SPES project at LNL

Venezia June 8-12, 2009

Gianfranco Prete
On behalf of SPES collaboration
Conclusions of the NuPECC Working group on the “Next Generation European Radioactive Ion Beam Facilities” (April 2000)

Next generation of RIB facilities should aim at intensities 1000 times higher than in the facilities presently running or at the commissioning stage. Two truly complementary facilities, based respectively on the « In flight and ISOL» methods are needed to cover the foreseen physics issues.

**Projectile Fragmentation**
- High energy,
- large variety of species

**ISOL**
- good beam quality,
- High flexibility,
- High intensity
Conclusions of the NuPECC Working group on the “Next Generation European Radioactive Ion Beam Facilities” (April 2000)

Next generation of RIB facilities should aim at intensities 1000 times higher than in the facilities presently running or at the commissioning stage. Two truly complementary facilities, based respectively on the «In flight and ISOL» methods are needed to cover the foreseen physics issues.
Second generation ISOL facilities toward EURISOL

HIE ISOLDE

SPES

SPIRAL2

Neutron rich exotic beams $10^8 - 10^{10}$ pps on target

Production target: UCx $10^{12}-10^{14}$ fission s$^{-1}$
Physics Domain with RIB

- Fusion-Fission, Reaction Cross Sections, Coulex
- One-Nucleon Transfer
- Two Nucleon Transfer
- Elastic, Inelastic Scattering
- Symmetry Studies
- Mass and Decay Measurements
- Radiative Capture

ENERGY (MeV/u)

INTENSITY (particles/sec)
SPES ISOL facility conceptual design

ALPI - Superconductive Linac
40 MV equivalent

High Resolution Mass Spectrometer

$^{132}\text{Sn} \ 10-15 \text{ AMeV}$

$10^{13} \text{ fiss/s}$

60kV extraction + 200kV platform

$\Delta M/M \sim 1/20000$

Two UCx Direct Target stations

Charge Breeder

PIAVE

INFN
The SPES Project @ LNL: a multi-user project
The SPES Project @ LNL: a multi-user project

High intensity proton linac:
TRIPS source - TRASCO RFQ 30 mA, 5MeV
Neutron facility for Medical, Astrophysics and Material science.
Neutron source up to $10^{14}$ n s$^{-1}$
Thermal neutrons: $10^9$ n s$^{-1}$ cm$^{-2}$

Approved for construction

Applied Physics with proton beam
70 MeV 450 μA

Primary Beam: 300 μA, 70 MeV protons from a 2 exit ports Cyclotron

Production Target: UCx $10^{13}$ fission s$^{-1}$

Re-accelerator: ALPI Superconductive Linac up to 11 AMeV for A=130
The SPES ISOL facility components

1. DRIVER
2. TARGET-ION SOURCE
3. BEAM TRANSPORT-SELECTION
4. CHARGE BREEDER
5. REACCELERATOR
The driver cyclotron
(Commercial solution)

IBA C70 characteristics:

• Diameter < 4m
• Weight > 120t
• Magnetic Gap: 30mm
• Magnetic field: 1.55T
• Extraction Radius: 1.2m
• 2 exit ports
• Particles: \( \text{H}^-/\text{D}^-/\text{He}^{2+}/\text{HH}^+ \)
• Variable Energy: \( 15 \text{ MeV} \rightarrow 70 \text{ MeV} \)

extraction Systems:

- Stripper \( \rightarrow \text{H}^-/\text{D}^- \)
- Deflector \( \rightarrow \text{He}^{2+}/\text{HH}^+ \)

Performances:

- \( 750 \mu\text{A H}^- \rightarrow 70\text{MeV} \)
- \( 35\mu\text{A He}^{2+} \rightarrow 70\text{MeV} \)
The SPES direct target

Ion source

exotic beam 50KeV 1+

Proton beam

40 MeV 200μA protons

Windows

UCx targets 30 gr
dump

Fission efficiency → 100p per 1.5 FF

~ 200 μA → 10^{13} fissions/sec

Beam power = 40 MeV p × 200 μA = 8 KW
**UC$_x$ Characterization: SEM & XRD**

- **SEM = Scanning Electron Microscope**
- **XRD = X Ray Diffraction**

![Graph of XRD peaks](image)

