Feasibility of *transmutational* production and magnetic extraction of Moly-99 via 1-neutron knockout and exchange reactions in auto-colliding beam of natural Mo ions in strong-focusing Precetron ("EXYDER") and electric energy recuperation by ion decelerator*

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*US Patent #4,788,024; also Patent Pending #62/139,034*
Making Mo-99 From Natural $^{92-100}$Mo

Colliding $^{98}$U with $^{100}$U

Knock out 1 n from 100, transition $98 \rightarrow 99 + 99$ Resulting in TWO $^{99}$Mo

$^{98}$Mo + $^{100}$Mo $\rightarrow$ $^{99}$Mo + $^{99}$Mo − 2.37 MeV

Stage 1

Stage 2

Stage 3

Stage 4

Stage 5

ALL WITHIN STATE OF THE OF ART PARTICLE BEAM PHYSICS & ACCEL. TECH.
7 Stable Mo Isotopes

- $A = 92$: 14%
- $A = 93$: 9.5%
- $A = 94$: 16%
- $A = 95$: 17%
- $A = 96$: 9.7%
- $A = 97$: 24%
- $A = 98$: 9.5%
7 Mo Isotopes $\rightarrow$ 12 1-n Exchange Reactions Producing 14 $^{99}$Mo

Mo-99 Production Rate

Mo-99 Production Rate

PERMUTATIONS

A = 92 93 94 95 96 97 98 99 100

92 + 100 $\rightarrow$ 99
94 + 98 $\rightarrow$ 99
95 + 100 $\rightarrow$ 99
96 + 98 $\rightarrow$ 99
96 + 100 $\rightarrow$ 99
97 + 98 $\rightarrow$ 99
98 + 98 $\rightarrow$ 99
100 + 100 $\rightarrow$ 99 + 100 + n
ISR: Intersecting Storage Rings at CERN, 1971

Opened

NEW ERA

In nuclear and particle physics
p (20 GeV) + p (20 GeV)

5 ADVANTAGES OF COLLIDING BEAMS

1. Energy Confinement Time:

\[ \tau = 5 \times 10^6 \text{ sec} \]
\[ = 2 \text{ months} \text{ (coasting)} \]

VACUUM \( \sim 10^{-10}, 10^{-11} \) torr

KEY: PREVENT THERMALIZATION OPPOSITE TO MAXWELLIAN PLASMAS, IT IS AN ORDERED PARTICLE MOTION SYSTEM CONTROLLED BY EXTERNAL STRONG FOCUSING FORCES AND EM FEED–BACK SIGNALS

2012: Brookhaven Relativistic Heavy Ion Collider (RHIC) collided

\[ ^{238}\text{U}^{92+} (100 \text{ GeV}) + ^{238}\text{U}^{92+} (100 \text{ GeV}) \] observed \( \sigma_{\text{total}} = 487 \text{ barn} = 13 \times \sigma_{\text{geo}} \)
5 ADVANTAGES OF COLLIDING BEAMS

2. ENERGY FACTOR OF 8

Beam-on-target

\[ E_{COM} = \frac{1}{4} E_{Lab} = 1 \text{ MeV} \]

\[ E_{lab} = 4 \text{ MeV} \]

Collider

\[ E_{COM} = E_{Lab} = 1 \text{ MeV} \]

\[ E_{lab} = 0.5 \text{ MeV} \]

3. FACTOR OF 10^6 MULTIPLE TRAVERSAL

Beam-on-target

Single Traversal

Collider

Multiple Traversal

\[ \omega \sim 10^6 \text{s}^{-1} \]

4. REACTION RATE

Beam-on-target

\[ \propto \text{ion current} - \text{LINEAR} \]

\[ (R \propto I) \]

Collider

\[ \propto (\text{ion current}) - \text{QUADRATIC} \]

\[ (R \propto I^2) \]

5. BEAM BUNCHING FACTOR (From 4) LARGE INSTANTANEOUS POWER

Time-of-Flight Selection
1975: INVENTION OF SELF-COLLIDING BEAM
One single beam collides head-on with itself via precession

KEY PHYSICS PRINCIPLE:
Canonical Angular Momentum = 0

MIGMA = ORDERED MIXTURE OF ORBITS

“PRECETRON”
The principle of Self-Colliding Orbits Part. Accel. 1, 121 (1970)
ACCELERATOR INJECTION ENERGY:

\[ D_2^{+} \text{ ions of 1.45 MeV} \]

SUPERCONDUCTING NiTi MAGNET

6 Tesla on coil, 3.2 Tesla midplane

VACUUM 10^{-11} \text{ Torr (static); } 10^{-9} \text{ (beam in)} \ V = 5 \text{ liter}

Baked 450°C 24 hours

Injected into center, dissociates $\rightarrow D^+, D^0$
Canonical Ang. Momentum $= 0$. 

$D_2^+ 1.45$ MeV
0.5 mA
Barkhausen Oscillator with virtual anode and cathode

Nonlinear Van der Pol equation:
\[ \ddot{x} + \eta \rho(x) + \nu_0 + \dot{x} + \dot{\nu}_0 = 0 \]
\( \eta \) weak nonlinearity, \( \rho \) nonlinear resistance. Negative resistance, \( \rho < 0 \) instability, \( \rho > 0 \) stability. Lashinsky and Dewan, IEEE Trans. Autom. Contr. 12, 244 (1967); 14 212 (1969).

Imposed \( \nu \) extracts energy from instability

Radial frequency vs. (A) \( d^+ \) ion peak at 20.7 MHz when only \( d^+ \)'s with a small impact parameter \( \leq 0.1 \text{ cm} \) are kept. Others removed by a mechanical scraper at \( R > 11 \text{ cm} \). (B) Instability peak at \( \nu_{\text{INS}} \) at 22.4 MHz axial oscillations.
Longest Ion Energy Confinement Time in Fusion

\[ \tau_{1/e} = 24 \pm 4 \text{ sec} \]

**GOAL:** Prevent Thermalization!

Energy spectrum of the neutrals from \( D^+ \) (fast) + \( D_2^0 \) (gas) \( \rightarrow D^0 \) (fast) + \( D_2^+ \) observed in CEND.
Massive T and $^3$He Production

Luminosity

$$L = 3 \times 10^{43} V \, [m^3] I^2 \, \text{amp}$$

PROOF OF BEAM$\rightarrow$BEAM
FUSION T AND $^3$He PRODUCTION
Molytron
With 3 MV Accelerator, $Z = 40 = 120$ MeV Beam!

**PERFORMANCE OF THE NEW EBIS PREINJECTOR**

![Diagram of heavy ion preinjector](image1)

**Figure 1:** Schematic of the EBIS-based heavy ion preinjector

![Image of EBIS source](image2)

**Figure 2:** The EBIS source, with the 2m long superconducting solenoid producing a 1.5 m trap region.

![Image of high energy end of RFQ](image3)

**Figure 3:** High energy end of the RFQ is seen on the right, linac (yellow) in the center, and the high energy transport on the left.
Auto-Collider MIGMA IV

Fig. 5. Top view of the conceptual design of the migma chamber for the IVb experiment. The 1.4 MeV H\textsuperscript{2}\textsuperscript{+} beam enters the chamber from the left through port #1; the undissociated beam goes to the beam dump through port #2.
Layout of the beam transport system, chamber, and super conduction magnet
Economy of Mass Production

Stacking of MIGMA Cells