

- MUNES: a MUltidisciplinar Neutron Source for BNCT (Boron Neutron Capture Therapy) and Nuclear Waste characterization in Italy. Applications
 - Advanced cancer treatments (BNCT)
 - Nuclear waste characterization (classification of nuclear waste barrels for disposal, determination of very low quantity of Pu)
- Background
- Why a «low energy» accelerator driven neutron source
- Key technologies development
- Conclusions





MUNES

MUltidisciplinar Neutron Source A. Pisent, P. Colautti, E. Fagotti

- First ideas with SPES-BNCT, based on TRASCO RFQ, built at LNL for Nuclear Wastes Transmutation Research.
- In 2011 trilateral agreement INFN,
 University of Pavia and SOGIN (public company for nuclear sites decommissioning) for the study of a neutron source based on INFN high intensity linear accelerator to be installed in Pavia.
- 2012 MUNES Granted as «progetto premiale» by Italian Ministery for research (5 M€, previous INFN investments in TRASCO RFQ and BNCT for about 10 M€)





MUNES

MUltidisciplinar NEutron Source

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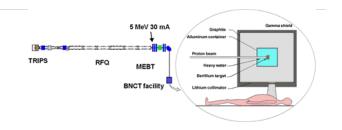
-Sezione di Pavia

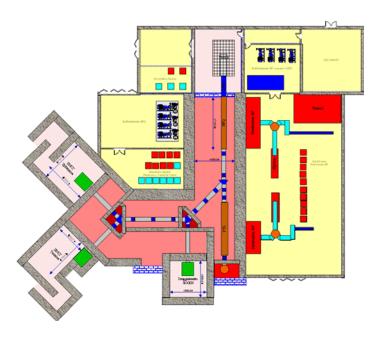
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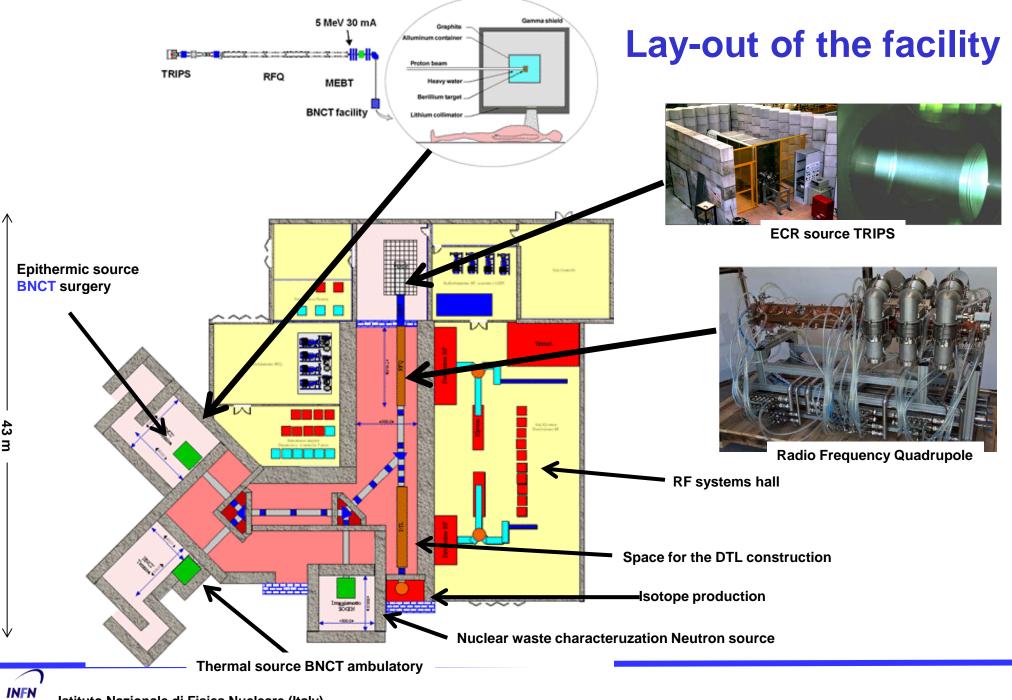
Main parameters of the system source-n production target-moderator

