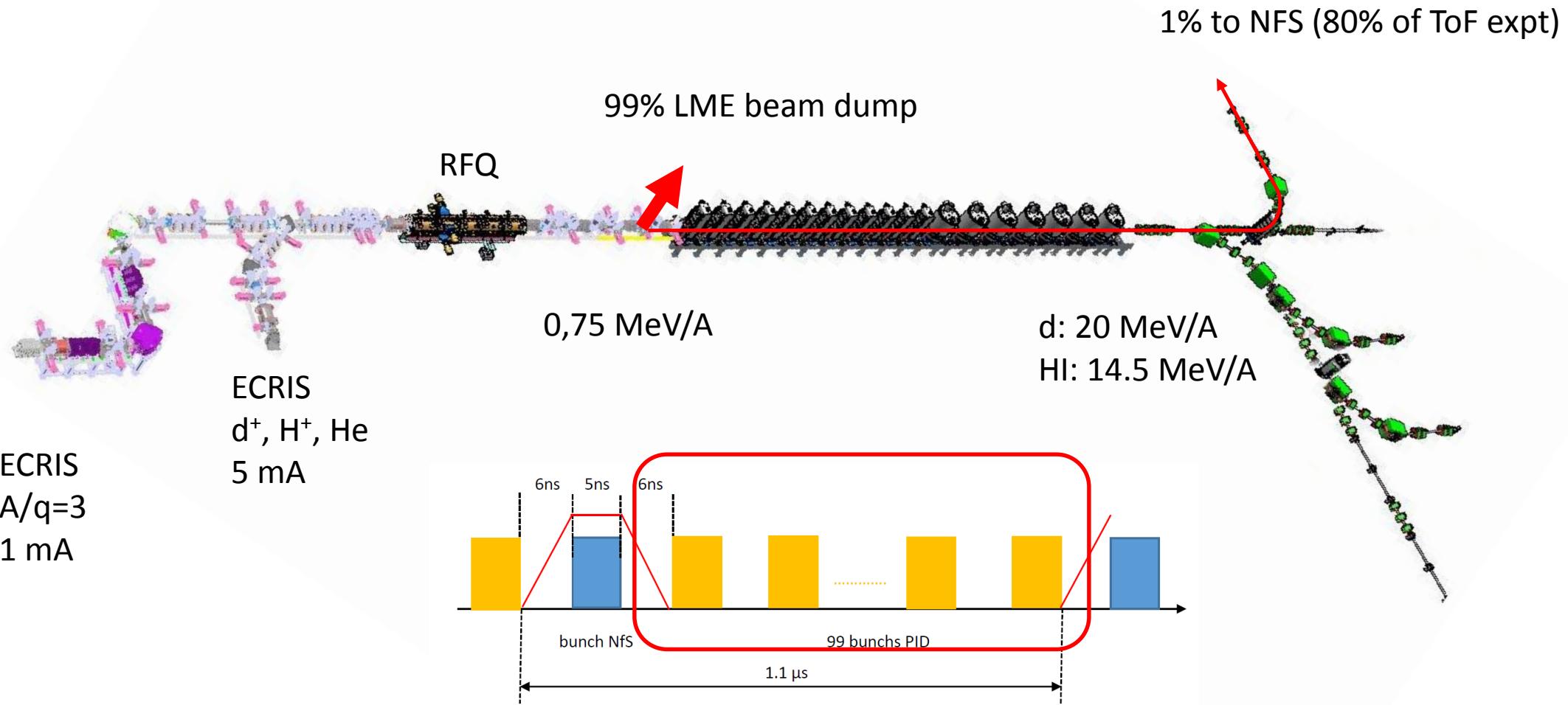


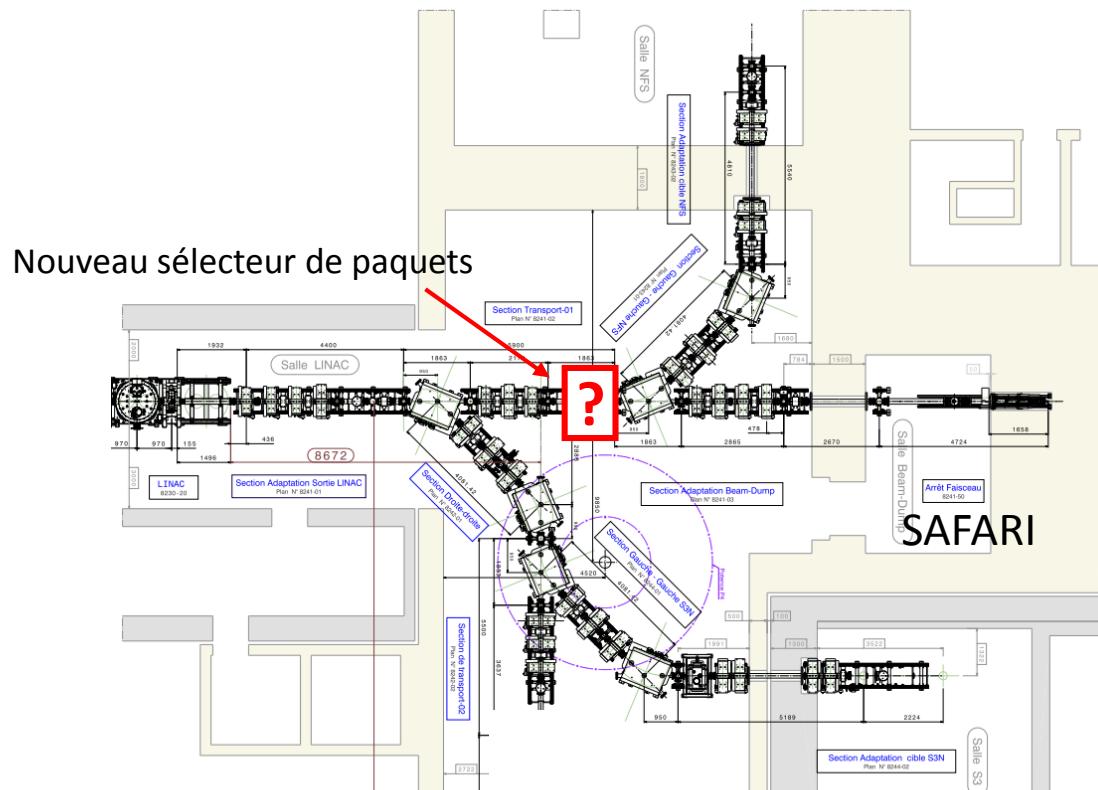
Une plateforme
interdisciplinaire auprès de
SPIRAL2

GANIL, SUBATECH, ARRONAX, IPHC, LPSC, CYCERON, CERN,...

SPIRAL2 Phase 1: situation actuelle



Un nouveau « kicker » HE?



- NFS-ToF: ~80% des demandes NFS requièrent sélecteur de paquets 1/100 => 99% du faisceau non utilisé collecté en LME (avant accélération par le LINAC)
