The ^{144}Ce source

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SOX's Cerium source

See Marco Pallavicini's talk for SOX Physics case

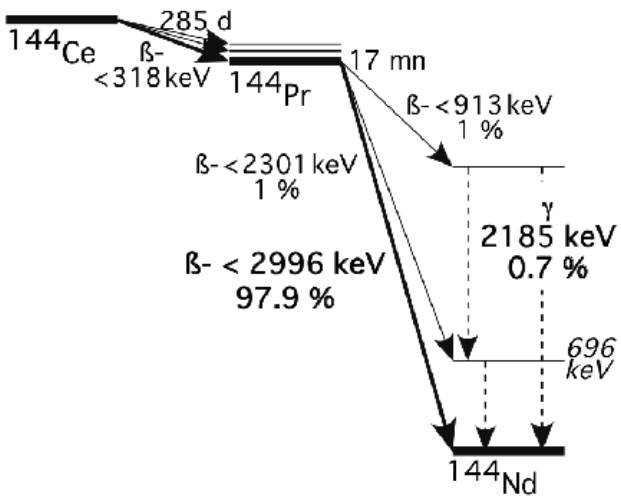
Why $^{144}\mathrm{Ce}/^{144}\mathrm{Pr}$ couple?

- Emit $\bar{\nu}_e$ above IBD threshold: $Q_\beta = 3\,\mathrm{MeV} > 1.806\,\mathrm{MeV}$
- Long half-life –285 days– for production & handling
- Relative ease of production of the material

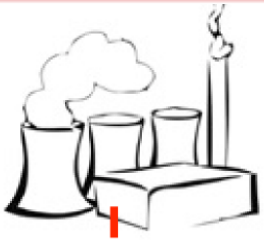
Built-in safety and background problem: $2.2\,\mathrm{MeV}\ \gamma$ rays with 0.7% branching ratio

CeSOX needs

- Activity $> 3.7\,\mathrm{PBq}$
- γ attenuation $\gtrsim 10^{12}$:
  - Avoid source-induced backgrounds
  - Dose limit $500\ \mu\mathrm{Sv/year}$.
- Fit easily in Borexino tunnel



Production at FSUE Mayak PA through 2016



The key requirements

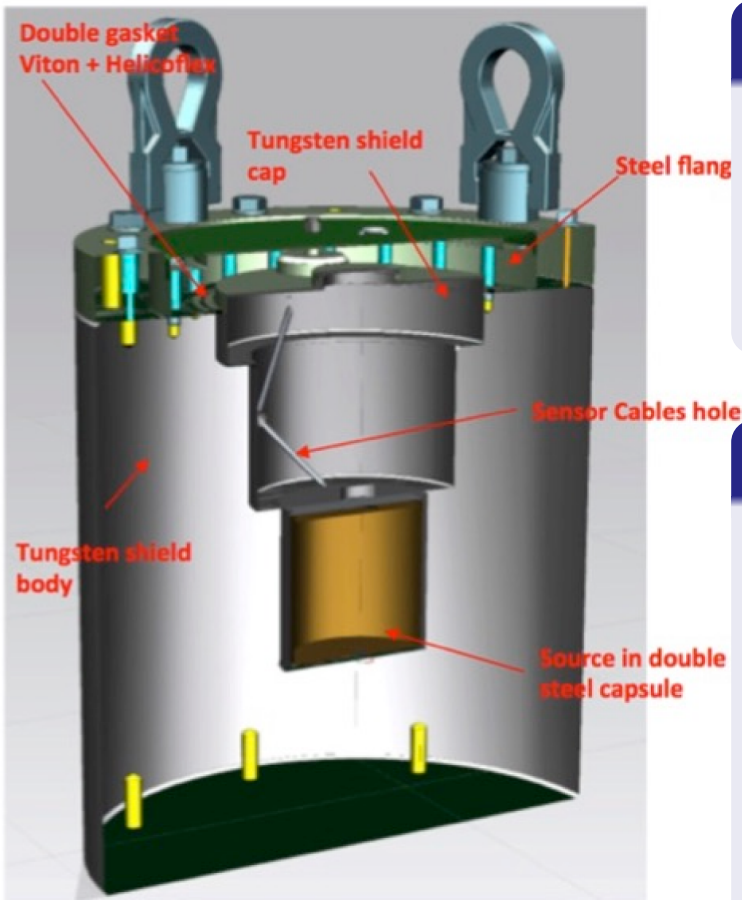
- Spent nuclear fuel reprocessing capabilities
- Large fuel amount to extract enough activity with 144Ce
- Handling of PBq-range activity