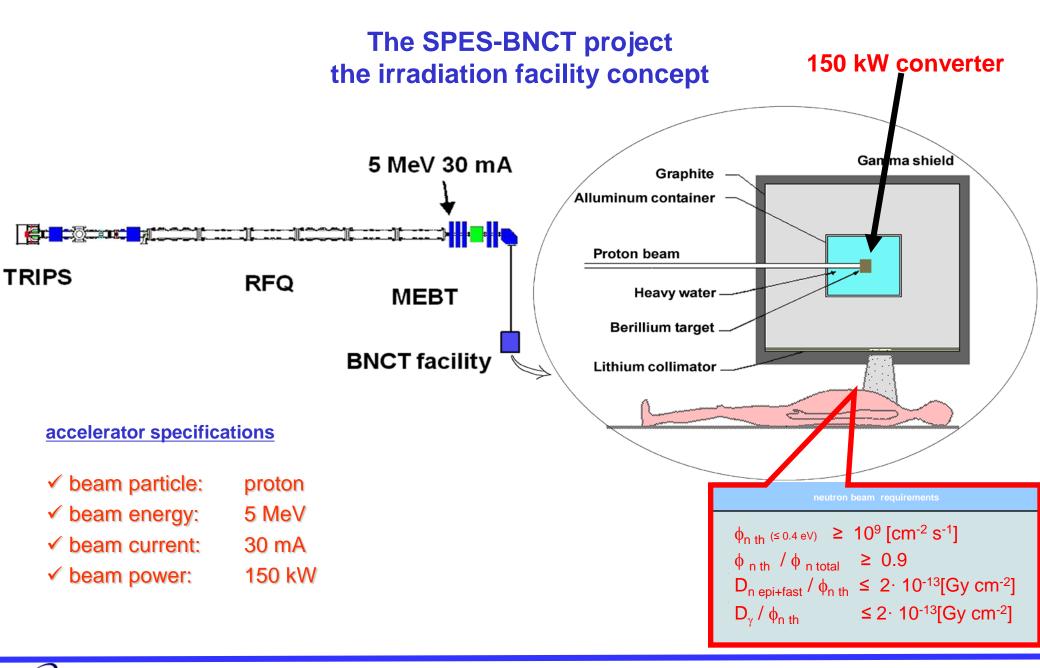




| Ion source | TRIPS | Proton energy 80 keV, 50 mA intensity | | | | |
|--------------------------|-----------------------------------|--|--|--|--|--|
| Accelerator type | RFQ | Radio Frequency Quadrupole | | | | |
| Final energy | 5 MeV | | | | | |
| Accelerated beam current | 30 mA | | | | | |
| Duty cycle | CW | Continous wave | | | | |
| Neutron converter | Berillio | Water cooled 150 kW | | | | |
| Neutron source intensity | ~10 ¹⁴ s ⁻¹ | On the entire solid angle, Ave. neutron energy 1.2MeV | | | | |
| RF power | 1.3 MW | 352 MHz | | | | |
| Electrical power | 5 MVA | | | | | |







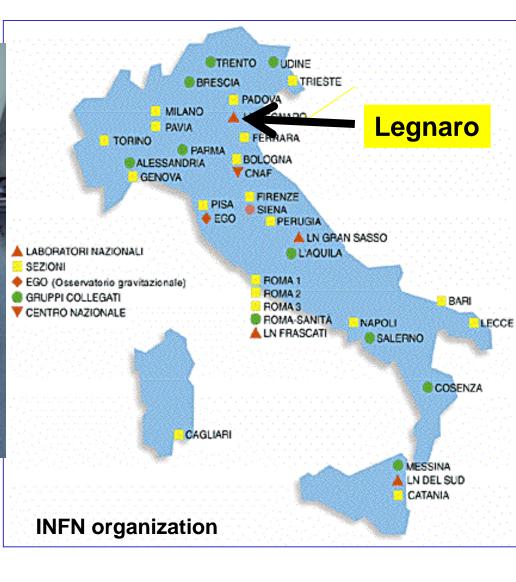
The background



INFN Laboratori Nazionali di Legnaro

ALPI PIAVE accelerates ions up to Gold, energies up 10 MeV/u, is the largest superconducting linac for ions in Europe





INFN Organization for the accelerator construction

Three projects are active in this moment for the development of high intensity linear accelerators in INFN

IFMIF EVEDA (International Fusion Material Facility)
MUNES (Multidisciplinar Neutron Source)

ESS (European Spallation sources) design

About 30 persons involved, 20 FTE, 10 dedicated contracts, dedicated funds from MIUR of about 30M€

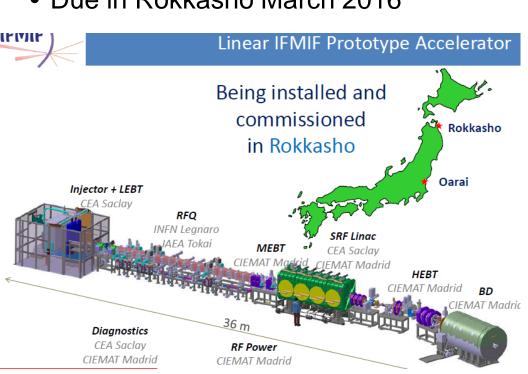
The sections indicated in the map are involved



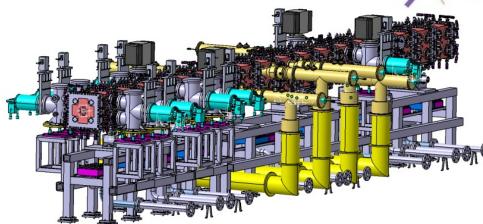
IFMIF-EVEDA RFQ (built by INFN)