- Pour pouvoir utiliser ce faisceau, nécessité d'installer un nouveau kicker en sortie du LINAC? Mais pas uniquement...
- => Etude: quel(s) développements pour pouvoir utiliser le faisceau qui autrement finirait dans un beam dump?...

Des opportunités multipliées pour SPIRAL2

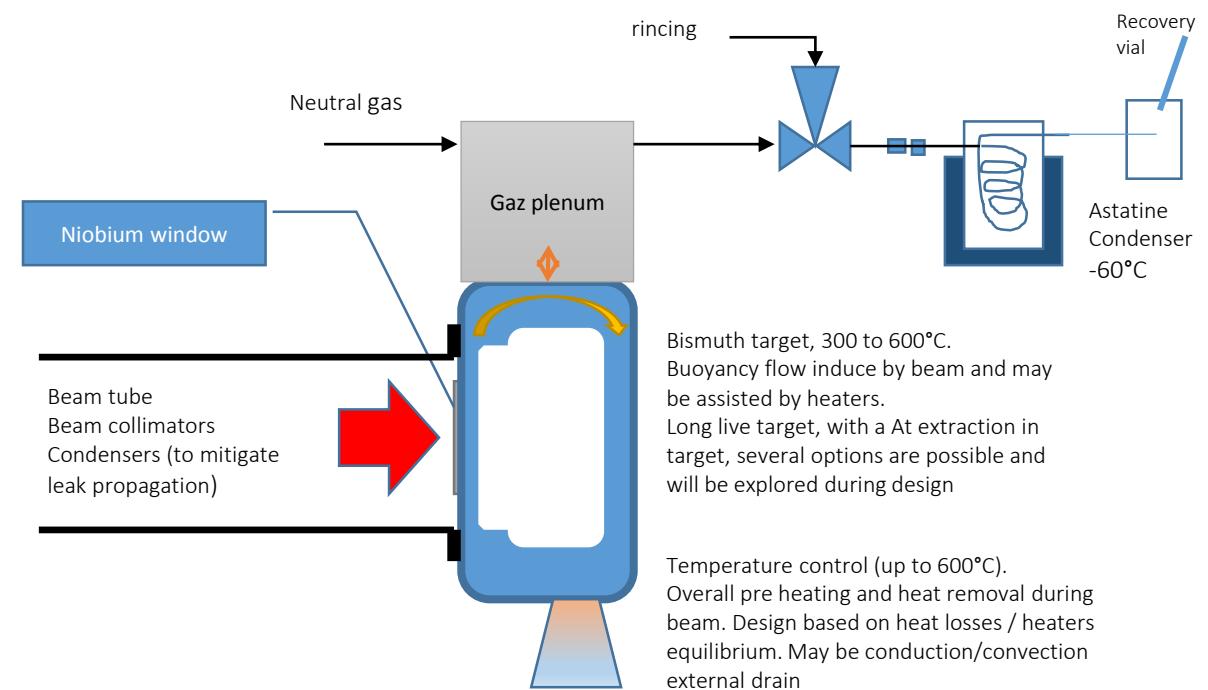
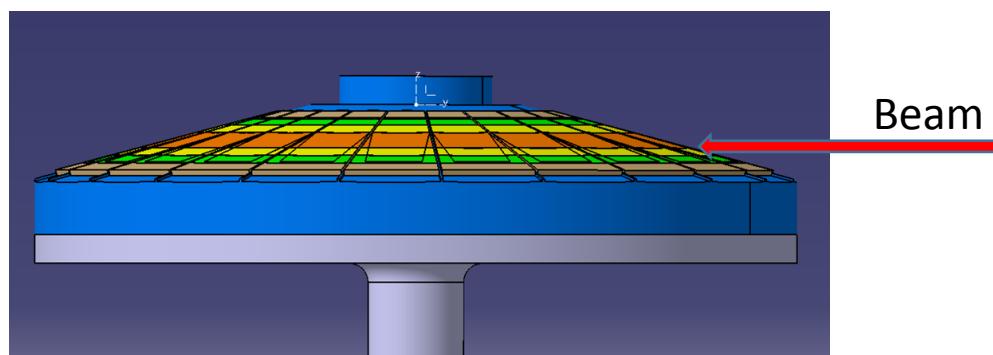
- Si une solution existe: SPIRAL2 devient une véritable facilité multiutilisateurs

