Texas A&M University
Cyclotron Institute

Precision Internal Conversion Coefficients Measurements for US Nuclear Data Program

N. Nica

Introduction:
ICC and Nuclear DATA Science

Internal Conversion Coefficients (ICC):

- ***Have great impact on the quality of nuclear science***
- ***Play a crucial role in the intensity balance of a level scheme***
- ***One of the central quantities in basic science and applications***
- ***Central for the nuclear data evaluation programs***
- ***Intensely studied by theory and experiment***
- ***What theoretical calculation gives best ICC results?***

- ***At TEXAS A&M Cyclotron Institute: benchmark series of precision ICC measurements***
- ***Found that best approach to calculations: Relativistic Dirac-Fock with "frozen orbitals" approximation for the inclusion of atomic vacancy***
- ***Is the series of measurements complete?***
- ***Are there other critical cases to measure?***
- ***Overview of the scope and completeness of the method***

2002RA45 survey ICC's theories and measurements

- **Theory: RHFS and RDF comparison**

  Exchange interaction, Finite size of nucleus, ***Hole treatment***

- **Experiment:**

  100 *E2, M3, E3, M4, E5* ICC values, 0.5%-6% precision,

  very few <1% precision!

- **Conclusions, Δ(exp:theory)%:**

  No hole*: +0.19(26)% *BEST!

  (bound and continuum states - SCF of neutral atom)

  ***Hole-SCF*: -0.94(24)%**

  (continuum - SCF of ion + hole (full relaxation of ion orbitals))

  ***Hole-FO*: -1.18(24)%**

  (continuum - ion field from bound wave functions of neutral atom (no relaxation of ion orbitals))

PHYSICAL ARGUMENT

K-shell filling time vs. time to leave atom

$\sim 10^{-15} – 10^{-17}$ s » $\sim 10^{-18}$ s

Texas A&M precision ICC measurements:

- **KX to γ rays ratio method**

$$\alpha_K \omega_K = \frac{N_K}{N_\gamma} \cdot \frac{\varepsilon_\gamma}{\varepsilon_K}$$

  - N_K, N_γ **measured from *only one K-shell converted transition***
  - ω_K **from 1999SCZX** (compilation and fit)

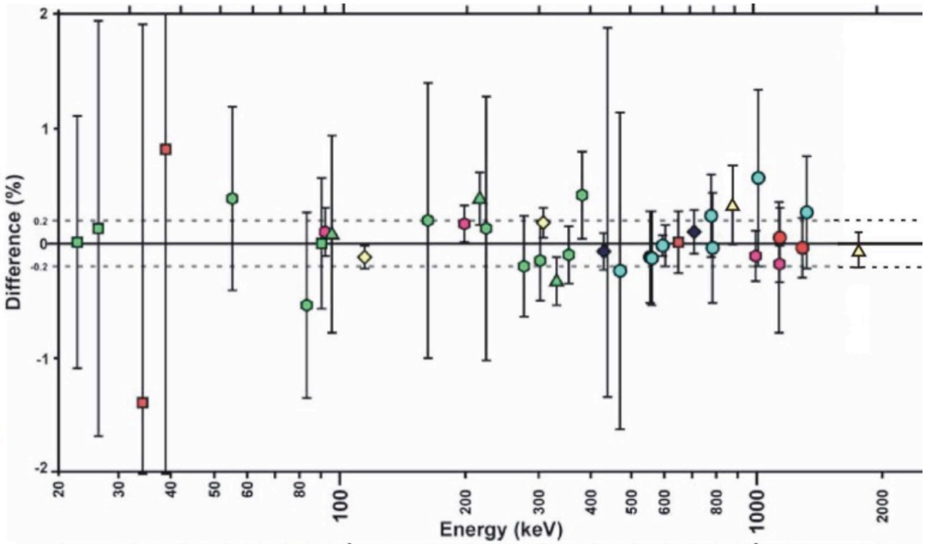
- **Very precise detection efficiency for ORTEC γ-X 280-cm^3 coaxial HPGe at standard distance of 151 mm:**
  - **0.2% , 50-1400 keV (2002HA61, 2003HE28)**
  - **0.4% , 1.4-3.5 MeV (2004HE34)**
  - **1% , 10-50 keV (KX rays domain)**