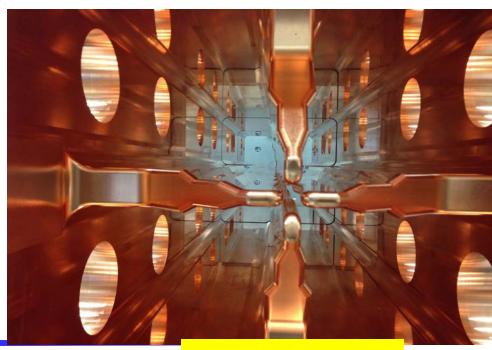
IFMIF LIPAC

- The most powerful RFQ beam (650kW)
- 130 mA deuterons accelerated
- 5 MeV final energy
- 9.8 m length, 18 brazed modules
- Due in Rokkasho March 2016



The 130 mA 9 MeV prototype built in EU and commissioned in JA

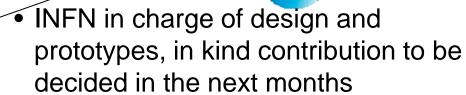




RFQ inside view

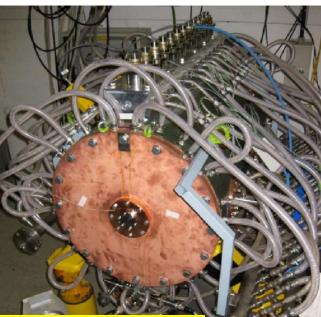
ESS: our contribution

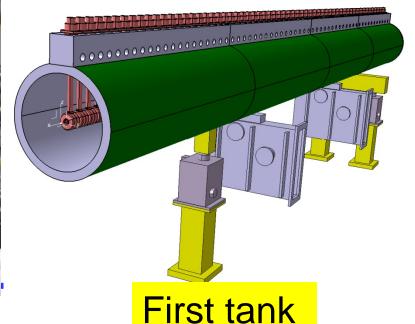




- Drift Tube Linac (3.6-90 MeV)
- Operating frequency 352.2 MHz
- 65 mA protons
- Duty cycle up to 7%









IST CERN-INFN prototype

Therapeutic neutron beam production



INTRODUCTION

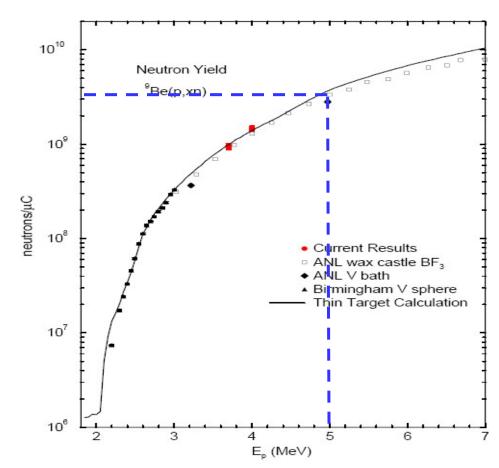
- New neutron sources are being developed for various applications (test of materials for fusion reactors, experimental oncological treatments, characterization of nuclear wastes...), based on high intensity "low energy" (up to 40 MeV) proton or deuteron linear accelerators.
- This kind of sources have recognized advantages respect to reactors and spallation sources for these applications



The choice of the target material and beam energy

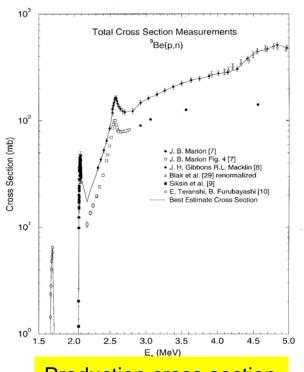
Be and not Li

- for better mechanical and thermal properties, (1278 instead of 180 deg C melting point)
- To avoid production of ⁷Be and tritium
- To avoid conventional safety issues
- Energy below 6 MeV, to reduce high energy neutron component, but large enough to get the necessary yield
- 5 MeV is about the maximum that a cw RFQ can reach.

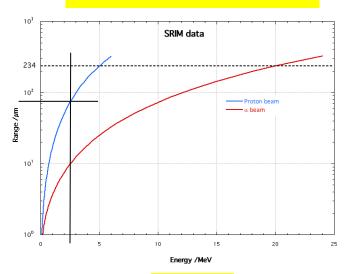


Neutron source gain factor expected at Ep= 5 MeV \cong 2.8 \rightarrow Yn \sim 2.9·10¹² s⁻¹mA⁻¹