Quoi qu'il en soit: gros potentiel pour un programme de physique:

- Physique nucléaire
- Radioéléments innovants
- Physique des matériaux
- AB-NCT
- Recherche industrielle?
- ...

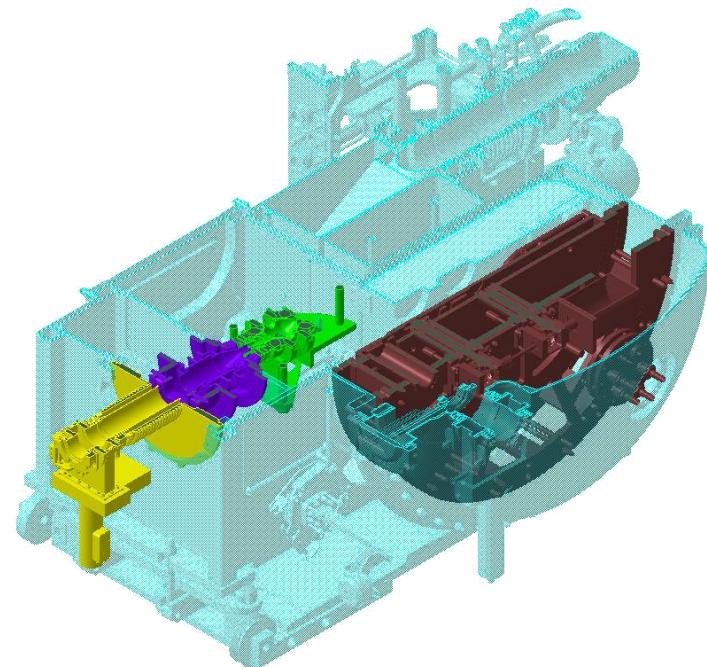
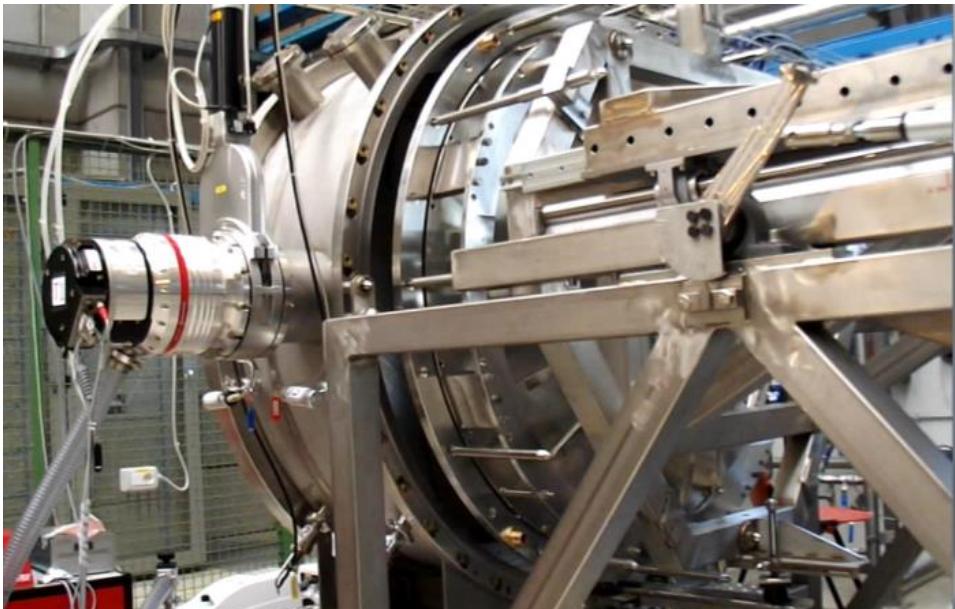
Radioéléments innovants

