EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

A=225 implantation for ^{221}Fr source for TRIUMF atom trap

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Abstract: The FrPNC collaboration is mounting an atom trap for parity violation experiments and precision spectroscopy on francium atoms at TRIUMF's ISAC facility. We would like to use ISOLDE's capability of simultaneously implanting A=225 (while another experiment runs online) to make a long-lived source feeding ^{221}Fr for tests of the trap. ^{225}Ra beta decays to ^{225}Ac, which then α decays, producing 100 keV ^{221}Fr $t_{1/2}$= 4.8 minute recoils. The implanted A=225 source would be shipped to TRIUMF, where it would be held for several minutes at a time a few mm from the same yttrium foil that normally receives the ISAC beam. SRIM calculations imply that 20% of the ^{221}Fr will be implanted in a 1 cm diameter spot on the yttrium. Then the yttrium foil is moved to the trap and heated to release the Fr atoms, just as in normal ISAC online operation. A test implantation will be done at 10^7/sec production for 1 day, testing whether carbon cracking on the implantation foil in the mass separator vacuum system will impede escape of the ^{221}Fr, and testing basic safety issues. We would then request further implantations at 10^8/sec production for several days. The first implantation would already produce rates at 10% of the maximum production achieved at Stony Brook, enough to test the trap. Full rates could allow parity-violating experiments on the single isotope ^{221}Fr.

Requested shifts: Implantations for off-line use in mass separator region: 3 shifts at 10^7/sec A=225 for test, 15 shifts at 10^8/sec for experiments.

1 Introduction and motivation

The FrPNC collaboration has three approved experiments at TRIUMF that would use an atom trap for francium:
S1218 Towards an optical parity violation experiment in Fr (G. Gwinner, U. Manitoba spokesperson);
S1065 Weak nucleon-nucleon interaction from nuclear anapole moment (L. Orozco, U. Maryland, spokesperson);
S1010 Hyperfine anomaly and spatial distribution of nuclear magnetism, (M. Pearson, TRIUMF, spokesperson).
The optical parity violating experiment in the 7S to 8S transition would measure the electron-quark parity-violating coupling, whose strength as a function of neutron number in francium would be sensitive to non-Standard Model parity-violating interactions. Precursor Stark interference experiments would also measure the M1 strength, testing relativistic effects in many-body atomic theory theory [1]. The anapole moment measurements would measure the isovector and isoscalar parts of the weak nucleon-nucleon interaction in the nuclear medium [5]. The hyperfine anomaly measurements would extend precision spectroscopy done at Stony Brook [2] to other isotopes, and also to spin isomers that may exist in ^{204,206}Fr.
The full TRIUMF proposals can be found at http://mis.triumf.ca/science/experiment/list.jsf

1.1 Readiness at TRIUMF

TRIUMF is designing and constructing an ion transport beamline now. This beamline will deliver francium to an electromagnetically shielded room in which the trap apparatus will be housed. The University of Maryland has built a two-trap apparatus that will go in this room, including a collection magneto-optical trap and an all-optical dipole force trap for experiments [6].
The goal is to install the trap at TRIUMF in August 2011.

2 A ^{221}Fr source from ^{225}Ra

2.1 Motivation for a source

Some tests of our trap can be made with stable rubidium isotopes, but many parts of the trap apparatus are best tested with francium atoms. The longest-lived francium isotope has $t_{1/2}$=21 minutes. Given the scarcity of on-line beamtime at all facilities, a longer-lived isotope feeding francium becomes very helpful. The A=225 chain to ^{221}Fr is almost unique. (The other possibility feeds ^{223}Fr from the 1% α decay of $t_{1/2}$=22 year ^{227}Ac, but the safety aspects of this isotope for production rates of ^{223}Fr are prohibitive.)
A similar techinque was used to trap ^{221}Fr at JILA [3]. This involved separating ^{225}Ra from a large ^{229}Th source by radiochemistry, and the preparation of an oven to release francium but not radium. Similar techniques provide the ^{225}Ra being used at Argonne Nation Lab for a trap-based electric dipole moment search.

Implantation from a mass separator will avoid radiochemistry techniques and is inherently much simpler. It also provides a method directly compatible with the online catcher system for that atom trap that has been developed for low-energy ion beams.
TRIUMF has recently demonstrated its first uranium carbide target. At the end of the beamtimes, after proton beam was off, it produced about 2x10^7/sec A=225 (about 2/3 ^{225}Ra and 1/3 ^{225}Ac) for about a day. We will ask that this be used for similar offline implantations at TRIUMF after beam is off, as TRIUMF does not have ISOLDE's implantation capability simultaneous with online production.