Process

- PUREX radiochemical reprocessing
- REE complex displacement chromatography
- Calcination to CeO_2
- Pressing & encapsulation
- Insertion into shielding & locking

Shielding

Requirement: suppress 2.2 MeV γ by a 10^{12} factor and keep dimension small enough to fit in Borexino 1 m side tunnel



High density material required

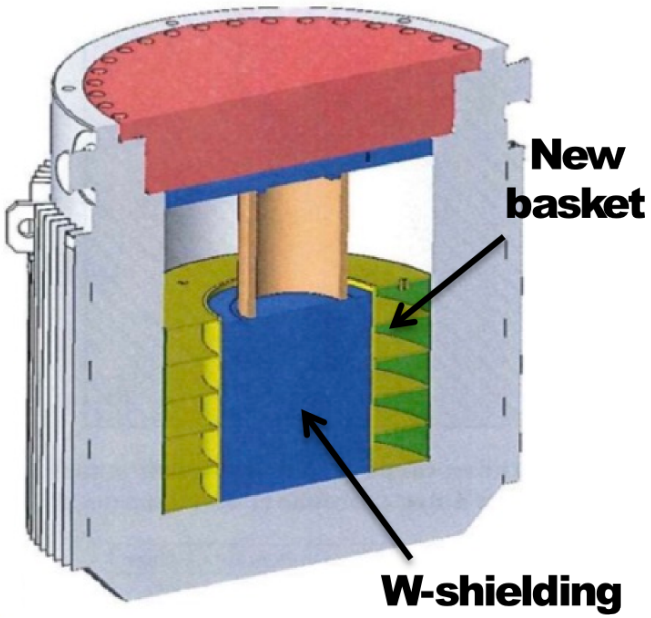
- W (95%), Fe, Ni alloy
- Density $\approx 18\,\mathrm{g/cm^3}$
- 19-cm thickness

Consequences

- 2.4 tons & H=60 ϕ=54 cm
- Biggest tungsten shielding ever built
- Manufactured at Xiamen Honglu Inc., China
- Delivery early 2016

Travel

- Mayak→St-Petersbourg→Le Havre→LNGS: < 3 weeks
- Areva TN MTR transportation cask with custom basket
- Cask certification & transportation authorization ✓
- Expected delivery date at LNGS: December 2016.



Source characterization

Activity measurement: calorimetry

Two calorimeters are being built by the collaboration for subpercent activity measurements. See Lea Di Noto's talk.

CeANG β spectrum: an essential point

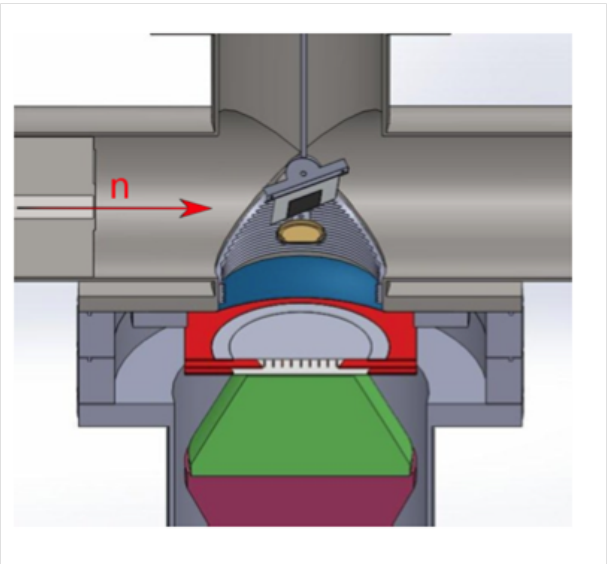
- Source activity measurement depends on mean decay energy
- Interaction rate in Borexino depends on source $\bar{\nu}_e$ spectrum
- Possible β emitting impurities