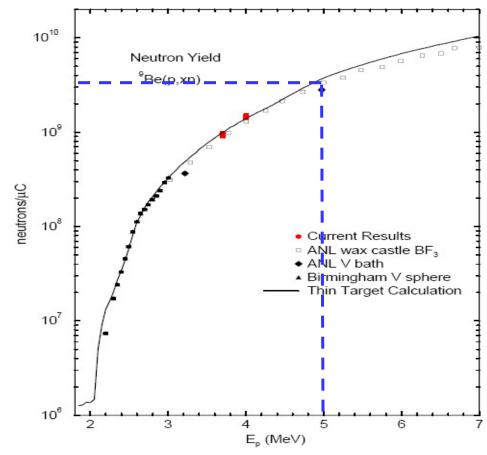




Production cross section



The choice of the target material and beam energy



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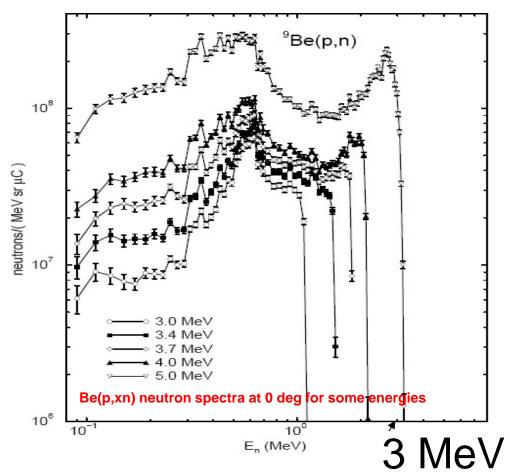


Three beam-target choices neutron production

• 5 MeV protons with Be target

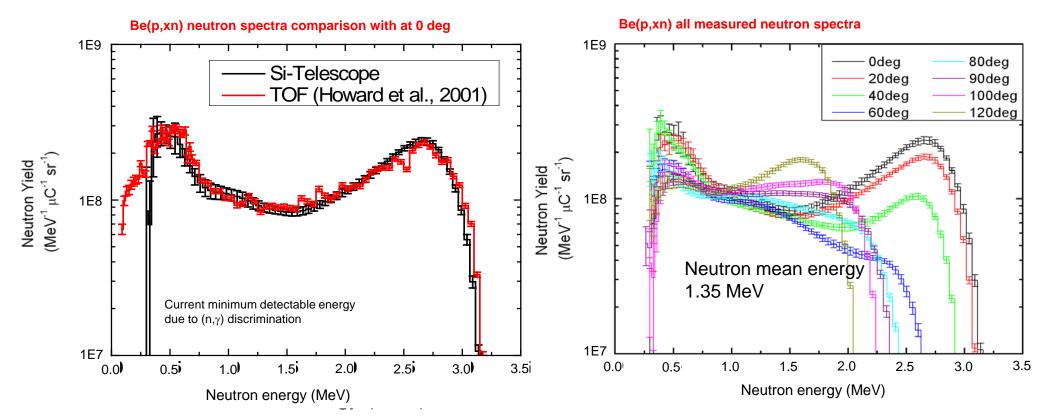


SPES BNCT Be target Now MUNES



• 150 kW about 10¹⁴n/s and 710⁸ n/s per W or 0.0004 n/p

Ep=5 MeV Be(p,xn) thick target neutron spectra measurements at the 6 MeV Van de Graff accelerator at LNL new p-recoil detector (Milan Polytechnic)



POLIMI - Silicon Telescope Be(p,xn) Ep= 5 MeV total neutron Yield measured

 $Y_{n (4\pi)} = 3.50 \pm 0.3 \cdot 10^{12} \text{ s}^{-1} \text{mA}^{-1}$

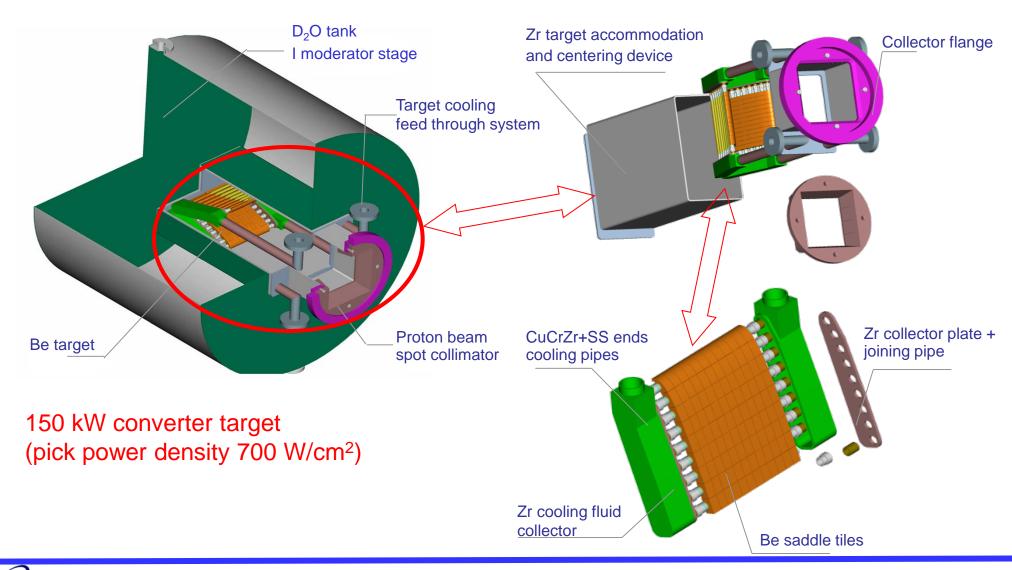
Neutron source level expected with TRASCO RFQ + Be target → Sn ~1.05·10¹⁴ s⁻¹