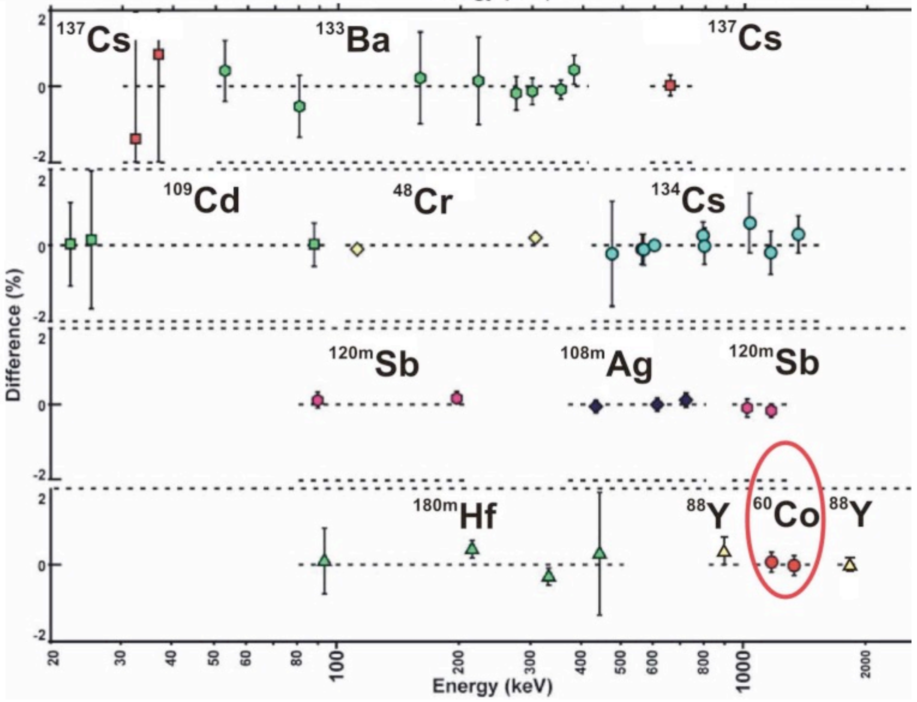
DETECTOR EFFICIENCY
50 keV < E_γ < 1.4 MeV

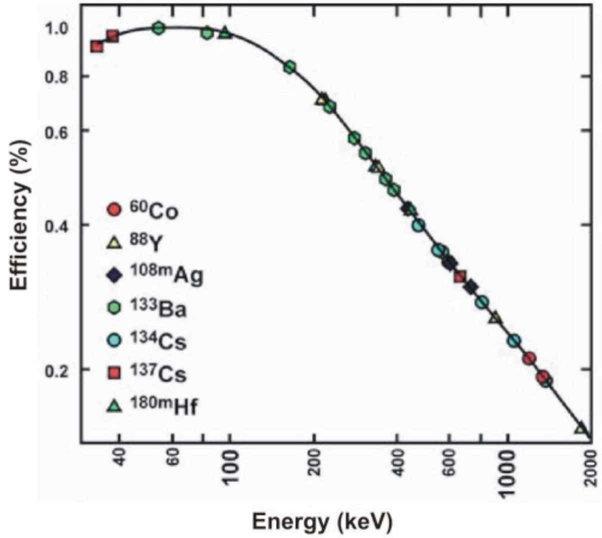
Coaxial 280-cc n-type Ge detector:

- Measured absolute efficiency (^{60}Co source from PTB with activity known to + 0.1%)
- Measured relative efficiency (9 sources)
- Calculated efficiencies with Monte Carlo (Integrated Tiger Series - CYLTRAN code)

