SPES secondary beam planning

A. Andrighetto
INFN – Laboratori di Legnaro
I. SPES construction phases & +1 L.E. line planning

II. Status of the RIB sistem

III. First beam for users

IV. Conclusion
Project construction phases

- **Phase 1. 2016** - Building + First operation with the cyclotron  
  - NOW!

- **Phase 2. 2017-19** - From C.B. to RFQ + SPES target, LRMS, 1+ Beam Lines

- **Phase 3. 2019-20** - From the LRMS to the CB + rom RFQ to ALPI

- **1) RIB production area**
- **2) Beam Manipulation area**
- **3) Post acceleration area**
The Low Energy 1+ beam line ("TIS – Tape System")

Goal: To Have first no-accelerated RIB before end 2019
Working plan for the 1+ (TIS – tape system)

Working plan and follow-up for the three main issues listed below:

1) Bunker beam line (proton & RIB)

2) 1+ beam line

3) SPES ISOL laboratories operation

Milestone 2019: first low intensity RIB @ SPES
### Planning of Bunker beam line

<table>
<thead>
<tr>
<th>Activity Description</th>
<th>Duration</th>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary and secondary beam line operation</td>
<td>603 giorni</td>
<td>01/06/16</td>
<td>29/06/19</td>
</tr>
<tr>
<td>Cyclotron commissioning with the high-power beam dump</td>
<td>6 giorni</td>
<td>01/06/16</td>
<td>31/06/16</td>
</tr>
<tr>
<td>Cooling</td>
<td>43 giorni</td>
<td>01/06/16</td>
<td>31/10/16</td>
</tr>
<tr>
<td>Decommissioning</td>
<td>22 giorni</td>
<td>01/06/16</td>
<td>30/11/16</td>
</tr>
<tr>
<td>Cleaning of the A6 room and accurate check for safety and radioprotection</td>
<td>22 giorni</td>
<td>01/12/16</td>
<td>30/12/16</td>
</tr>
<tr>
<td>Delivery of the technical subsystems of the ISOL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tender for the execution of ISOL rooms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installation of the main plant (for the complete secondary beam lines)</td>
<td>06/16</td>
<td>01/06/16</td>
<td>29/12/16</td>
</tr>
<tr>
<td>Preliminary assembly of the protonic front-end</td>
<td>06/16</td>
<td>01/06/16</td>
<td>31/07/17</td>
</tr>
<tr>
<td>Mechanical installation of the protonic front-end</td>
<td>06/16</td>
<td>01/06/16</td>
<td>30/04/18</td>
</tr>
<tr>
<td>Preliminary assembly of the electrostatic quadrupoles</td>
<td>06/16</td>
<td>01/06/16</td>
<td>30/12/16</td>
</tr>
<tr>
<td>Mechanical installation of the electrostatic quadrupoles</td>
<td>06/16</td>
<td>01/06/16</td>
<td>31/12/16</td>
</tr>
<tr>
<td>Technical documentation</td>
<td>45 giorni</td>
<td>02/07/18</td>
<td>31/08/18</td>
</tr>
<tr>
<td>Tender for the vacuum system components</td>
<td>133 giorni</td>
<td>01/06/16</td>
<td>30/12/16</td>
</tr>
<tr>
<td>Installation of the vacuum secondary beam lines</td>
<td>260 giorni</td>
<td>02/01/17</td>
<td>29/12/17</td>
</tr>
<tr>
<td>Technical documentation</td>
<td>130 giorni</td>
<td>01/01/18</td>
<td>29/06/18</td>
</tr>
<tr>
<td>Testing of the power supplies and of the control system</td>
<td>213 giorni</td>
<td>03/09/18</td>
<td>28/06/18</td>
</tr>
<tr>
<td>Beam line test with low intensity proton beam in the high power Faraday cup</td>
<td>215 giorni</td>
<td>03/09/18</td>
<td>28/06/18</td>
</tr>
<tr>
<td>Beam line test with stable ion beams</td>
<td>215 giorni</td>
<td>03/09/18</td>
<td>28/06/18</td>
</tr>
<tr>
<td>Horizontal handling machine test</td>
<td>0 giorni</td>
<td>28/06/18</td>
<td>28/06/18</td>
</tr>
<tr>
<td>Primary and secondary beam lines commissioning</td>
<td>0 giorni</td>
<td>28/06/18</td>
<td>28/06/18</td>
</tr>
</tbody>
</table>