2.2 Experimental method

The catcher will be tantalum, mounted in a holder compatible with the ISOLDE implantation and with simple mounting to the vacuum system at TRIUMF.
The sequence:
1) Implant 60 keV A=225 (Ra and Ac) at ISOLDE
2) Ship to TRIUMF
3) place source 3mm from Yt catcher (Fig. 1)
4) α decay of ^{225}Ac ejects 100 keV ^{221}Fr into 1 cm spot (Fig. 2)
5) withdraw source
6) move Yt catcher to trap, heat, trap (Fig. 1)
The moving yttrium catcher was used on-line at Stony Brook [4]. We have heated the Yt catcher in the past by direct current. To improve reliability, we are considering heating it by CO_2 laser.
Radioactivity safety The test implantation of 10^7/sec for 1 day will create 50 μCurie of a combination of $t_{1/2}$ = 15 day ^{225}Ra and $t_{1/2}$=10 day ^{225}Ac. (This ratio is 2:1 in the TRIUMF surface ion source with a uranium carbide target and a rhenium ionizer.) As little as 1/10 this amount would still be a useful test. The decay chain procedes through several α and β decays, feeding 45 minute ^{213}Bi and 4 hour ^{209}Pb with the same decay rates in equilibrium. The chain terminates in stable ^{209}Bi.
NY State Annual Limit on Intake (ALI) for 225Ra is 8 μC for ingestion, 0.7 μC for inhalation. ALI for 225Ac is 50 μC for ingestion, 0.3μC for inhalation. ALI for ^{213}Bi is 300μC for inhalation. Since about 30% of the Bi and Pb will be airborne, shipment must be in hermetically sealed container.
A possible contaminant is 22-year ^{227}Ac [7]; ALI is 0.3 μC ingestion, 4x10^{-4} inhalation. This is probably best assayed by α decay of the 227Th 18-day daughter.
Summary of requested shifts: 3 shifts at 10^7/sec production (or less time if production is higher).
At a future date, 10^8/sec for a week would be helpful.

References

[1] some details can be found in: “Standard model tests with trapped radioactive atoms”, J A Behr and G Gwinner 2009 J. Phys. G: Nucl. Part. Phys. 36 033101 doi: 10.1088/0954-3899/36/3/033101

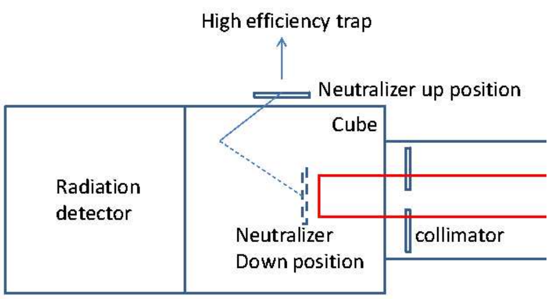

Figure 1: Left: Catcher assembly for the ISAC beam, showing the yttrium ‘neutralizer’. Right: Sketch of planned source location. The source will move in and out with a pneumatically actuated bellows. ISAC beam is incident from the front.

[2] “Hyperfine Anomaly Measurements in Francium Isotopes and the Radial Distribution of Neutrons”, J. S. Grossman, L. A. Orozco, M. R. Pearson, J. E. Simsarian, G. D. Sprouse, and W. Z. Zhao, Phys. Rev. Lett. 83, 935 (1999).

[3] “Efficient Collection of 221Fr into a Vapor Cell Magneto-optical Trap”, Z.-T. Lu, K. L. Corwin, K. R. Vogel, C. E. Wieman, T. P. Dinneen, J. Maddi, and Harvey Gould, Phys. Rev. Lett. 79, 994 (1997).

[4] “High efficiency magneto-optical trap for unstable isotopes” Rev. Sci. Instrum. 74, 4342 (2003); doi:10.1063/1.1606093 S. Aubin, E. Gomez, L. A. Orozco, and G. D. Sprouse.

[5] “Measurement method for the nuclear anapole moment of laser-trapped alkali-metal atoms” E. Gomez, S. Aubin, G. D. Sprouse, L. A. Orozco, and D. P. DeMille, Phys.