- Stations haute puissance irradiation R&D radioéléments innovants (ANR REPARA):
 - Cible rotative 10 kW
 - Cible liquide si faisable
 - Générateur Rn/At
 - Impact R&D sur l'alphathérapie (^{211}At)



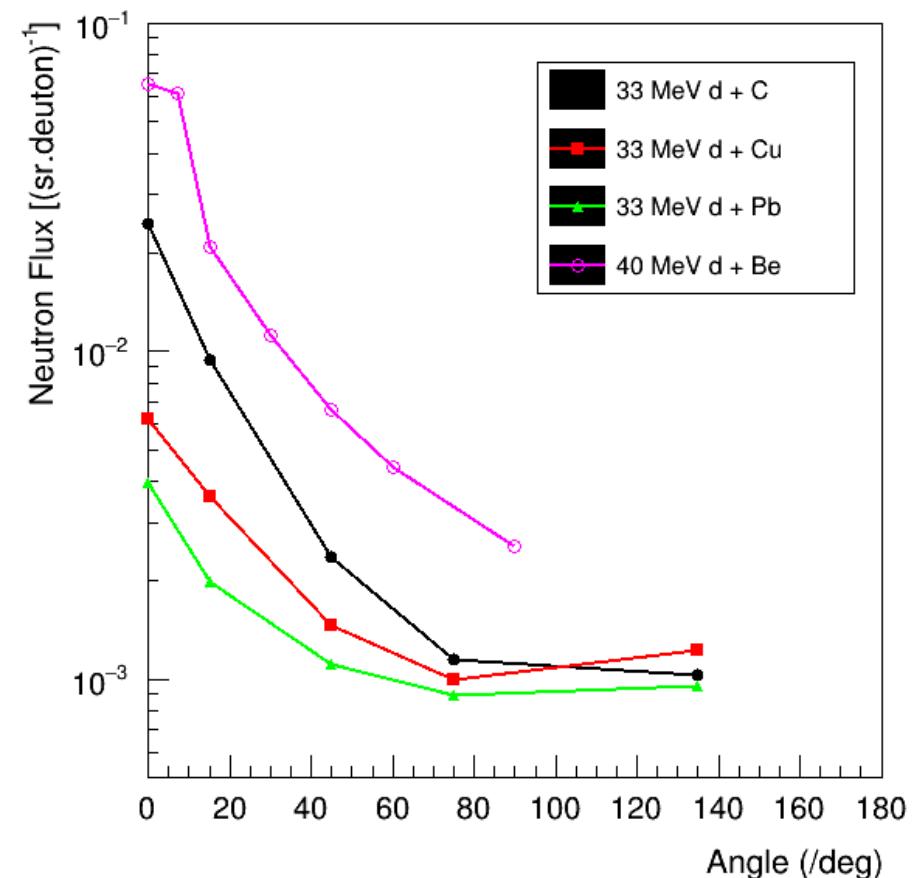
Une source de neutrons compact a SP2?

- Strong request (shutdown of research reactors)
- Neutron source using the SP2 converter
 - Designed for SP2 Phase2
 - 40 MeV; 5 mA d (200 kW)/proto 50 kW (1.25 mA)
 - Converter (200 kW): 10^{12} n/cm².s
 - Non reactor based



Une source de neutrons compact a SP2?

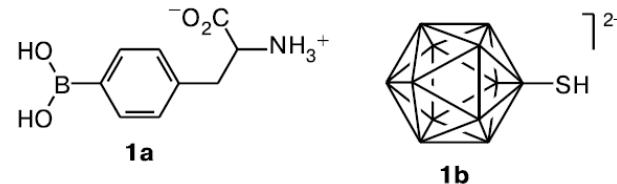
- Neutron converter
 - Neutron Converter: 10^{12} n/cm².s
 - Rotating wheel (400-600 turns/min) with graphite as converter material
 - Working temperature up to 1850 °C
 - Radiation cooling 50 kW (tested)
 - Focusing ~1pi forward angles
- Neutron irradiation
- Neutron radiography
- Radioelements
- Material science



