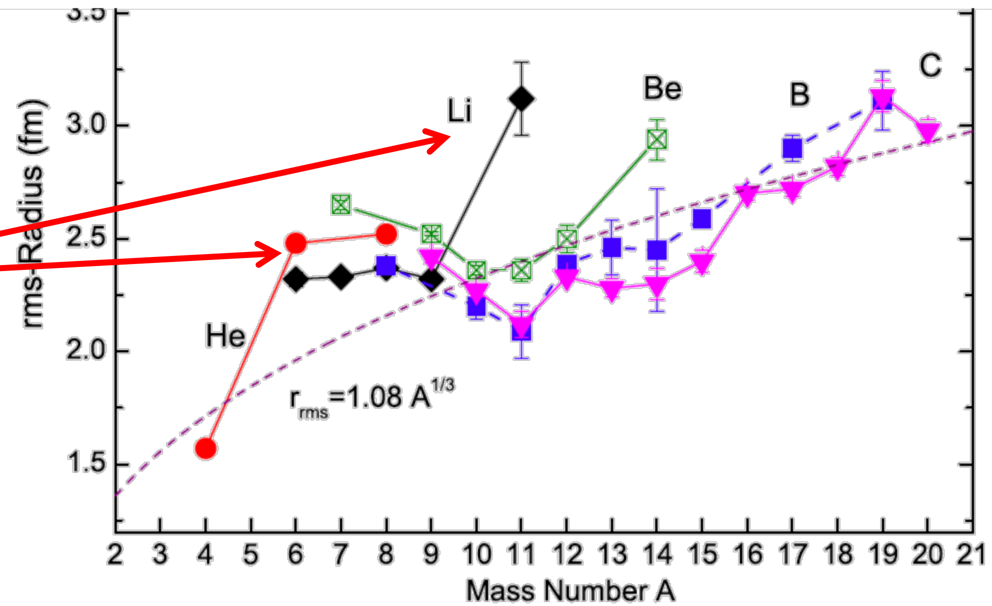
F. Halo Nuclei



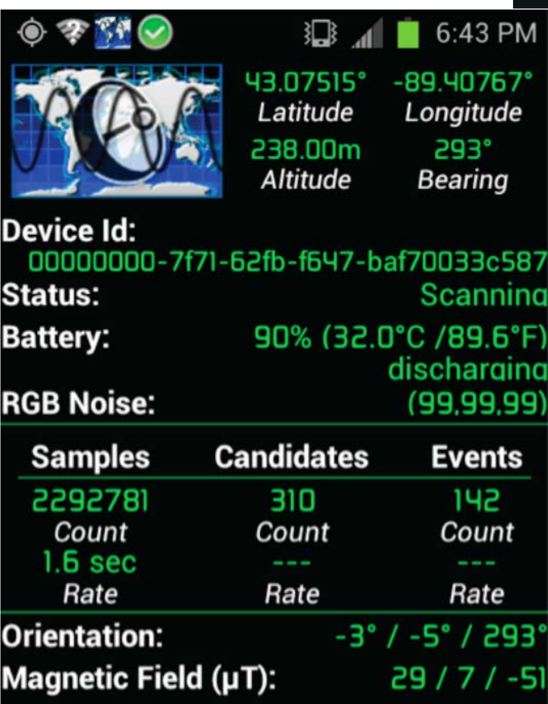
Borromean nuclei – they appear to have halos of weakly bound neutrons that surround a more strongly bound core.

Nakamura et al. (2009)

The binding energy of these halo neutrons approach zero, making the nuclei nearly unbound which results in large radii.



G. Compactness: Portable Devices



Whiteson et al. (2014)

We welcome your ideas and comments,…and sincerely solicit your help.

Let's Discuss &…
To Achieve a List of Action Items