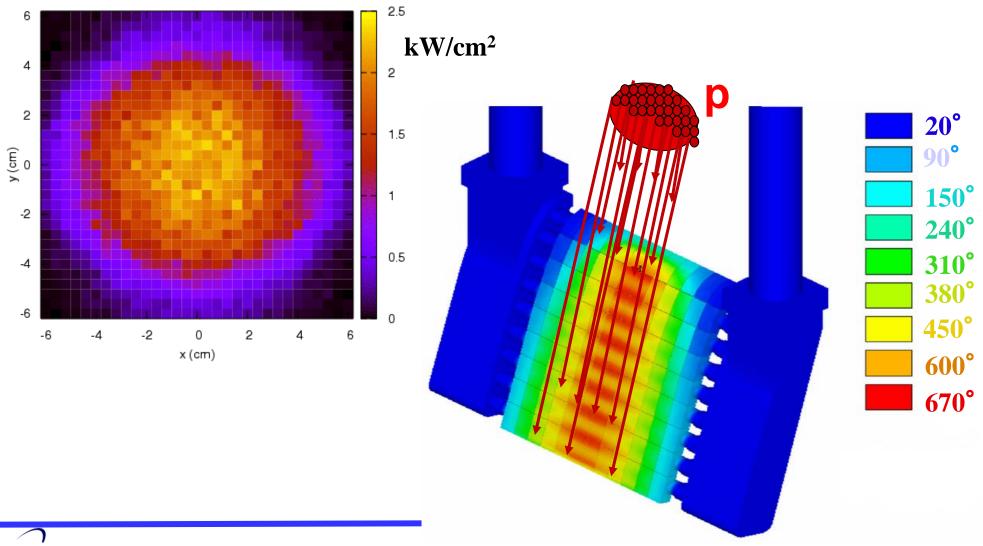
The LNL-BNCT project

Efremov Step II neutron converter prototype design





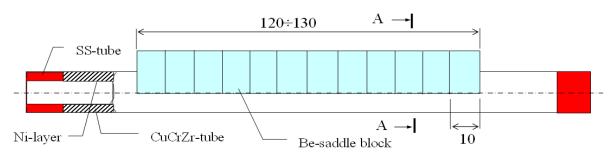
Beam power distribution at target

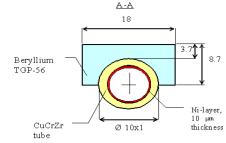


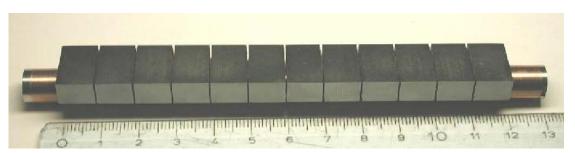
The LNL-BNCT project

the neutron converter prototype design R&D in support of target design

New brazing technologies for Be saddle-block cooling pipes







Be-CuCrZr mock-up

Brazing alloys: Cu-In-Ni-Sn, T_{braz.} = 800°C





The LNL-BNCT project

neutron converter prototype assembling and first full beam power test



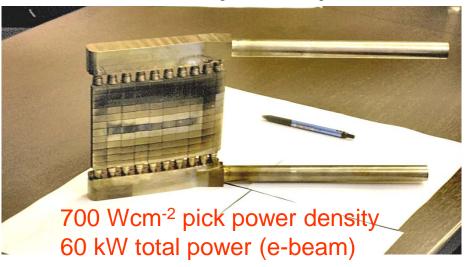
1. Be tile brazed cooling pipes



2. collector plates welding & EDM manufacturing process



3. Final target assembling

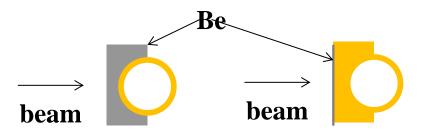


4. Visual inspections after e-beam full power test



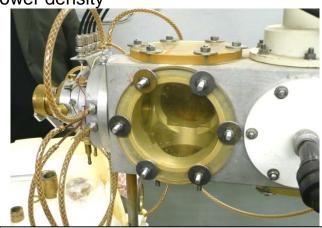
Test of target damage by protons

- Assesment of target duration (Be has high melting point 1278 degC and high heat conductivity, but gas permeability if extremely low (9 order lower than average materils). H bubbles can be trapped in bulk beryllium and couse fractures.
- Proton radiation damage effects on Be surface were planned in 2008, measurements at the State
 Polytechnic Institute (SPbSPU), St. Petersburg
 (Russia) (interrupted for funds problem, contract now under preparation)
- New target design to be tested based on a very thin Be foil brazed on Cu alloy tube





Be element equipped with collimator to simulate the proper proton hitting angle on target surface with same power density