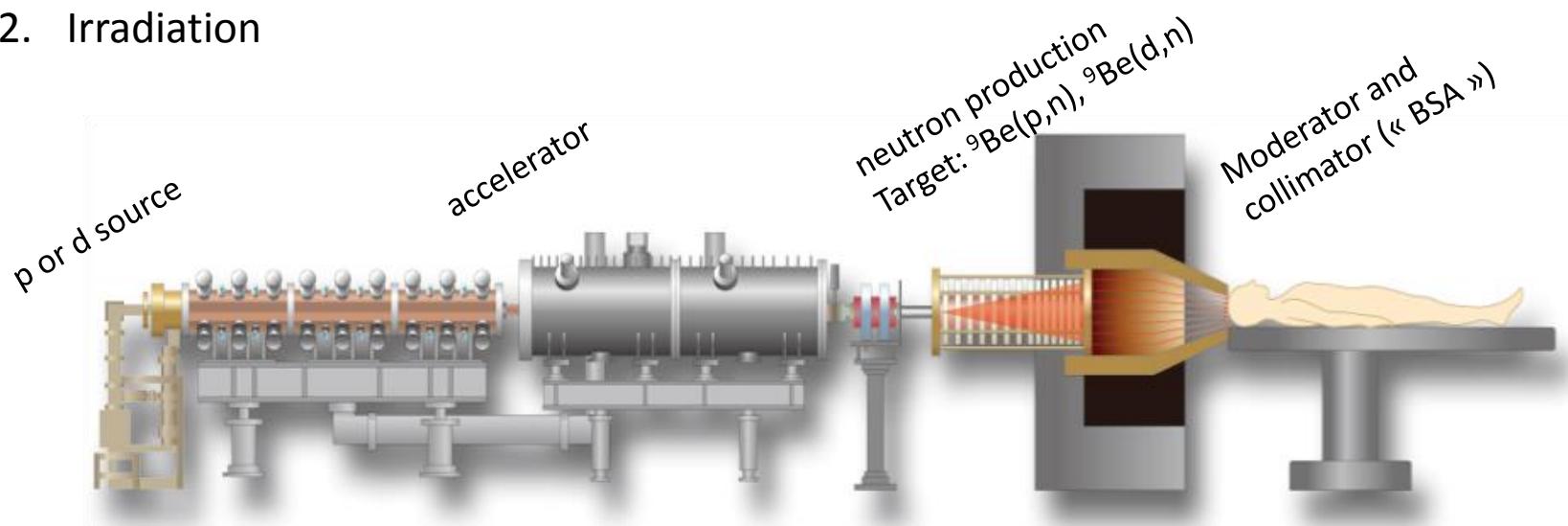
AB-NCT

BPA (*p*-borophenylalanine) and BSH (disodium mercaptoundecahydrododecaborate $\text{Na}_2[\text{B}_{12}\text{H}_{11}\text{SH}]$)

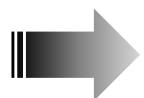
1. Injection of BNCT agent targeting specifically tumour cells



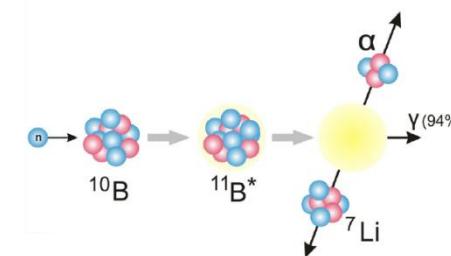
2. Irradiation



Epithermal neutrons
0.4 eV – 10 keV



Thermal neutrons :
 $10^9 \text{n}/(\text{cm}^2 \text{s})$
(tumour site)



AB-NCT worldwide

Table 1 – Current status of the different accelerators intended for AB-BNCT facilities worldwide. Data displayed comprise institute and location, type of machine and its status, proposed target and reaction, beam energy and highest neutron energy, actual or necessary beam intensity and references.

Institute-location	Machine (status)	Target and reaction	Beam energy neutron energy (MeV)	Beam current (mA)	Reference
Budker Institute Russia	Vacuum insulated Tandem (ready)	Solid $^7\text{Li}(\text{p},\text{n})$	2.0 <1	2	Aleynik et al. 2011 ¹
IPPE-Obninsk Russia	Cascade generator KG-2.5 (ready)	Solid $^7\text{Li}(\text{p},\text{n})$	2.3 <1	3	Kononov et al. 2004 ²
Birmingham Univ. UK	Dynamitron (ready)	Solid $^7\text{Li}(\text{p},\text{n})$	2.8 <1.1	1	Ghani et al. 2008 ³
KURRI Japan	Cyclotron (clinical trials started)	$^9\text{Be}(\text{p},\text{n})$	30 <28	1	Tanaka et al. 2011 ⁴
Soreq Israel	RFQ-DTL ^a (ready)	Liquid $^7\text{Li}(\text{p},\text{n})$	4 <2.3	2	Halfon et al. 2011 ⁵
INFN Legnaro Italy	RFQ (under construction)	$^9\text{Be}(\text{p},\text{n})$	4-5 <2-3	30	Ceballos et al. 2011 ⁶
Tsukuba Japan	RFQ-DTL (under construction)	$^9\text{Be}(\text{p},\text{n})$	8 <6	10	Kumada et al. 2011 ⁷
CNEA Buenos Aires Argentina	Single ended ESQ ^b	$^9\text{Be}(\text{d},\text{n})$	1.4 <5.7	30	Kreiner et al. 2011, 2013 ⁸
	Tandem ESQ (under construction)	Solid $^7\text{Li}(\text{p},\text{n})$	2.5 <1	30	

^a RFQ-DTL stands for Radio Frequency Quadrupole-Drift Tube Linac.