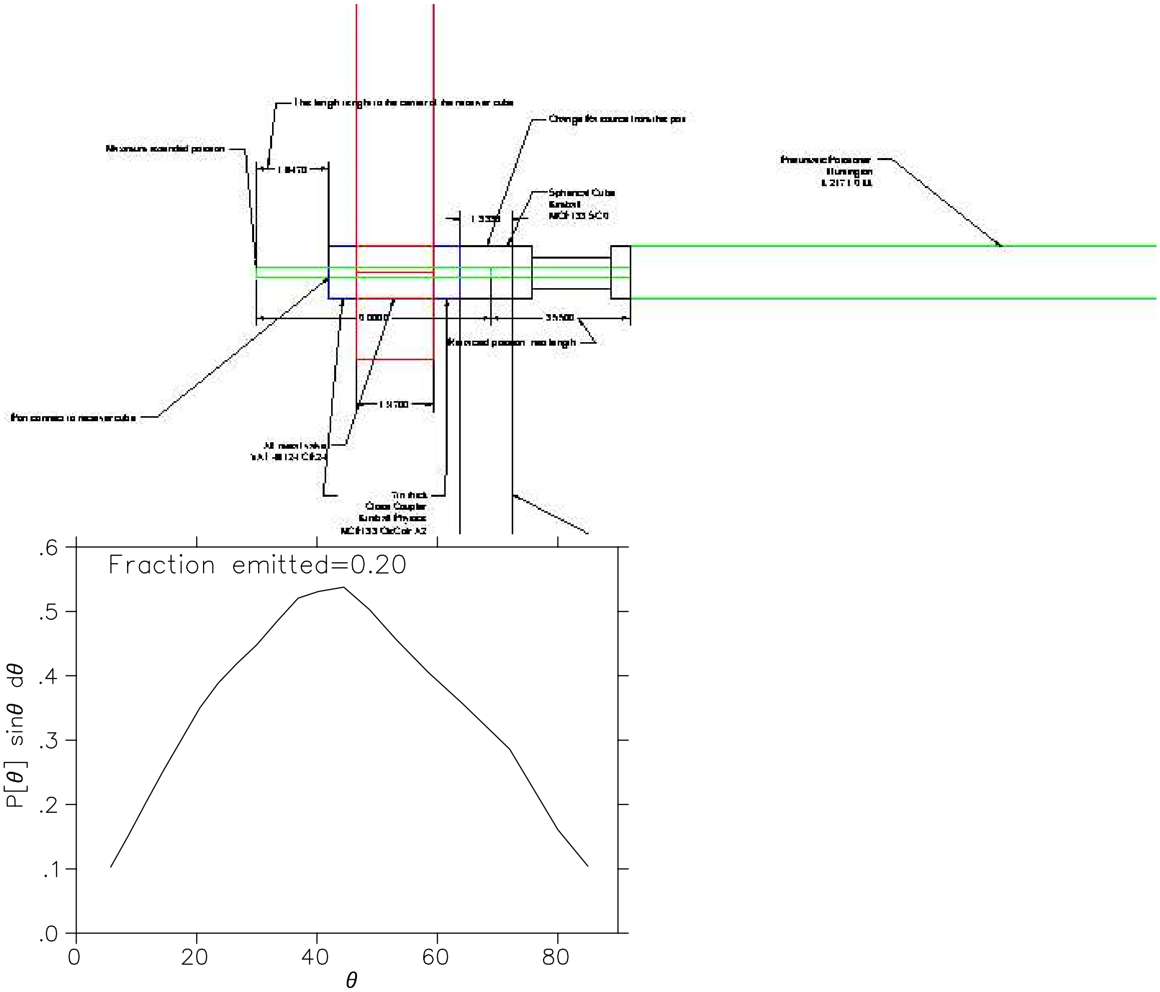

Figure 2: Top: more details of the source assembly at TRIUMF. Bottom: SRIM calculation of ^{221}Fr emitted from foil after 60 keV implantation. Approximately 20% will be implanted in a 1 cm diameter spot if the catcher is 3mm away.

Rev. A 75, 033418 (2007)

[6] "Preliminary studies for anapole moment measurements in rubidium and francium" D Sheng, L A Orozco and E Gomez 2010 J. Phys. B: At. Mol. Opt. Phys. 43 074004; doi: 10.1088/0953-4075/43/7/074004

[7] Matts Lindroos, private communication.

Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT
The experimental setup comprises: (*SSP-GLM chamber*)

Part of the	Availability	Design and manufacturing
SSP-GLM chamber	☒ Existing	☒ To be used without any modification
Tantalum foil for implantation	☒ New	☐ Standard equipment supplied by a manufacturer ☒ Collaboration responsible for the design and/or manufacturing (need drawings from CERN)

HAZARDS GENERATED BY THE EXPERIMENT Hazards named in the document relevant for the SSP-GLM chamber; ionizing radiation hazard outlined in text **Radioactivity safety** in Section 2.2 above.

Additional hazards:

Hazards	[Part 1 of experiment/ equipment]	[Part 2 of experiment/ equipment]	[Part N of experiment/ equipment]
• Isotope	225Ra, 225Ac	225Ra, 225Ac	225Ra, 225Ac
• Activity	50 μC	1000 μC	1000 μC