New measurements are necessary

- $^{144}\mathrm{Ce}$ and $^{144}\mathrm{Pr}$ spectra present non-unique forbidden transitions, for wich spectral shape is uncertain at few % level.
- Past measurements don't agree: up to 10-15% discrepancies

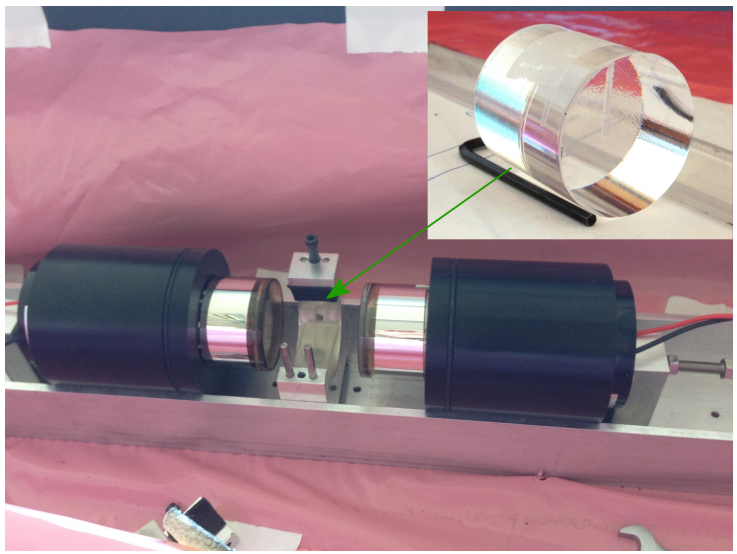
β spectroscopy

TUM spectrometer (PRL. 112, 122501)



Plastic scintillator + multiwire chamber
γ veto

CEA spectrometer (under development)



Plastic scintillator + encased source
High coverage & light collection

- Preliminary samples received from Mayak, from 6 year old nuclear fuel –so not representative of the final CeANG
- Ongoing calibration and measurements in Saclay

β spectroscopy

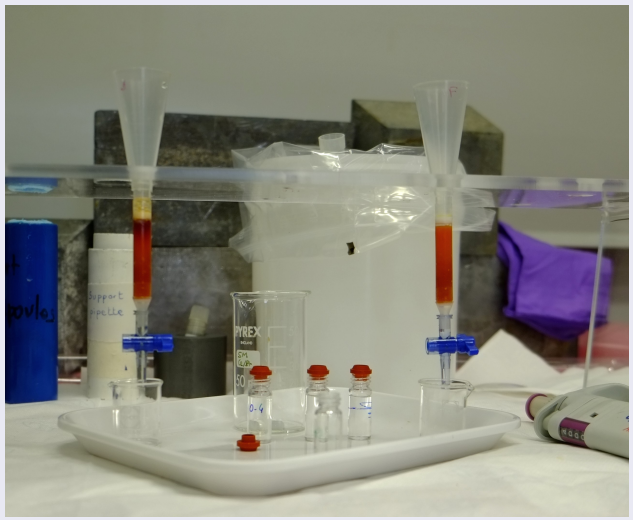
^{144}Ce-^{144}Pr measurement

- Both spectra are required for activity estimation
- But both spectra are always mixed