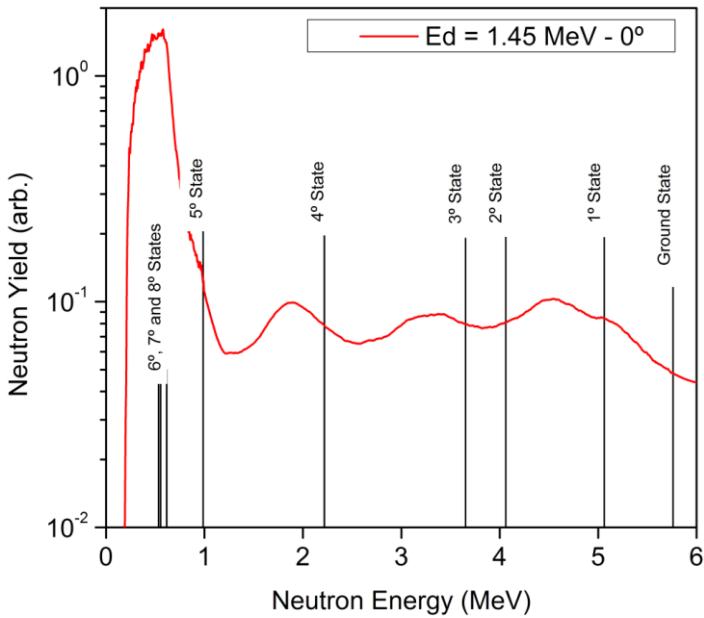
^b ESQ means Electrostatic Quadrupole.

J.A. Kreiner et al, Reports of Practical Oncology and Radiotherapy 21 (2016) 95

- Lithium target: $T_f=180.5^\circ\text{C}$, low thermal conductivity, very reactive metal, ^7Be as a product, tritium, ...
- High energy neutrons from $^9\text{Be}(30 \text{ MeV p},\text{n})$ => activation of part of the facility; difficult to thermalize => large moderator => loss of flux; size of the machine
- High intensity, low energy p for $^9\text{Be}(4-5 \text{ MeV p},\text{n})$ => 30 mA not possible with cyclotrons (space charge)

${}^9\text{Be}(\text{d},\text{n}){}^{10}\text{B}$

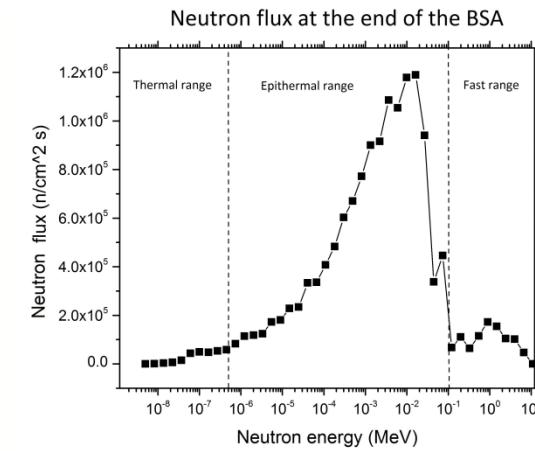
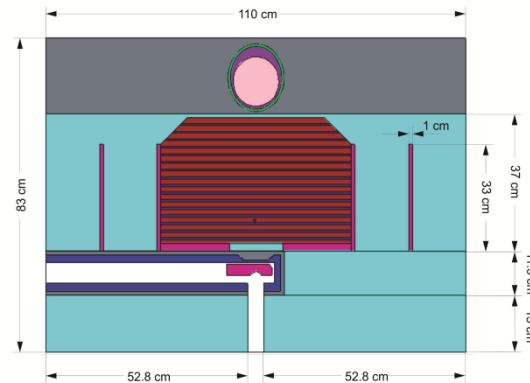
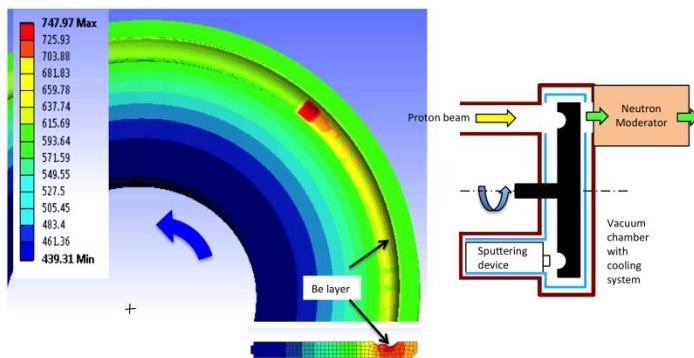
M. Capoulat et al, LNL annual report 2015



${}^9\text{Be}(\text{d},\text{n}){}^{10}\text{B}$ @ 1.45 MeV:

- Exothermic but Q-value=4.36 MeV
- thin target (a few μm): strong feeding of a 5.11 MeV excited state => Endothermic for this state
- $E_{\text{seuil}}=0.915 \text{ MeV} \Rightarrow$ low energy neutrons
- Small machine, cost effective

Rotating Be target and « BSA » LPSC



AB-NCT@SPIRAL2?

