Opportunities with Tellurium

Szymon Manecki, September 30th, 2025

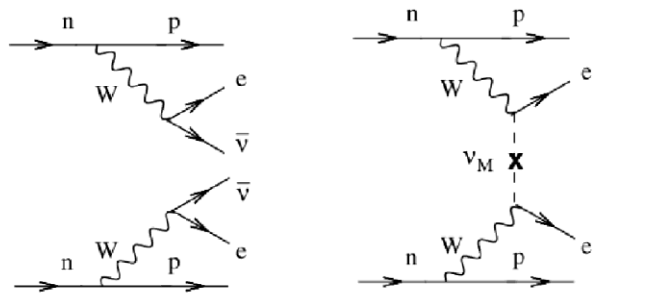
Double Beta Decay

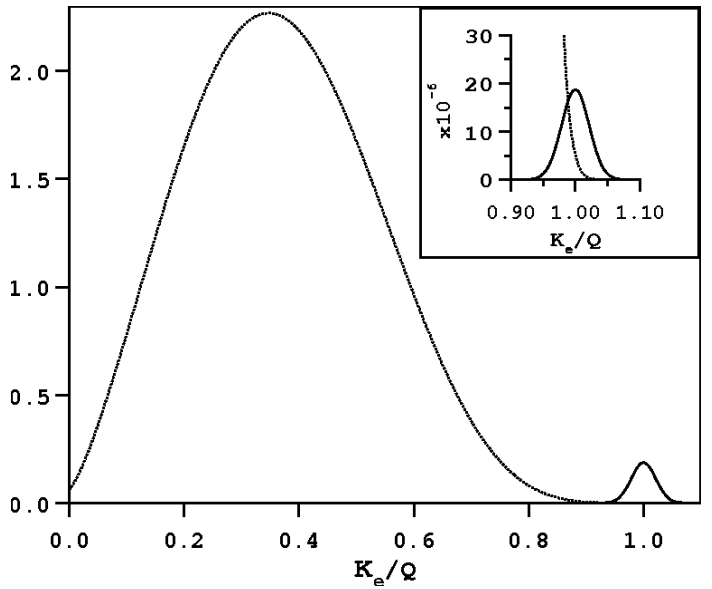
- Are neutrinos their own anti-particles?
- 2νββ (Dirac)
  $(A, Z) \rightarrow (A, Z + 2) + 2e^- + 2\nu_e$
  ~ 10^{18}-10^{21} years
- 0νββ (Majorana)
  $(A, Z) \rightarrow (A, Z + 2) + 2e^-$
  > 10^{25} years
- We measure:

$$\frac{1}{T_{1/2}} = G\, g_A^4\, \mathcal{M}^2 \left(\frac{m_{\beta\beta}}{m_e}\right)^2$$