**Contingency & Tests**

- September 2018 – June 2019

**Scheduling**

- September 2018
- October 2018
- November 2018
- December 2018
- January 2019
- February 2019

**Delivery**

- September 2018
- October 2018
- November 2018
- December 2018
- January 2019

**Installation**

- September 2018
- October 2018
- November 2018
- December 2018
- January 2019

**Commissioning**

- September 2018
- October 2018
- November 2018
- December 2018
- January 2019
Planning of 1+ beam line

1+ beam line operation
preparation of the technical documentation for the plants and subsystems of the 1+ beam line
803 giorni
mer 01/06/16 - ven 20/06/19

bunker A6

CONSTRUCTION & INSTALLATION

service plants to hubs (hydraulic, electrical, ...)

mechanical installations

vacuum

service plants from hubs to the main apparatus

controls & power supplies

CONTINGENCY & TESTS
March – June 2019
1+ beam line operation (from TIS to tape system)

WIP for the specific 1+ beam line components

- Magnetic dipole
- Electrostatic triplet of quads
- Electrostatic dipole
- Tape system
- Beam diagnostic box
Future Implementations

- Tape station for beam characterization
- Low intensity beam monitors
  - MCP & grid beam monitor
- Electrostatic dipoles
- Low Energy Experimental Room (not financed yet)
Status of the RIB complex
The SPES TIS complex

- Ions
- Fission fragments
- 8kW proton beam
- 7 UCx target discs
- Hot Transfer Line
- Extraction Electrode (GND)
- Ion Source (up to +40 kV)
The OFF-LINE fron-end
Laboratories & Organization

WG1: TIS
WG2: Materials
WG3: Laser
WG4: Handling
WG5: Front End
TIS unit endurance test:

Tests at high temperature with Joule heating thermal load (1300A target heater, 350A line):

- Heating power ≈ 12 kW > primary proton beam thermal load (≈10 kW)

- ≈ 415 testing hours at high temperature -> ≈ 220 hours at maximum power (12kW)

- 79 heating cycles sustained -> 9 with current ramps of 1 s from 0 A to 1300A (!) to 350A (!)

TIS UNIT STILL OPERATIVE!!
Plasma Ion Sources: off-line beam production

<table>
<thead>
<tr>
<th>beam</th>
<th>ion. eff. (%)</th>
<th>injection mode</th>
<th>cathode temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar</td>
<td>6</td>
<td>gas tube</td>
<td>2200</td>
</tr>
<tr>
<td>Br</td>
<td>WIP</td>
<td>oven</td>
<td>2200</td>
</tr>
<tr>
<td>Kr</td>
<td>8.5</td>
<td>gas tube</td>
<td>2200</td>
</tr>
<tr>
<td>Y</td>
<td>very low</td>
<td>oven</td>
<td>2300</td>
</tr>
<tr>
<td>Sn</td>
<td>10</td>
<td>oven</td>
<td>2200</td>
</tr>
<tr>
<td>I</td>
<td>19</td>
<td>oven</td>
<td>2200</td>
</tr>
<tr>
<td>Xe</td>
<td>11</td>
<td>gas tube</td>
<td>2200</td>
</tr>
</tbody>
</table>
Sourface ion sources: off-line beam production

### Table

<table>
<thead>
<tr>
<th>Beam</th>
<th>Ion. Eff. (%)</th>
<th>Hot-cavity Temp. (°C)</th>
<th>Hot-cavity Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>47.6</td>
<td>2200</td>
<td>Ta</td>
</tr>
<tr>
<td>K</td>
<td>55.4</td>
<td>2200</td>
<td>Ta</td>
</tr>
<tr>
<td>Ga</td>
<td>1.4</td>
<td>2200</td>
<td>Ta</td>
</tr>
<tr>
<td>Rb</td>
<td>54.5</td>
<td>2200</td>
<td>Ta</td>
</tr>
<tr>
<td>Sr</td>
<td>18.5</td>
<td>2200</td>
<td>Ta</td>
</tr>
<tr>
<td>In</td>
<td>3.2</td>
<td>2200</td>
<td>Ta</td>
</tr>
<tr>
<td>Cs</td>
<td>43.2</td>
<td>2200</td>
<td>Ta</td>
</tr>
<tr>
<td>Ba</td>
<td>58.8</td>
<td>2200</td>
<td>Ta</td>
</tr>
<tr>
<td>La</td>
<td>20.1</td>
<td>2200</td>
<td>Ta</td>
</tr>
</tbody>
</table>
Target materials production and tests