IBD threshold$\rightarrow$special interest in $^{144}\mathrm{Pr}$ β for energy $\in [0, 1\mathrm{MeV}]$

We want^{144}Pr specific measurement

- 17 min lifetime$\rightarrow$repeated hour-scale measurements
- Chemical $^{144}\mathrm{Pr}$ separation with oxydation sensitive resin



Source impurity measurements

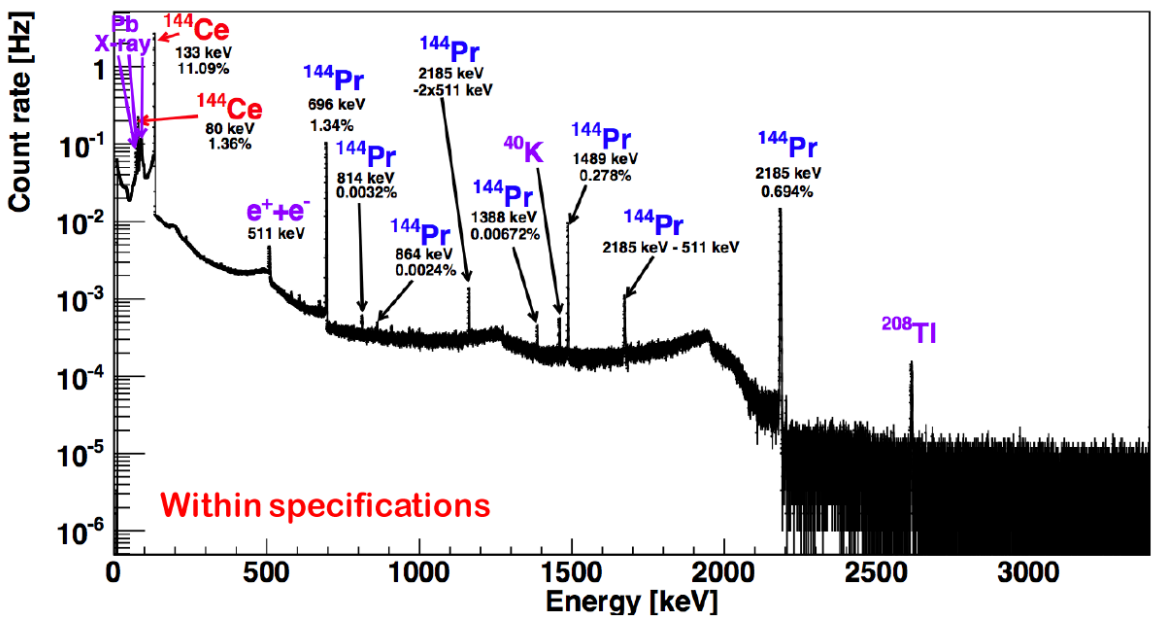
Reprocessed fuel + hot cells→possible presence of impurities

Gamma spectroscopy & mass spectrometry for

- Background studies including γ & neutron emitters
- Relative abundance of Cerium isotopes measurements
- Quantifying long lifetime impurities for SOX decommissioning
- Checking complex chromatography separation

γ spectroscopy results on preliminary samples

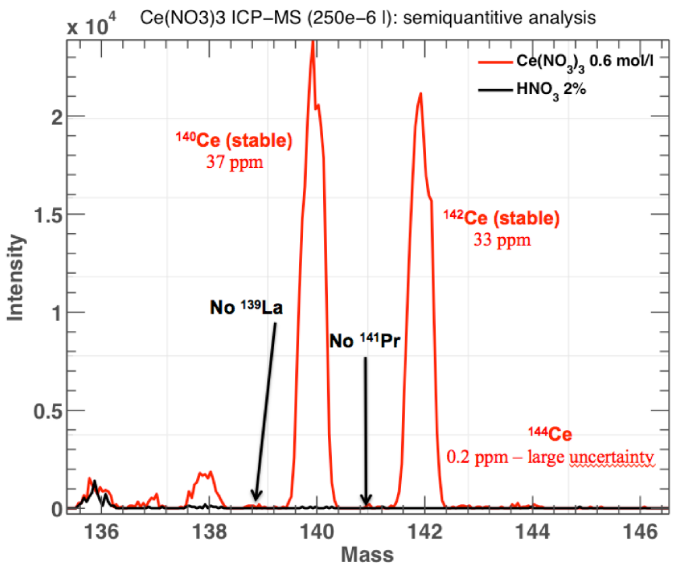
Specification:
$< 10^{-3}\mathrm{Bq/Bq}\,\gamma$ activity
Satisfactory first samples