- GANIL:

- High intensity d beam
- RFQ 1.45 MeV
- NFS

- LPSC/CEA-LETI:

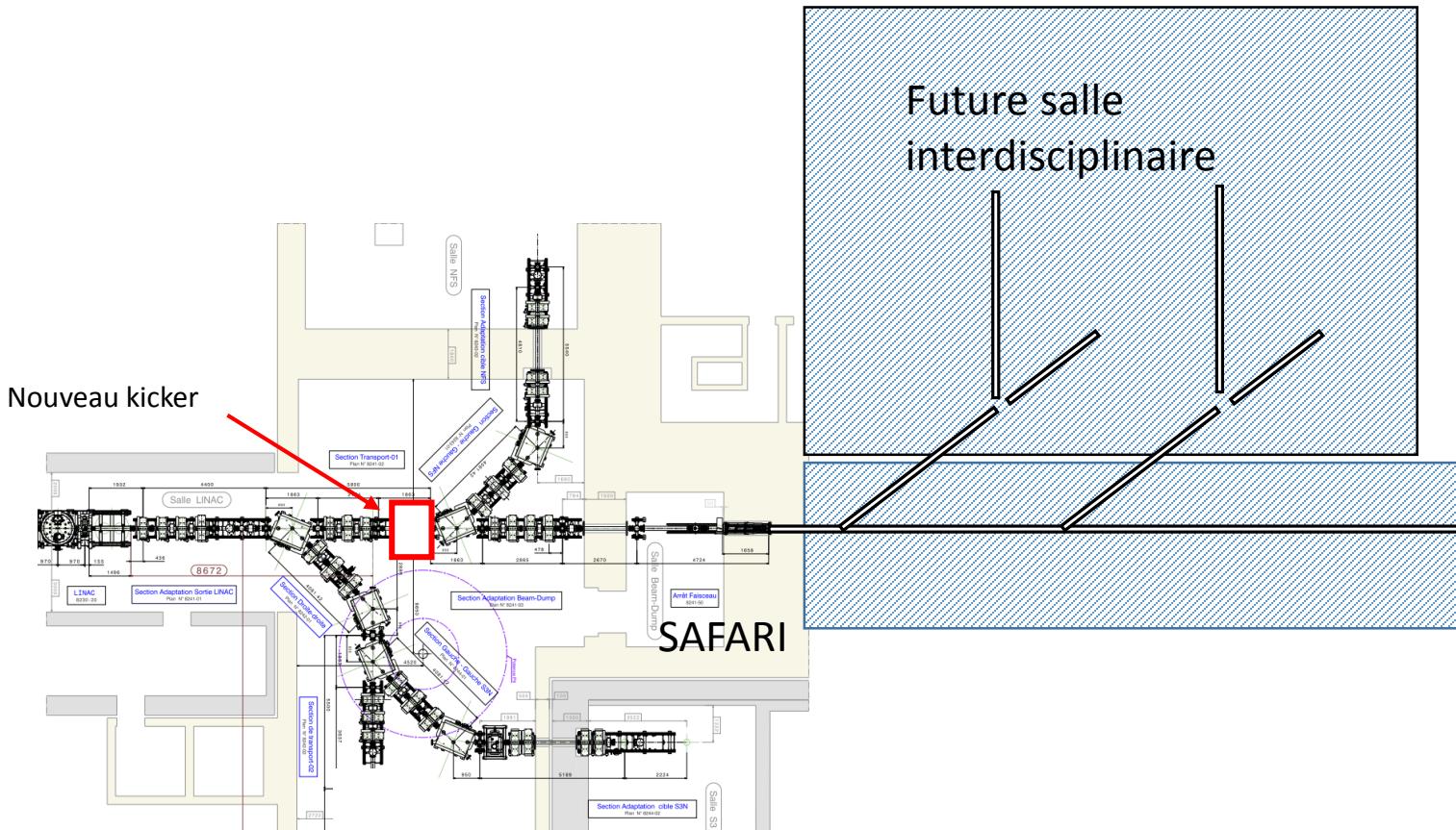
- Rotating Be target
- Moderator (BSA)
- Low energy neutrons detectors MIMAC
- Gamma-camera