New laboratory for the production of UC$_x$ at Legnaro

Ready for UC$_x$ production.

Ventilation and fire extinguishing systems are ready, instruments are placed and ready to be used.
Target material and UCx production

- On-line testing of the SPES target material and architecture @ ORNL (2010-2012)
- 40 MeV, 50 nA proton beam on a UCx target

### 2010 Test
- Standard UCx

### 2011 Test
- Low density UCx

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>4.25</td>
<td>2.59</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>12.50</td>
<td>13.07</td>
</tr>
<tr>
<td>Thickness (g/cm²)</td>
<td>0.41</td>
<td>0.41</td>
</tr>
<tr>
<td>Calculated porosity (%)</td>
<td>58</td>
<td>75</td>
</tr>
</tbody>
</table>
Target materials production and tests

Synthesis of a novel type of UC$_x$ using graphene

Experiment submitted & accepted at Karlsruhe: n. AUL-176 "Study of the use of Reduced Graphene Oxide as source of carbon for UC$_x$-Graphene nanocomposites production"

Final phase (Nov-Dec 2015, JRC-ITU Karlsruhe, ActusLab)

Production of uranium carbide using graphite or graphene as carbon sources

\[ \text{UO}_2 + 6C \rightarrow \text{UC}_2 + 2C + 2\text{CO} \]
Laser Laboratories..

Offline: Spectroscopy
- 3 Dye Laser @ 10 Hz rep. rate

Online (SS laser): RIB prod.
- 3 TiSa Laser @ 10 kHz rep. rate

Diagnostic tools:
- Monochromator
- HCL
- ToF Mass Spectrometer

Diagnostic tools:
- Λ-meter
- Alignments System
- Ion-Beam
Development of the RIB apparatus: resonant laser ionization

**Spectroscopy:**
- Study of different elements of interest
- Offline-lab with 10Hz dye laser system
- HCL & ToF-MS

**New SS laser:**
- Defining RIB production laser requirements
- 10 kHz TiSa laser
- New laser lab requirements

**Laser FE:**
- ToF system
- Hot cavity
- Efficiency measurements
The SMO test at LNL

- Simulation software Siemens in Tia Portal
- Movement test in automatic mode
- Experimental tests with 3 transponder
The agv trip
The new Chamber Unit Storage

The layout:

Storage cartesian system prototype
ISOL front end: mechanical design upgrades

Proton Beam collimator box

Proton Beam diagnostic cross

Power cables without insulation

Pneumatic, hydraulic and power fast connections

Within April 2017

Within April 2017

end 2016

end 2016

General remarks for the Front-End design

- Elastomer seals are foreseen only in the fast connection for both the pneumatic and hydraulic loops (maybe VAT valves).
- Hydraulic loops have compatible interfaces for demineralized water (AISI304L/316L - copper or AISI304L/316L - aluminum) in order to prevent corrosion phenomena.

for:
- High Power Faraday Cup
- High Power Beam Profiler

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III SPES workshop: 10th October 2016
ISOL front end: general design upgrades

Proton beam line

Collimators

High Power Beam Profiler and Faraday Cup

end 2017

RIB line

Electrostatic module upgrade for the Wien Filter

actual

NEW

July 2016

Mass resolution improvement from 80 to 140

Upgraded diagnostic boxes

end 2016

elastic system for wires tested
RESULTS of the study on elastomeric vacuum O-rings for the target chamber

1. Dosimetry calculations with MCNPX: LNL – UniPv – UniBs
2. Irradiation in a mixed n+γ field at TRIGA reactor: UniPv (LENA)
3. Mechanical and physical tests at MaST Laboratory: UniBs