- *α-UC$_2$ pdf # 84-1344
- § Graphite pdf #

**UC$_x$ after thermal treatment**

![SEM image of UC$_x$ after thermal treatment](image)
SPES beams: Isotopes Release

- GEANT4 toolkit and the RIBO codes.
- Experimental data available from ISOLDE-CERN, ORNL and PNPI Gatchina

\[ T_{\text{diff}}^{Sn} = 1 \text{sec (ISOLDE UCx material)} \]
\[ T_{\text{eff}} = \text{walking time in the container} \]
\[ T_{\text{Sticking}}^{Sn} = 10^{-6} \text{ sec} \]

Release time \[ \tau = T_{\text{diff}} + (T_{\text{tof}} + N \times T_{\text{sticking}}) \]
\[ Sn \tau_{\text{SPES}}^{Sn} = 1 + 0.1 + 0.1 = 1.2 \text{ s} \]

<table>
<thead>
<tr>
<th>element</th>
<th>Diffusion time (s)</th>
<th>Nr of collisions</th>
<th>Effusion Time (s)</th>
<th>Release Time (s)</th>
<th>T_{1/2} (s)</th>
<th>Total Release Fraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{132}\text{Sn})</td>
<td>1</td>
<td>(10^5)</td>
<td>0.2</td>
<td>1.2</td>
<td>40</td>
<td>98</td>
</tr>
<tr>
<td>(^{133}\text{Sn})</td>
<td>1</td>
<td>(10^5)</td>
<td>0.2</td>
<td>1.2</td>
<td>1.4</td>
<td>40</td>
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<tr>
<td>(^{133}\text{Sn})</td>
<td></td>
<td></td>
<td></td>
<td>40</td>
<td>1.4</td>
<td>1</td>
</tr>
</tbody>
</table>

UCx target 25 gr U
Some expected Beams at SPES

**Accelerated RIB beams**

- Ionization efficiencies:
  - (1+) 30% and (n+) 4% for Kr and Xe,
  - (1+) 90% and (n+) 12% for Kr and Xe,
- Transport efficiency 50%
The SPES Ion Sources

Ionization schema with a Surface ionizer coupled to a Laser beam

Surface ionization

Atom → Ion

Hot surface

continuum

< 5-6 eV

Ionization energy

Ground state

Laser beam

Excited states

Ionization energy

< 9 - 10 eV

Ground state

Conductive band

Fermi energy

Ground state

Laser ionization

Atom → Ion

continuum

INFN-Pavia

SPES Laser Laboratory
Surface Ionization Source
ANSYS simulation

Thermo-mechanical simulation

Electrostatic field

Ions trajectory

PRELIMINARY
Beam transfer in the Front End

The beam is accelerated to 60KeV by the puller and shaped by electrostatic devices. TraceWin will be used for beam calculation.
RIB Front end construction
In collaboration with INFN Milano & INFN Pavia

Following ISOLDE font end design
RIB Front end construction
In collaboration with INFN Milano & INFN Pavia

Following ISOLDE font end design
RIB Front end
(status at May ‘09)
SPES High Voltage platform

Front end | Wien filter | (RFQ cooler)

2.5 m | 1.5 m | 2.0 m

3.5 m

8 m

60kV

200 kV

HV platform: EXCYT – HRIBF design
Beam selection and identification

**Beam**: Isobaric mixed Beam: $A=82$

- Identification of beam and beam-like particles by Ionization Chamber, total rates up to $10^5$ particles per second.
- $A = 82$ beam was composed of several isotopes: stable $^{82}\text{Se}$ (85%), $^{82}\text{Ge}$ (15%) and a trace of $^{82}\text{As}$ (<1%).
- HRIBF: $5 \times 10^{11}$ f/s

**Reaction**: $^2\text{H}(^{82}\text{Ge},p)^{83}\text{Ge}$
Direct reaction in inverse kinematic

First study of the level structure of the $r$-process nucleus $^{83}\text{Ge}$

ORNL-HRIBF J. S. Thomas et al. PHYSICAL REVIEW C 71, 021302 (2005)
Comparison of the main parameters of the EXCYT and the SPES mass spectrometer.