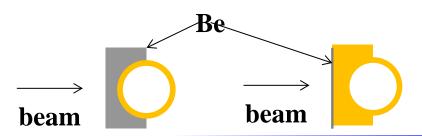


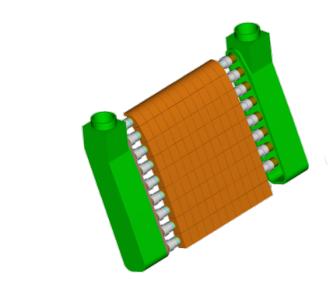
Test camera at the Cyclotron facility proton beam Ep=5 MeV, I= 20 µA

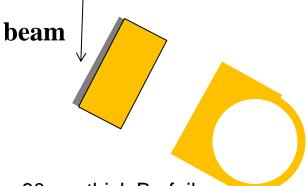


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60 um thick Be foil

Brazed to copper substrate in specialized company Construction of the target in Cu and 316L substrate Possible at LNL



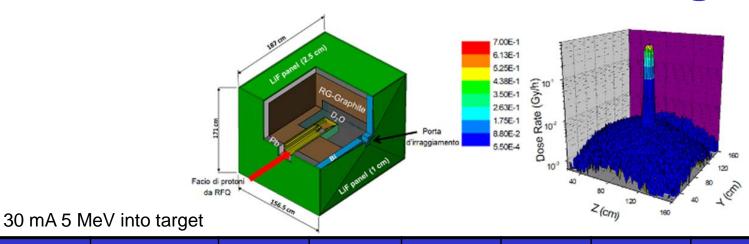
New target and moderator development



Moderator, low power@CN accelarator at Inl



Thermal moderator design



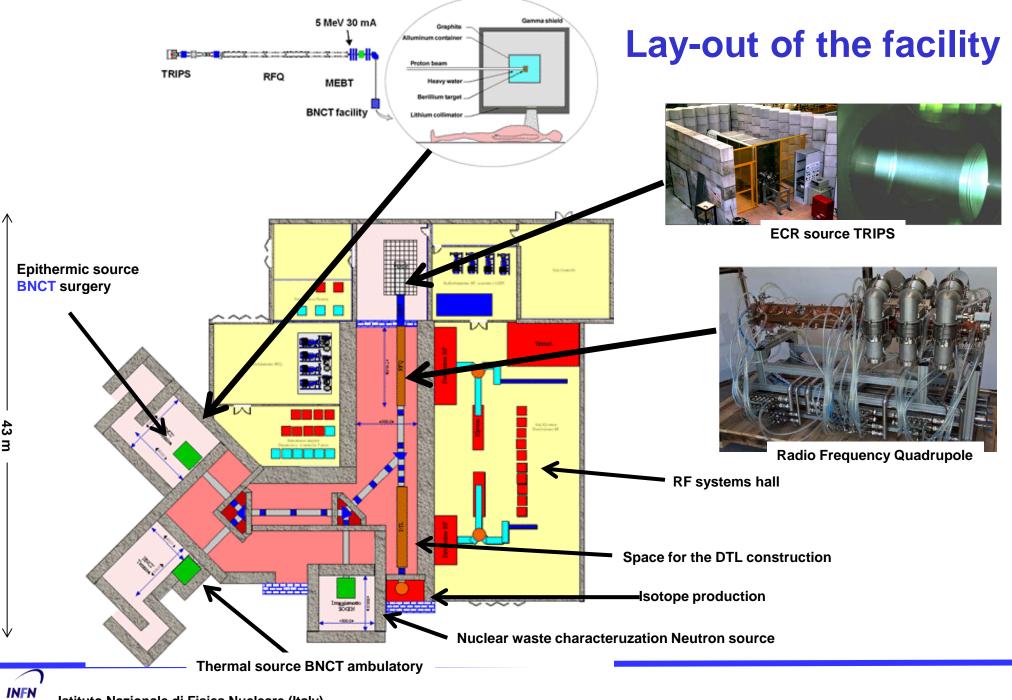
| | $\Phi_{\text{th}} \; (\text{E}{\leq} \; \text{0.5 eV}) \\ (\text{cm}^{\text{-2}}\text{s}^{\text{-1}})$ | Φ_{th}/Φ_{total} | K _{nth} (Gy·h⁻¹) | K _{n epi-fast} (Gy·h⁻¹) | Κ _γ (Gy·h ⁻¹) | $K_{\gamma} / K_{n \text{ tot}}$ | ${ m K_{n~(E>10~eV)}}$ / ${ m \Phi_{th}}$ (Gy·cm²) | $	extsf{K}_{\gamma}$ / $\Phi_{	extsf{th}}$ (Gy·cm²) |
|------------------------------|--|--------------------------|------------------------------|-------------------------------------|---|----------------------------------|--|---|
| IAEA ref. parameters | > 1E+09 | > 0.90 | | | | | ≤ 2E-13 | ≤ 2E-13 |
| RG- Graphite reflector | 2.84E+09 | 0.995 | 1.70 | 0.023 | 1.24 | 0.72 | 2.27E-15 | 1.23E-13 |