FOUR TESTED PRODUCTS:

 Episcopal
 DICTOMATIK
 James Walker

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EPDM 2
- Best price/performance ratio
- Recommended up to 15 days life cycle and beyond

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PROSPECTS FOR RDS_SPES ACTIVITIES:

- Experimental study of other components: lubricants and greases, optical fibers, cable insulators, etc.
- Possible collaboration with ESS for rad-hard test of materials in reactor n+γ mixed fields
First Beam for users
List Beam for users (SPES web-page)

VISIT: https://web.infn.it/spes/index.php/characteristics/spes-beams-7037/spesbeamstable
Rb beams (Surface Ion Source)

Rubidium (Rb)
alcohol metal
atomic number Z = 37
standard atomic weight = 85.468
first ionization potential = 4.18 eV
ionization efficiency = 54.5 %
working temperature (hot-cavity) = 2200 °C
injection technique = folded Ta ribbon inside a tubing Ta oven
calibrated solution = 10 µl (RbNO₃ in HNO₃(aq))
total beam intensity ≈ 300 nA
beam RMS emittance = 1.5 π mm mrad
extraction voltage = 25 kV
Selectivity: Very Good (also without HRMS)

stable Isotopes:
- ⁸⁵Rb (72.17 %)
- ⁸⁷Rb (27.83 %)

Production Yield: Very Good

isotopes produced @ SPES
(p→²³⁸U, 40 MeV 200 µA)

Possible First Beam

Mass scanning
Cs beams (Surface Ion Source)

Cs (Caesium)
- alkali metal
- atomic number $Z = 55$
- standard atomic weight = 132.905
- first ionization potential = 3.89 eV
- ionization efficiency = 43.2%
- working temperature (hot-cavity) = 2200 °C
- injection technique = folded Ta ribbon inside a tubular Ta oven
- calibrated solution = 20 µl (CsNO$_3$ in HNO$_3$(aq))
- total beam intensity ≈ 300 nA
- beam RMS emittance = 1.5 π mm mrad
- extraction voltage = 25 kV
- Selectivity: Good (also without HRMS)
- stable Isotopes:
  - $^{133}$Cs (100 %)
  - isotopes produced @ SPES ($p\rightarrow^{238}$U, 40 MeV 200 µA)

Production Yield: Very Good

Possible Second Beam

Mass scanning

![Cs beams diagram](image)
Ba beams *(Surface Ion Source)*

**Barium (Ba)**
- alkaline earth metal
- atomic number $Z = 56$
- standard atomic weight = 137,327
- first ionization potential = 5,21 eV
- ionization efficiency = 58,8%
- working temperature (hot-cavity) = 2200 °C
- injection technique = folded Ta ribbon inside a tubular Ta oven
- calibrated solution = 20 µl (BaCO$_3$ in HNO$_3$(aq))
- total beam intensity $\approx$ 300 nA
- beam RMS emittance = 1,5 $\pi$ mm mrad
- extraction voltage = 25 kV
- Selectivity: Good (also without HRMS)
- **stable Isotopes:**
  - $^{134}$Ba (2,42%)
  - $^{135}$Ba (6,60%)
  - $^{136}$Ba (7,85%)
  - $^{137}$Ba (11,23%)
  - $^{138}$Ba (71,7%)
- **Production Yield:** Good
- **isotopes produced @ SPES**
  (p$\rightarrow^{238}$U, 40 MeV 200 µA)
  - $^{130}$Ba
  - $^{131}$Ba
  - $^{132}$Ba
  - $^{133}$Ba
  - $^{134}$Ba
  - $^{135}$Ba
  - $^{136}$Ba
  - $^{137}$Ba
  - $^{138}$Ba
  - $^{139}$La
  - $^{140}$La
  - $^{141}$La
  - $^{142}$La
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  - $^{229}$La
  - $^{230}$La
  - $^{231}$La
  - $^{232}$La
  - $^{233}$La
  - $^{234}$La
  - $^{235}$U
  - $^{236}$U
  - $^{238}$U