0.2% uncertainty for the interval 50-1400 keV







KX to γ rays ratio method

- Sources for n_{th} activation
  - Small selfabsorption (< 0.1%)
  - Dead time (< 5%)
  - Statistics (> 10^6 for γ or x
  - High spectrum purity
  - Minimize activation time (0.5 h)

- Impurity analysis - *essentially based on ENSDF*
  - Trace and correct impurity to 0.01% level
  - Use decay-curve analysis
  - Especially important for the K X-ray region

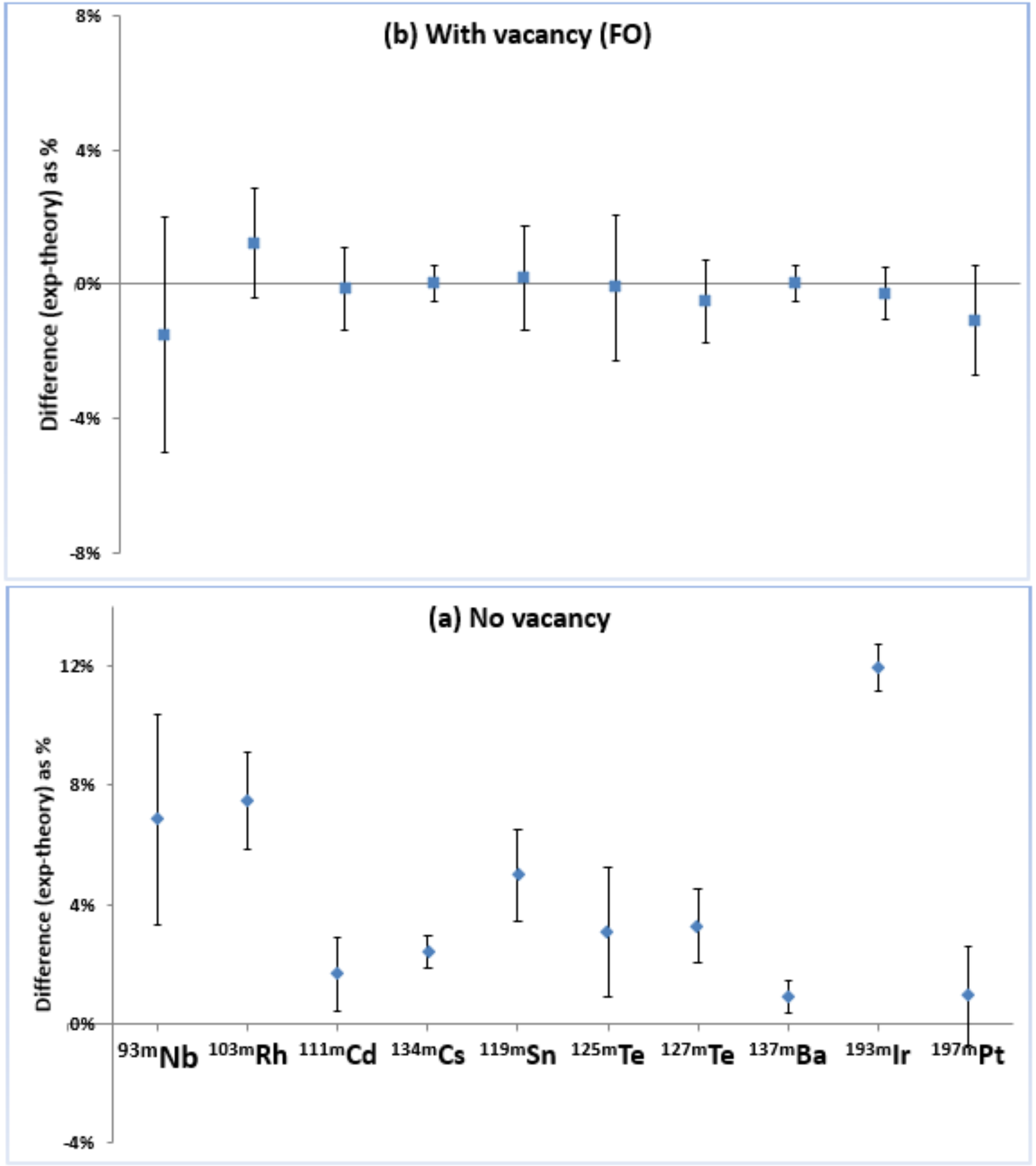
- Voigt-shape (Lorentzian) correction for X-rays
  - Done by simulation spectra, analyzed as the real spectra