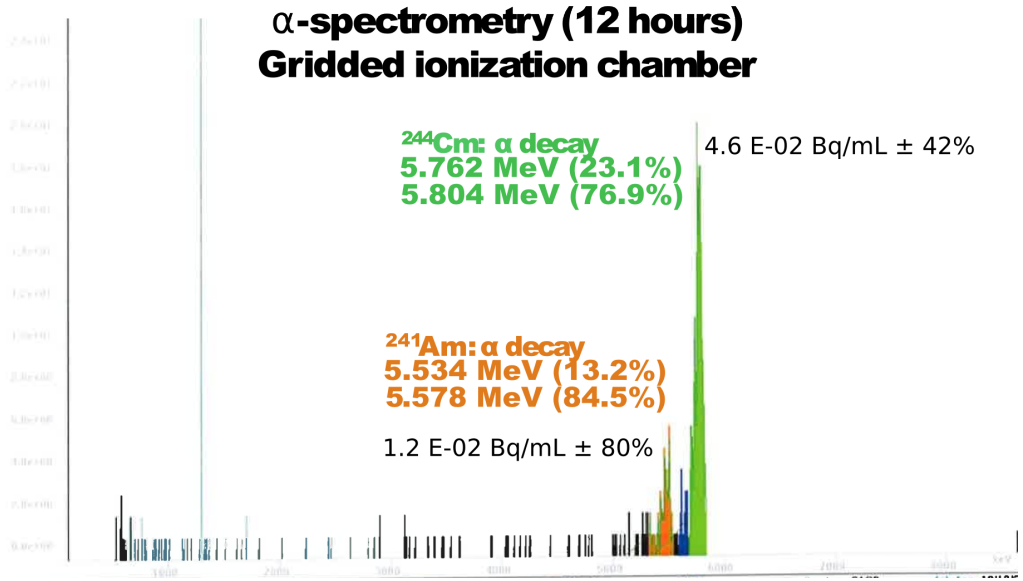


Source impurity measurements

Semi-quantitative ICP-MS preliminary results

- $^{140}\mathrm{Ce}/^{142}\mathrm{Ce}/^{144}\mathrm{Ce}$ ratios as expected for 6 year old fuel
- No $^{139}\mathrm{La}/$ or $^{141}\mathrm{Pr}$ $\rightarrow$effective separation





Targeted alpha spectrometry

- Search for $^{244}\mathrm{Cm}$ & $^{241}\mathrm{Am}$
- Activities within specification $< 10^{-6}\mathrm{Bq(n)/Bq}(\beta)$

Summary

- CeANG production and transportation:
  - 3.7 PBq $^{144}\mathrm{Ce}$-$^{144}\mathrm{Pr}$ up to 3 MeV $\bar{\nu}_e$ source
  - extracted and isolated from spent nuclear fuel during 2016 at FSUE "Mayak" PA : delivery by end of 2016
  - packed in 2.4 tons W shielding –delivered by end of 2015
  - transport solution frozen and authorized
- CeANG characterization:
  - activity measurement: calorimetry
  - β and $\bar{\nu}_e$ spectra: β spectroscopic measurements ongoing at Saclay
  - γ, α and mass spectrometries on preliminary samples show no impurity problem for production process

Thanks for your attention