**Mass scanning**
Sr beams (Surface Ion Source)

Strontium (Sr)
alkaline earth metal
atomic number \( Z = 56 \)
standard atomic weight = 87.62
first ionization potential = 5.70 eV
ionization efficiency = 18.5 %
working temperature (hot-cavity) = 2200 °C
injection technique = folded Ta ribbon inside a tubular Ta oven
calibrated solution = 40 µl (Sr(NO₃)₂ in HNO₃(aq))
total beam intensity ≈ 300 nA
beam RMS emittance = 1.5 π mm mrad
extraction voltage = 25 kV
Selectivity: Good (also without HRMS)

stable Isotopes:
- \(^{84}\text{Sr} (0.56 \%)\)
- \(^{86}\text{Sr} (9.86 \%)\)
- \(^{87}\text{Sr} (7.00 \%)\)
- \(^{88}\text{Sr} (82.58 \%)\)

isotopes produced @ SPES
\((p\rightarrow^{238}\text{U}, 40 \text{ MeV} 200 \mu\text{A})\)

Production Yield: Good

Mass scanning

Possible good Beam
Sn beams (Plasma Ion Source)

**Tin (Sn)**
- post-transition metal
- atomic number $Z = 50$
- standard atomic weight = 118,710
- first ionization potential = 7,334 eV
- ionization efficiency = 9.5%
- working temperature = 2200 °C
- injection technique = folded Ta ribbon inside a tubular Ta oven (Sn metal)
- Sn beam intensity observed during the tests ≈ 300 nA
- beam RMS emittance = 5 π mm mrad
- anode voltage = 150 V
- extraction voltage = 25 kV

**stable Isotopes:**
- $^{112}\text{Sn}$ (0.97 %)
- $^{114}\text{Sn}$ (0.66 %)
- $^{115}\text{Sn}$ (0.34 %)
- $^{116}\text{Sn}$ (14.54 %)
- $^{117}\text{Sn}$ (7.68 %)
- $^{118}\text{Sn}$ (24.22 %)
- $^{119}\text{Sn}$ (8.59 %)
- $^{120}\text{Sn}$ (32.58 %)
- $^{122}\text{Sn}$ (4.63 %)
- $^{124}\text{Sn}$ (5.79 %)

**isotopes produced @ SPES (p→$^{238}\text{U}$, 40 MeV 200 µA):**
- $^{112}\text{Sn}$
- $^{114}\text{Sn}$
- $^{115}\text{Sn}$
- $^{116}\text{Sn}$
- $^{117}\text{Sn}$
- $^{118}\text{Sn}$
- $^{119}\text{Sn}$
- $^{120}\text{Sn}$
- $^{122}\text{Sn}$
- $^{124}\text{Sn}$

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III SPES workshop: 10th October 2016
**Sn in Laser Laboratory (Future LIS)**

**Tin (Sn)**
- post-transition metal
- atomic number \( Z = 50 \)
- standard atomic weight = 118,710
- first ionization potential = 7.34 eV
- ionization efficiency = NA
- working temperature (hot-cavity) = NA
- injection technique = yes
- calibrated solution = yes
- total beam intensity ≈ NA

**Ionization wavelength path = yes**

**stable Isotopes:**
- \(^{114}\)Sn (0.96 %)
- \(^{115}\)Sn (0.66 %)
- \(^{116}\)Sn (1.43 %)
- \(^{117}\)Sn (7.61 %)
- \(^{118}\)Sn (24.03 %)
- \(^{119}\)Sn (8.58 %)
- \(^{120}\)Sn (32.85 %)
- \(^{122}\)Sn (4.72 %)
- \(^{124}\)Sn (5.94 %)

**Mass scanning**

**Production Yield: Good**

**isotopes produced @ SPES**
(p→\(^{238}\)U, 40 MeV 200 µA)

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III SPES workshop: 10th October 2016
Kr beams (Plasma Ion Source)

**Krypton (Kr)**
- Noble gas
- Atomic number \( Z = 36 \)
- Standard atomic weight = 83,798
- First ionization potential = 13.99 eV
- Ionization efficiency = 4.6 %
- Working temperature = 2200 °C
- Gas injection rate (leak) = 5.0 \( \times \) 10\(^{-6} \) mbar l/s
- Total beam intensity ≈ 3000 nA
- Beam RMS emittance = 5 \( \pi \) mm mrad
- Anode voltage = 150 V
- Extraction voltage = 25 kV