- Coincidence summing correction

Texas A&M Evaluation Center
Precision Internal Conversion Coefficients Measurements
for the US Nuclear Data Program

Texas A&M Center implied decisively by decade-long program of Internal Conversion Coefficient (ICC) Precision Measurements to guide USNDP for best approach of theoretical ENSDF database ICC values

					Calculated α_K values:		
	Parent State	Multipolarity	Transition Energy (keV)	Measured α_K	No vacancy	"Frozen Orbitals"	SCF
1	^{93m}Nb	M4	30.760(5)	25600(900)	23960	25990	25440
2	^{103m}Rh	E3	39.752(6)	141.1(23)	131.3	139.4	137.2
3	^{111m}Cd	E3	150.825(15)	1.449(18)	1.425	1.451	1.446
4	^{119m}Sn	M4	65.660(10)	1621(25)	1544	1618	1603
5	^{125m}Te	M4	109.276(15)	185.0(40)	179.5	185.2	184.2
6	^{127m}Te	M4	88.23(7)	484(6)	468.6	486.4	483.1
7	^{134m}Cs	E3	127.502(3)	2.742(15)	2.677	2.741	2.73
8	^{137m}Ba	M4	661.659(3)	0.0915(5)	0.09068	0.0915	0.091
9	^{193m}Ir	M4	80.22(2)	103.0(8)	92.0	103.3	99.7
10	^{197m}Pt	M4	346.5(2)	4.23(7)	4.191	4.276	4.265
				χ^2:	**252**	**1.5**	**21.5**


(b) With vacancy (FO)
Difference (exp-theory) as %
8%
4%
0%
-4%
-8%
(a) No vacancy
Difference (exp-theory) as %
12%
8%
4%
0%
-4%
93mNb
103mRh
111mCd
134mCs
119mSn
125mTe
127mTe
137mBa
193mIr
197mPt

Texas A&M Evaluation Center
Precision Internal Conversion Coefficients Measurements Follow-up

- **Covered the interval 93<A<197 of nuclear chart and concluded that the "frozen orbitals" hole calculations are best describing the results.**
- **The calculation methodology is an approximate description of reality with no obvious reason, other than the empirical evidence, that it is universally valid.**
- **Used HPGe and Si(Li) detectors that were painstakingly calibrated for detection efficiency and are now fit to explore for ICC measurements in the underrepresented regions A>200 and A<100.**

- Conclusions:

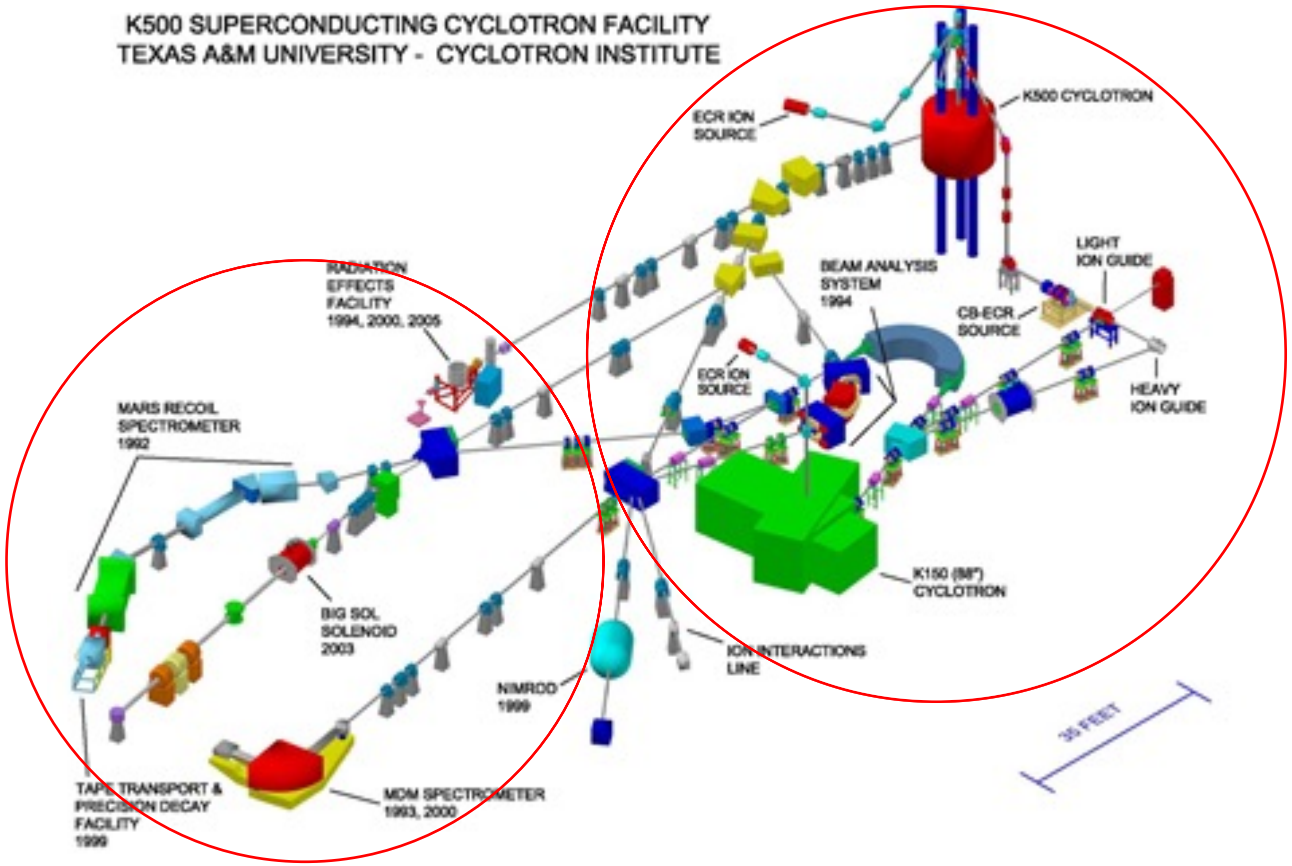
- ✓ ***Solved the ICC problem for the US Nuclear Data Program***
- ✓ ***It is still possible to improve the ICC test by extending the A range***