<table>
<thead>
<tr>
<th>Project name</th>
<th>EXCYT</th>
<th>SPES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of dipoles</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Bending Angle</td>
<td>90°</td>
<td>110°</td>
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<tr>
<td>Bending radius</td>
<td>2.6 m</td>
<td>2.6 m</td>
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<tr>
<td>Entrance/exit angle</td>
<td>12.8°</td>
<td>32°</td>
</tr>
<tr>
<td>Magnetic field range</td>
<td>0.6 - 4.4 kGauss</td>
<td>1.0 - 4.4 kGauss</td>
</tr>
<tr>
<td>beam size at analysis slits</td>
<td>0.4 mm</td>
<td>0.4 mm</td>
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<tr>
<td>Teta acceptance</td>
<td>40 mrad</td>
<td>40 mrad</td>
</tr>
<tr>
<td>(x,x’) emittance</td>
<td>4 \pi \text{ mm.mrad}</td>
<td>4 \pi \text{ mm.mrad}</td>
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<tr>
<td>Y beam size</td>
<td>2 mm</td>
<td>2 mm</td>
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<tr>
<td>Phi acceptance</td>
<td>10 mrad</td>
<td>10 mrad</td>
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<tr>
<td>(y,y’) emittance</td>
<td>4 \pi \text{ mm.mrad}</td>
<td>5 \pi \text{ mm.mrad}</td>
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<tr>
<td>Resolving power</td>
<td>&gt;15,000</td>
<td>&gt;20,000</td>
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<tr>
<td>Dispersion</td>
<td>16 m</td>
<td>28 m</td>
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</tbody>
</table>
Multi-pass Time-of-Flight system: concept

Pulsed ion source
MCP detector or electrostatic gate

Pulsed entry electrode

Individual electrodes

1st Electrostatic Mirror

2nd Electrostatic Mirror

MTOF Spectrometer: Spectrum taken with MCP

MTOF Separator: Physical separation using fast electrostatic gate

Development of a high resolution isobar separator for study of exotic decays

A. Plochaczek b, V. Shchepunov b, H.K. Carter b, J.C. Batchelder b, E.F. Zganjar b, S.N. Liddick b, H. Wollnik b, Y. Hu a, b, O. Griffith b

a Louisiana State University, Baton Rouge, LA, USA
b UNMIL, Oak Ridge, Associated Universities, Oak Ridge, TN, USA

2008

N₂ time spectrum, ToF = 2.6ms
FWHM ~ 60ns
⇒ m/Δm(FWHM) = 22,000
CB For the SPES Project

*CHOICE of the Charge BOOSTER*

ECR-Charge Breeder

- ROBUST
- SIMPLE
- IDEAL FOR INJECTION INTO ALPI (Sit on a HV platform)
CB For the SPES Project

ECR ION SOURCE

• FULLY PERMANENT MAGNET @ 14 GHz
  FPMS

• ROOM TEMPERATURE @ 14-18GHz
  RTS

• HT SUPERCONDUCTING @ 18 GHz
  HTS

• FULLY SUPERCONDUCTING @ >18 GHz
  FSS
**REQUIREMENTS**

- Production of high charge state with good efficiency: $^{132}\text{Sn}^{26+}$
- Injection into RFQ PIAVE at fixed $\beta$

**POSSIBLE DEVELOPMENTs**

- Optics and beam injection
- Use of UHV materials
- Explore combination of magnetic and electrostatic selection
- Explore compatibility with HV platform
Reacceleration

PIAVE up-grade:
new cryostat
improved diagnostic
new bunching section

ALPI up grade:
Low Beta cavities
Stronger Magnetic lenses
SC-RFQ PIAVE SPES upgrade

Present layout

new bunching section  new diagnostics  new cryostats

Superconductive solenoid for transversal focusing

ISACII-like cryostats

NEW CRYOSTAT

PIAVE cryostat

SPES layout

Superconductive solenoid for transversal focusing
The ALPI post accelerator

Superconductive linac based on QW resonators.