**Selectivity:** Bad (without HRMS)

**Stable isotopes:**
- \(^{78}\text{Kr} \) (0.35 %)
- \(^{80}\text{Kr} \) (2.25 %)
- \(^{82}\text{Kr} \) (11.6 %)
- \(^{83}\text{Kr} \) (11.5 %)
- \(^{84}\text{Kr} \) (57 %)
- \(^{86}\text{Kr} \) (17.3 %)

**Isotopes produced @ SPES**
(p \( \rightarrow \) \(^{238}\text{U} \), 40 MeV 200 µA)

- > 10\(^{11} \)
- 10\(^{10} \) - 10\(^{11} \)
- 10\(^{9} \) - 10\(^{10} \)
- 10\(^{8} \) - 10\(^{9} \)
- 10\(^{7} \) - 10\(^{8} \)
- 10\(^{6} \) - 10\(^{7} \)
- 10\(^{5} \) - 10\(^{6} \)
- 10\(^{4} \) - 10\(^{5} \)
- 10\(^{3} \) - 10\(^{4} \)
- 10\(^{2} \) - 10\(^{3} \)
- 10 - 10\(^{2} \)
- < 10

---

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III SPES workshop: 10th October 2016
Xe beams (Plasma Ion Source)

Xenon (Xe)
- noble gas
- atomic number $Z = 54$
- standard atomic weight = 131,293
- first ionization potential = 12,13 eV
- ionization efficiency = 5.3 %
- working temperature = 2200 °C
- gas injection rate (leak) = $5.0 \times 10^{-6} \text{ mbar l/s}$
- total beam intensity ≈ 3000 nA
- beam RMS emittance = $5 \pi \text{ mm mrad}$
- anode voltage = 150 V
- extraction voltage = 25 kV
- Selectivity: Bad (without HRMS)

stable Isotopes:
- $^{124}\text{Xe}$ (0.1 %)
- $^{131}\text{Xe}$ (21.2 %)
- $^{126}\text{Xe}$ (0.09 %)
- $^{132}\text{Xe}$ (26.9 %)
- $^{128}\text{Xe}$ (1.91 %)
- $^{134}\text{Xe}$ (10.4 %)
- $^{129}\text{Xe}$ (26.4 %)
- $^{136}\text{Xe}$ (8.9 %)
- $^{130}\text{Xe}$ (4.1 %)

isotopes produced @ SPES
($p \rightarrow ^{238}\text{U}, 40 \text{ MeV} 200 \mu\text{A}$)

Mass scanning
# Beam Selectivity Calculation (using ORNL model)

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Half-life (seconds)</th>
<th>Intensity (pps)</th>
<th>Purity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>69</td>
<td>1.71E+02</td>
<td>9.87E+06</td>
<td>100</td>
</tr>
<tr>
<td>70</td>
<td>4.50E+00</td>
<td>7.89E+06</td>
<td>100</td>
</tr>
<tr>
<td>71</td>
<td>1.95E+01</td>
<td>1.69E+07</td>
<td>100</td>
</tr>
<tr>
<td>72</td>
<td>6.60E+00</td>
<td>1.39E+07</td>
<td>100</td>
</tr>
<tr>
<td>73</td>
<td>3.90E+00</td>
<td>9.17E+06</td>
<td>89</td>
</tr>
<tr>
<td>74</td>
<td>1.50E+00</td>
<td>3.81E+06</td>
<td>81</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Half-life (seconds)</th>
<th>Intensity (pps)</th>
<th>Purity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>88</td>
<td>1.02E+04</td>
<td>4.04E+09</td>
<td>44</td>
</tr>
<tr>
<td>89</td>
<td>1.89E+02</td>
<td>3.99E+09</td>
<td>46</td>
</tr>
<tr>
<td>90</td>
<td>3.23E+01</td>
<td>4.37E+09</td>
<td>53</td>
</tr>
</tbody>
</table>