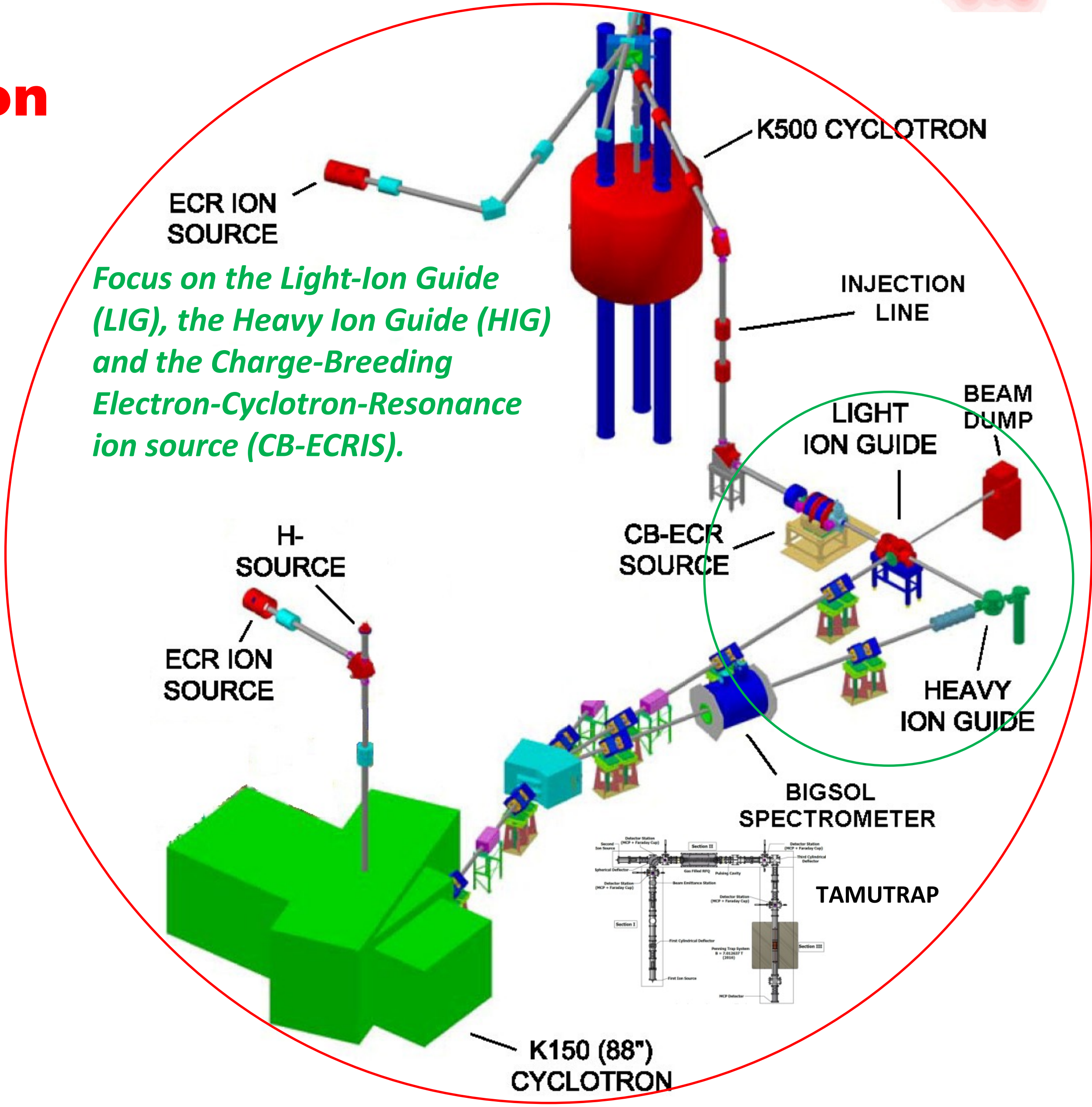
- Possible candidates: ^{58m}Co, ^{198m}Au

CYCLOTRON INSTITUTE
Texas A&M University

Texas A&M Evaluation Center:

Data Evaluation Station at Cyclotron Radioactive Ion Beam Facility to assist experiments and pre-evaluate data





Focus on the Light-Ion Guide (LIG), the Heavy Ion Guide (HIG) and the Charge-Breeding Electron-Cyclotron-Resonance ion source (CB-ECRIS).

Texas A&M NSDD Evaluation Center
Strategic Priorities for NDAC LRP 2022

- **Continuing ENSDF Mass Chain Evaluation**

  First Strategic Priority according to the Mission Statement.

  All other priorities will be strictly subordinated to this purpose

- **Produce experimental nuclear data to aid data evaluation**

  Precision Internal Conversion Coefficients Measurements at Cyclotron Institute, Texas A&M University to give USDNP the best approach for ENSDF ICC-calculated values (concluding cases pending on conditions)

  Precision βγ Spectroscopy for $T_{1/2}$ and BR for Standard Model

- **Experimental studies of Medical Isotopes**

  Invers kinematics methodology, Cyclotron Institute, Texas A&M University

- **Reevaluation of data procedures for basic science and data evaluation**

  Level scheme re-concept based on Repeatability, a newly revealed experimental data evidence