The second moderator will be for epithermal (0.5<E $_n$ <10 keV) neutrons, needed for deep tumours is being designed by INFN Pavia group. (see the talk by Ian Postuma Thursday)



The other applications





Nuclear Waste Characterization

- Part of the management of radiactive waste produced in Italy by industrial research and medical processes is the so called Passive/Active Waste Assay System (PANWAS).
- It uses neutron differential die-away technique to quantify the fissile content (235U, 239Pu etc.)
- Uses a pulsed neutron source (sealed D-T tube, 10⁶ n/pulse in 10 us 100 Hz) and He3 neutron detector.
- With MUNES (10⁹ n/pulse in 10 us 100 Hz, neutron average energy 1.2 MeV against 14) the sensitivity to Pu contaminiation can be dramatically improved.
- Present sensitivity is to about 1 mg of Pu on a barrel of 400 liters, 1500 kg) 0.1 mg has to be guaranteed for disposal (the limit is 0.1 bq/g, and Pu natural radioactivity is 2 Gbq/g, 10^-10 in mass

WM'06 Conference, February 26-March 2, 2006, Tucson, AZ



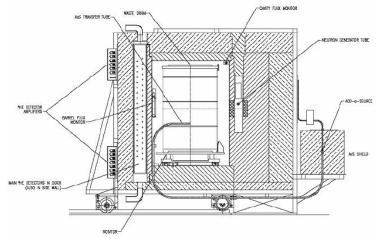


Fig. 1. Photograph and cut-away side view of the PANWAS System



Nuclear Waste Characterization

Part of the management of radiactive waste
 produced in Italy by industrial research and



WM'06 Conference, February 26-March 2, 2006, Tucson, AZ



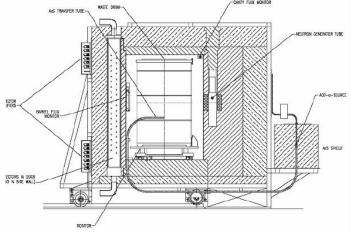
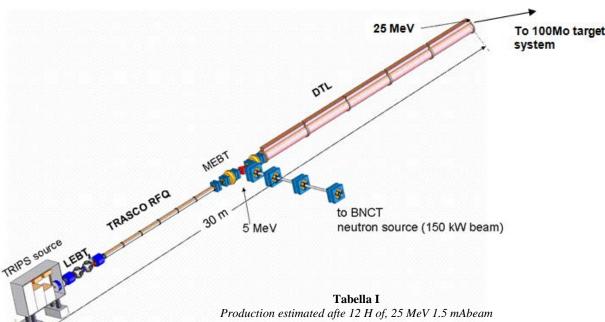


Fig. 1. Photograph and cut-away side view of the PANWAS System



- With the construction of a **pulsed DTL booster** it is possible to built
 a very effective facility for isotope
 production (1.5 mA average 25
 MeV, 50 Hz, 0.6 ms.)..
- The facility could treat patients during the day and prepare radioisotopes overnight
- DTL design is being developed for ESS on the bases of CERN linac4 design.
- Modern klystrodes coupled with high power solid state preamplifier allow high duty cycle.

DTL for ISOTOPE production for radiopharmaceuticals (as 99mTc or precursor 99Mo)



| Metodo di produzione | ¹⁰⁰ Mo(p,x) ⁹⁹ Mo | ¹⁰⁰ Mo(p,2n) ^{99m} Tc |
|---------------------------------|---|---|
| Wictions of produzione | target 100% ¹⁰⁰ Mo | target 100% ¹⁰⁰ Mo |
| Corrente di fascio max | Ip= 1500 μA | Ip= 1500 μA |
| densità di potenza sul campione | 500 W/cm ² | 500 W/cm ² |
| Energia protoni | 25 MeV | 25 MeV |
| Massa del campione | 97 g | 97 g |
| Attività in target (EOB) [Ci] | 8.2 | 212.9 |
| Attività specifica As [mCi/g] | 85.4 | 2209.2 |

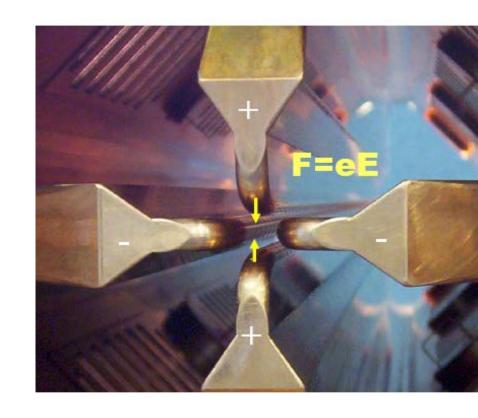


Accelerator issues and development



- 150 kW beam should be accelerated in a small clearance (about 5 mm diameter) to counteract space charge
- with low beam losses and activation of the structure so as to allow hands-on maintenance of the structure itself (Tolerances of the order of 10-50 um).
- A long RFQ (7.3 m to get 5 MeV) implies tolerances proportional to L⁻²
- 800 kW RF dissipated on copper surface: necessity to keep geometrical tolerances, to manage hot spots and counteract potential instability.
- For a reliable production of RFQ (present and future)
 - We fully exploited INFN internal production capability (design machining, measurement and brazing)
 - Make production accessible for different industrial partners
 - Cinel, Padua (Italy), has built the RFQ
- At present the RFQ has been produced and tested at full RF power