**Proton beam: E= 40 MeV , I=200 µA**

**No HRMS**

## Copper (Cu) Z=29

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Half-life (seconds)</th>
<th>Intensity (pps)</th>
<th>Purity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>86</td>
<td>1.61E+06</td>
<td>1.90E+09</td>
<td>100</td>
</tr>
<tr>
<td>87</td>
<td>1.50E+18</td>
<td>7.99E+09</td>
<td>100</td>
</tr>
<tr>
<td>88</td>
<td>1.07E+03</td>
<td>2.21E+10</td>
<td>99</td>
</tr>
<tr>
<td>89</td>
<td>9.09E+02</td>
<td>4.75E+10</td>
<td>99</td>
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<tr>
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<td>9.62E+10</td>
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</tr>
<tr>
<td>91</td>
<td>5.84E+01</td>
<td>9.62E+10</td>
<td>97</td>
</tr>
<tr>
<td>92</td>
<td>4.49E+00</td>
<td>5.09E+10</td>
<td>91</td>
</tr>
<tr>
<td>93</td>
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<tr>
<td>94</td>
<td>2.70E+00</td>
<td>1.37E+10</td>
<td>76</td>
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</tbody>
</table>

## Kripton (Kr) Z=36

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Half-life (seconds)</th>
<th>Intensity (pps)</th>
<th>Purity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>94</td>
<td>7.53E+01</td>
<td>1.27E+10</td>
<td>79</td>
</tr>
<tr>
<td>95</td>
<td>2.39E+01</td>
<td>3.00E+09</td>
<td>100</td>
</tr>
<tr>
<td>96</td>
<td>1.07E+00</td>
<td>1.57E+07</td>
<td>100</td>
</tr>
<tr>
<td>97</td>
<td>4.26E-01</td>
<td>1.31E+06</td>
<td>100</td>
</tr>
<tr>
<td>98</td>
<td>6.53E-01</td>
<td>6.16E+05</td>
<td>100</td>
</tr>
<tr>
<td>99</td>
<td>2.69E-01</td>
<td>2.80E+04</td>
<td>100</td>
</tr>
<tr>
<td>100</td>
<td>2.02E-01</td>
<td>2.30E+03</td>
<td>100</td>
</tr>
</tbody>
</table>

## Rubidium (Rb) Z=37

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Half-life (seconds)</th>
<th>Intensity (pps)</th>
<th>Purity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>94</td>
<td>7.53E+01</td>
<td>1.27E+10</td>
<td>79</td>
</tr>
<tr>
<td>95</td>
<td>2.39E+01</td>
<td>3.00E+09</td>
<td>100</td>
</tr>
<tr>
<td>96</td>
<td>1.07E+00</td>
<td>1.57E+07</td>
<td>100</td>
</tr>
<tr>
<td>97</td>
<td>4.26E-01</td>
<td>1.31E+06</td>
<td>100</td>
</tr>
<tr>
<td>98</td>
<td>6.53E-01</td>
<td>6.16E+05</td>
<td>100</td>
</tr>
<tr>
<td>99</td>
<td>2.69E-01</td>
<td>2.80E+04</td>
<td>100</td>
</tr>
<tr>
<td>100</td>
<td>2.02E-01</td>
<td>2.30E+03</td>
<td>100</td>
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</table>

## Strontium (Sr) Z=38
### Beam Selectivity Calculation (using ORNL model)

#### Tin (Sn) Z=50

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Half-life (seconds)</th>
<th>Intensity (pps)</th>
<th>Purity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>123</td>
<td>1.12E+07</td>
<td>1.28E+10</td>
<td>62</td>
</tr>
<tr>
<td>125</td>
<td>8.33E+05</td>
<td>3.50E+10</td>
<td>96</td>
</tr>
<tr>
<td>126</td>
<td>3.16E+12</td>
<td>4.21E+10</td>
<td>100</td>
</tr>
<tr>
<td>127</td>
<td>7.56E+03</td>
<td>4.08E+10</td>
<td>100</td>
</tr>
<tr>
<td>128</td>
<td>3.54E+03</td>
<td>3.18E+10</td>
<td>100</td>
</tr>
<tr>
<td>129</td>
<td>1.34E+02</td>
<td>1.75E+10</td>
<td>100</td>
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<tr>
<td>130</td>
<td>2.23E+02</td>
<td>7.89E+09</td>
<td>99</td>
</tr>
<tr>
<td>131</td>
<td>5.60E+01</td>
<td>3.42E+09</td>
<td>76</td>
</tr>
<tr>
<td>132</td>
<td>3.97E+01</td>
<td>1.56E+09</td>
<td>100</td>
</tr>
</tbody>
</table>