2003: Upgraded to $V_{eq} \sim 40$ MV

Original Pb/Cu cavities substituted with

Nb/ Cu spattered cavities or bulk Nb cavities
Upgrading of ALPI medium β QWRs

The possibility of an effective improvement of medium β resonators by Nb/Pb replacement was shown in 1998; 44 upgraded QWRs were installed by 2004; they are working now at an average field of 4.7 MV/m @7 Watt.

- Brazed joints
- Flat shorting plate
- Beam ports shape
- Inductive coupler (hole in high current region)

Limited the reached performance to 4.7MV/m @7W, a factor 2 higher than when Pb plated, but lower than the high β resonators performance.

In 2005 we had the possibility to build 4 new substrates having:
- New beam port design
- A rounded shorting plate
- A capacitive coupler
- No holes in high current regions
- No brazing in the outer resonator body

They are now ready to be installed; 6 MV/m expected on line.
The substitution of Pb with Nb increased substantially the ALPI available equivalent voltage \( V_{eq} = \sum E_a l \) where \( l \) is the resonator active length and \( E_a \) is the accelerating field of the operating resonators. An improvement is aspected soon by installation of the new ready medium beta cavities. A further increased in performance is foreseen in future (next slides).
ALPI upgrade for SPES

Optimum beta
\[ \beta_0 = 0.047 \]
\[ \beta_0 = 0.056 \]
\[ \beta_0 = 0.11 \]
\[ \beta_0 = 0.13 \]

ALPI layout

To be funded:
- 2 additional LowBeta Cryostats (CR1, CR2) a New buncher
- New magnetic lenses (upgrade from 20 to 30 T/m)
Final performance for stable beams: 2009 and SPES scenarios

\[ U(Z_1, Z_2)[\text{MeV/A}] \approx \frac{A_1 + A_2}{A_1 A_2} \frac{Z_1 Z_2}{A_1^{1/3} + A_2^{1/3}} \]

- 2009 - max. current
- 2009 - after source develop.
- upgrade - max. current
- upgrade - max. energy
- Coulomb barrier on Pb
<table>
<thead>
<tr>
<th>Activity</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
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<td>Facility design</td>
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<td>First Target and ion source</td>
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<td>Authorization to operate</td>
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<td>Building construction</td>
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<td>Target installation and commissioning</td>
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<td>Completion of RFQ for Neutron Facility</td>
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<td>Installation and commissioning Neutron Facility</td>
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<td>Cyclotron construction</td>
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<td>Cyclotron Installation and commissioning</td>
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<td>Alpi preparation for post acceleration</td>
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<tr>
<td>Installation of RIBs transfer lines and spectrometer</td>
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<td>Complete commissioning</td>
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The INFN Legnaro Laboratory

Total cost for ISOL facility ~ 40M€
SPES Collaborations

Laboratori Nazionali di Legnaro – Laboratori Nazionali del Sud
Sez INFN: Padova, Milano, Bologna, Catania, Firenze, Napoli, Bari

Ingegneria Meccanica (Sezione Materiali) – Univ. di Padova
Dipartimento Scienze Chimiche – Univ. di Padova
Ingegneria Meccanica (Sezione Progettazione) – Univ. di Padova
Ingegneria Meccanica (Sezione Meccatronica) – Univ. di Trento
Ingegneria Informatica – Univ. di Padova
ENEA Bologna  ENEA Faenza
Ingegneria Nucleare-Univ. di Palermo
(Ing. Energetica Politecnico di Torino)

Target development

Nuclear safety

International collaborations:
ISOLDE-CERN, HRIBF-ORNL
SPIRAL2-(LEA), ISAC-TRIUMF, TRIAC-KEK