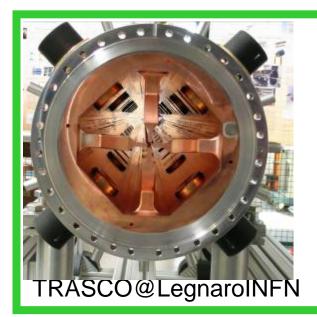
RFQ challenges





TRASCO RFQ (developed for ADS studies)

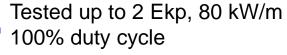
| | Name | Lab | ion | energy | vane beam | | RF Cu | Freq. length | | Emax | Power density | | operate | | |
|--------|-------------|------|-----|--------|-----------|---------|-------|--------------|-----|------|---------------|--------|-------------------|-------------------|--------|
| | | | | | voltage | current | power | power | | | | | ave | max | |
| | | | | MeV/u | kV | mΑ | kW | kW | MHz | m | lambda | kilpat | W/cm ² | W/cm ² | |
| | IFMIF EVEDA | LNL | d | 2,5 | 79-132 | 130 | 650 | 585 | 175 | 9,8 | 5,7 | 1,8 | 3,5 | 60 | RF yes |
| CW | LEDA | LANL | р | 6,7 | 67-117 | 100 | 670 | 1450 | 350 | 8 | 9,3 | 1,8 | 11,4 | 65 | YES |
| | FMIT | LANL | d | 2 | 185 | 100 | 193 | 407 | 80 | 4 | 1,0 | 1 | 0,4 | | YES |
| high p | IPHI | CEA | p | 3 | 87-123 | 100 | 300 | 750 | 352 | 6 | 7,0 | 1,7 | 15 | 120 | NO |
| | TRASCO | LNL | p | 5 | 68 | 30 | 150 | 847 | 352 | 7,3 | 8,6 | 1,8 | 6,6 | 90 | RF yes |















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Nucleare sloveno, polemiche in Friuli-Venezia

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ITALIA - Ricerca

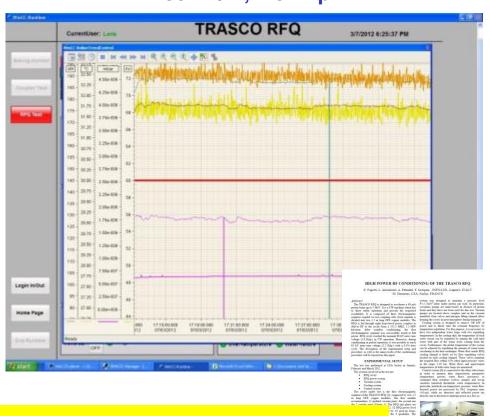
21-03-2012

Un acceleratore italiano da record



Se nel campo
dell'en ergia nu cleare
l'Italia è assente dalla
scena internazionale,
per quanto riguarda la
ricerca nucleare ha e
mantiene un ruolo di
primo piano a livello
mondiale. Ora questa
posizione è confermata

Within IFMIF program the RFQ of TRASCO has been tested at Saclay (CEA) stable condition cw nominal field 80kW/m, 1.8 Ekp







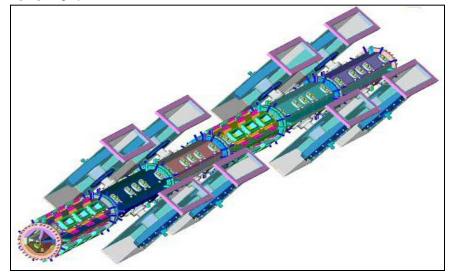
With MUNES new applications need new technologies



Eight independent 125 kW amplifiers (one per RF coupler) are coming (5 amplifiers ordered).

Each amplifier needs 3 racks as in the following scheme (including power supply)





Advantages respect to a klystron

- Lower operating costs (cost and duration of components)
- Availability e reliability (no stop operation in case of components failure)
- Absence of high voltages very important for the operation in a hospital



Conclusions

- MUNES is a small size accelerator based neutron source, designed for BNCT and nuclear waste classification.
- The source is very intense (10¹⁴ neutrons/s) and relatively compact (suitable to be installed in a Hospital or in a nuclear disposal environment).
- It is based on a high performance proton RFQ and a high power be target, so the main challanges are to obtain the best reliability for those technologies.
- The specific choices like the kind of target (Be solid, water cooled) and kind of RF system (solid state) are done in this direction.

Special thanks to Enrico Fagotti, Paolo Colautti, Davide Moro, Silva Bortolussi, Valeria Conte, Francesco Grespan, Antonio Palmieri, Michele Comunian