#### Laser I. S.

#### Surface I. S.

#### Plasma I. S.

#### Xenon (Xe) Z=54

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Half-life (seconds)</th>
<th>Intensity (pps)</th>
<th>Purity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>135</td>
<td>3.29+04</td>
<td>1.96E+10</td>
<td>44</td>
</tr>
<tr>
<td>137</td>
<td>2.29E+02</td>
<td>9.86E+09</td>
<td>28</td>
</tr>
<tr>
<td>138</td>
<td>8.45E+02</td>
<td>1.01E+10</td>
<td>29</td>
</tr>
</tbody>
</table>

#### Barium (Ba) Z=56

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Half-life (seconds)</th>
<th>Intensity (pps)</th>
<th>Purity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>141</td>
<td>1.10E+03</td>
<td>1.61E+10</td>
<td>43</td>
</tr>
<tr>
<td>142</td>
<td>6.38E+02</td>
<td>9.33E+09</td>
<td>79</td>
</tr>
<tr>
<td>143</td>
<td>1.43E+01</td>
<td>1.48E+08</td>
<td>25</td>
</tr>
</tbody>
</table>

#### Surface I. S.

#### Proton beam: E= 40 MeV, I=200 μA

#### No HRMS

**SPES devoted as $^{132}$Sn factory?**
**Yield for possible n-poor beams**

**Graphite Target**

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-life</th>
<th>Total Yield (FLUKA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-&gt; 12C</td>
<td>t1/2</td>
<td>[nuclei/s]</td>
</tr>
<tr>
<td>7Be</td>
<td>53 d</td>
<td>4.37E+12</td>
</tr>
<tr>
<td>8B</td>
<td>770 ms</td>
<td>6.64E+11</td>
</tr>
<tr>
<td>11C</td>
<td>20 m</td>
<td>2.45E+13</td>
</tr>
<tr>
<td>12B</td>
<td>20 s</td>
<td>3.50E+08</td>
</tr>
<tr>
<td>12N</td>
<td>11 ms</td>
<td>5.72E+11</td>
</tr>
<tr>
<td>13N</td>
<td>9.9 m</td>
<td>3.33E+10</td>
</tr>
<tr>
<td>15O</td>
<td>122 s</td>
<td>6.99E+08</td>
</tr>
</tbody>
</table>

**Silicon Carbide Target (test 2006)**

![Graphite Target Image](image1.png)

![Silicon Carbide Target Image](image2.png)

**Aluminum Isotopic Chain**

![Graphite Target Image](image3.png)

![Silicon Carbide Target Image](image4.png)
Conclusion
Concerning the RIB complex...

The RIB source is almost ready for operation.

- TIS Unit ready; endurance tests running.
- UCx LNL laboratory ready for operation.
- Laser off-line lab fully operational; Al, Ge, Sn ionization scheme tested successfully.
- New handling lab ready; AGV is moving in remote mode.
- Rad-hard test for critical materials & components started.
Collaboration network with partners

- ITHEMBA
- RISP-KOREA
- ORNL- HRIBF
- CERN- ISOLDE
- GANIL-SPIRAL 2
- ORSAY-ALTO

**SPES**

- Exotic Beam

**Partners**

- INFN- Pavia
- INFN- Milano
- INFN- Bologna
- INFN- LNS
- INFN- Padova

**Statistics**

- 33 Tesi Magistrali
- 20 Tesi Triennali
- 3 Tesi di PhD
- 15 Ospiti Stranieri (FAI)

**DESIRED REFERENCES**

- 125I: 100
- 90Y
- 131I
- 129Xe
- 85Sr
- 85Se

**ABSTRACT**

"Method for producing beta emitting radiopharmaceuticals, and beta emitting radiopharmaceuticals thus obtained"
Second conclusion: thanks to the team!

Thanks for your attention!

Few results without them ...