- Characterisation neutron flux
- Demonstrator AB-NCT

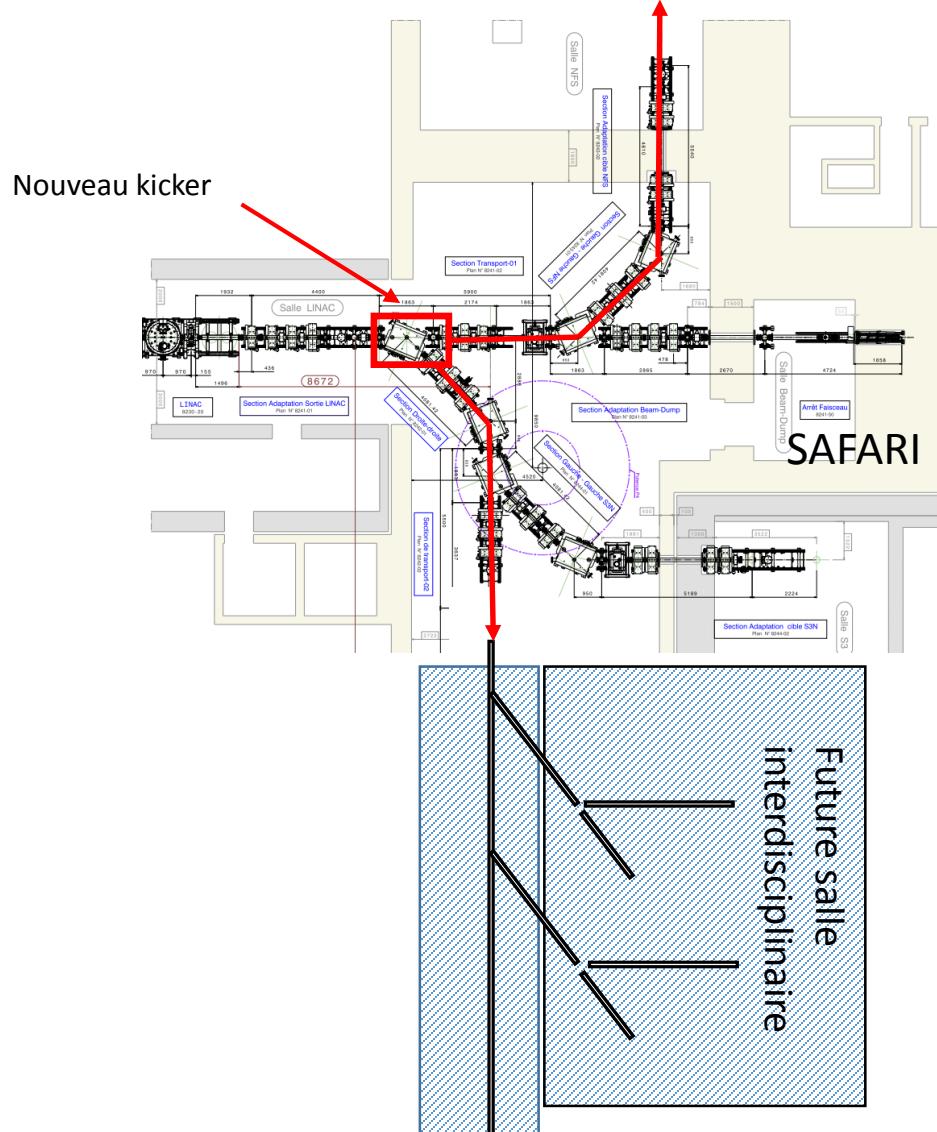
→
Exp NFS small target (energy, angular distribution,...)

Implantation realistic target (flux, demonstration,...)

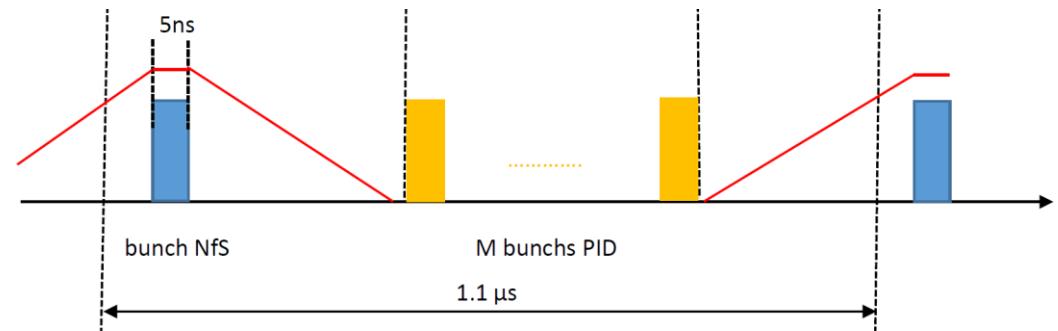
Des opportunités multipliées pour SPIRAL2



Des opportunités multipliées pour SPIRAL2



- Structure en temps sélecteur de paquets en LME



- Kicker+déviateur en LHE
- Pas 99% mais 60% de la puissance « récupérée »
- Probablement plus simple côté LHE (voir sûreté)

Conclusions

- SPIRAL2: véritable facilité multiutilisateurs si nouveau sélecteur de paquets/kicker possible
- Extension du programme scientifique de SPIRAL2 Phase 1
 - Utilisation faisceaux LINAC/Physique nucléaire haute intensité
 - R&D radioéléments innovants
 - Source de neutrons compacte
 - Science des matériaux/physique du solide. Discussions en cours avec CIMAP.
 - AB-NCT; compétences françaises; modèle démonstrateur pour hôpital?
 - ...