Phase space factor

Nuclear matrix element





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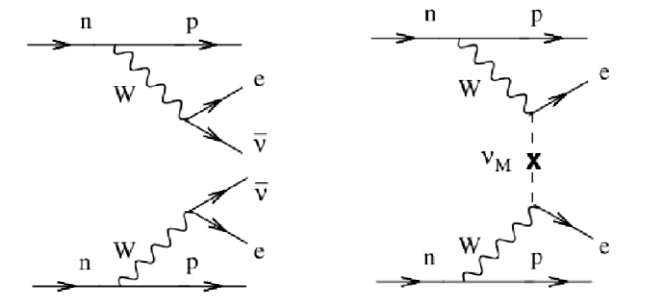
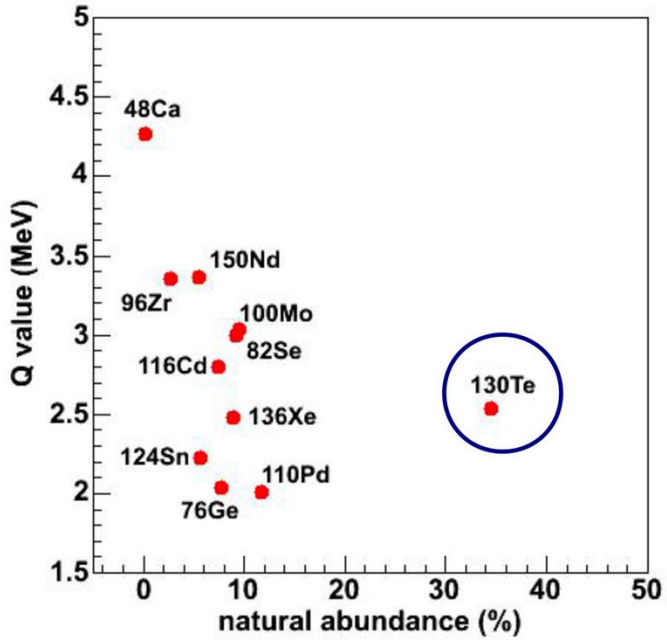
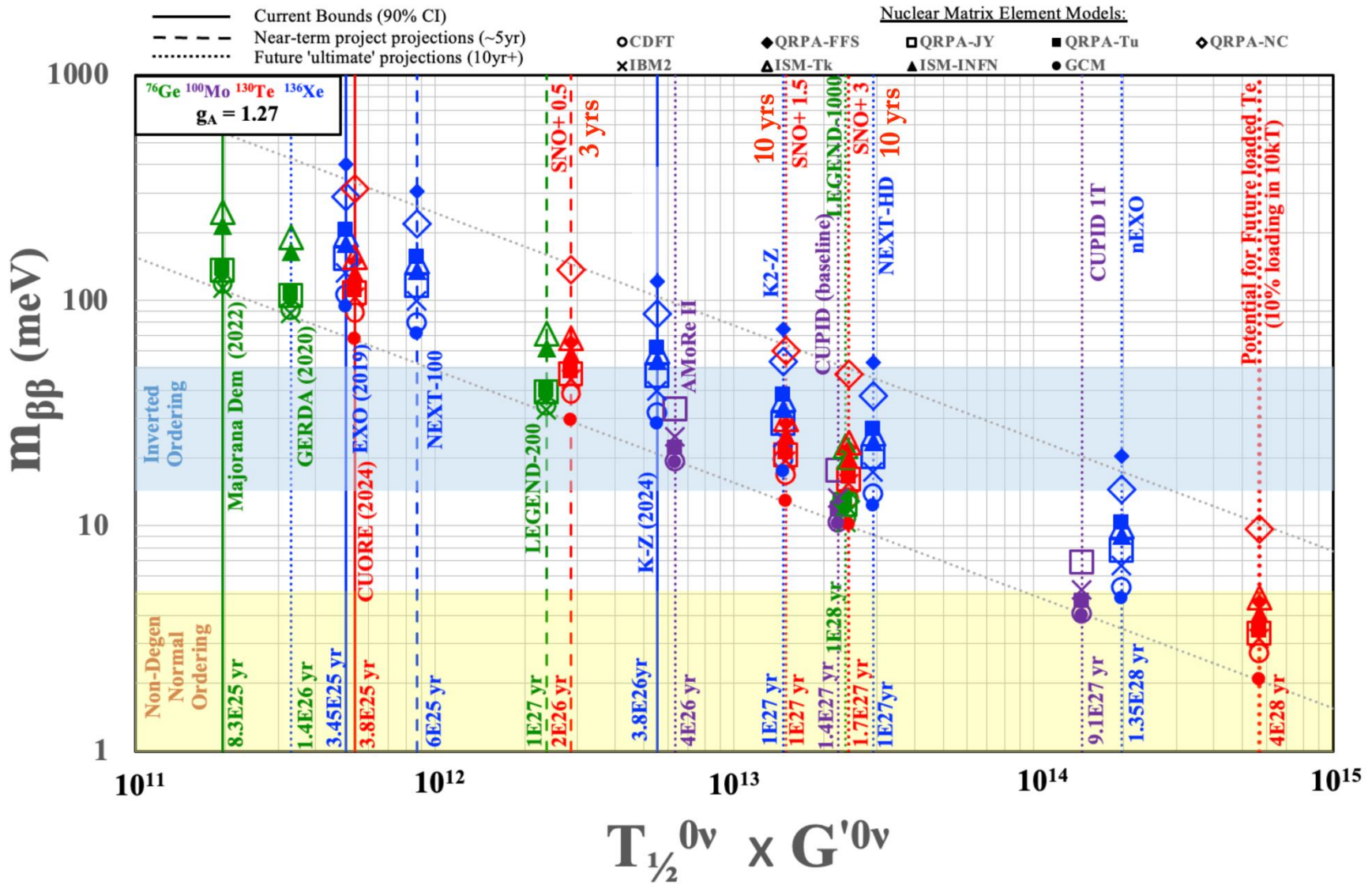


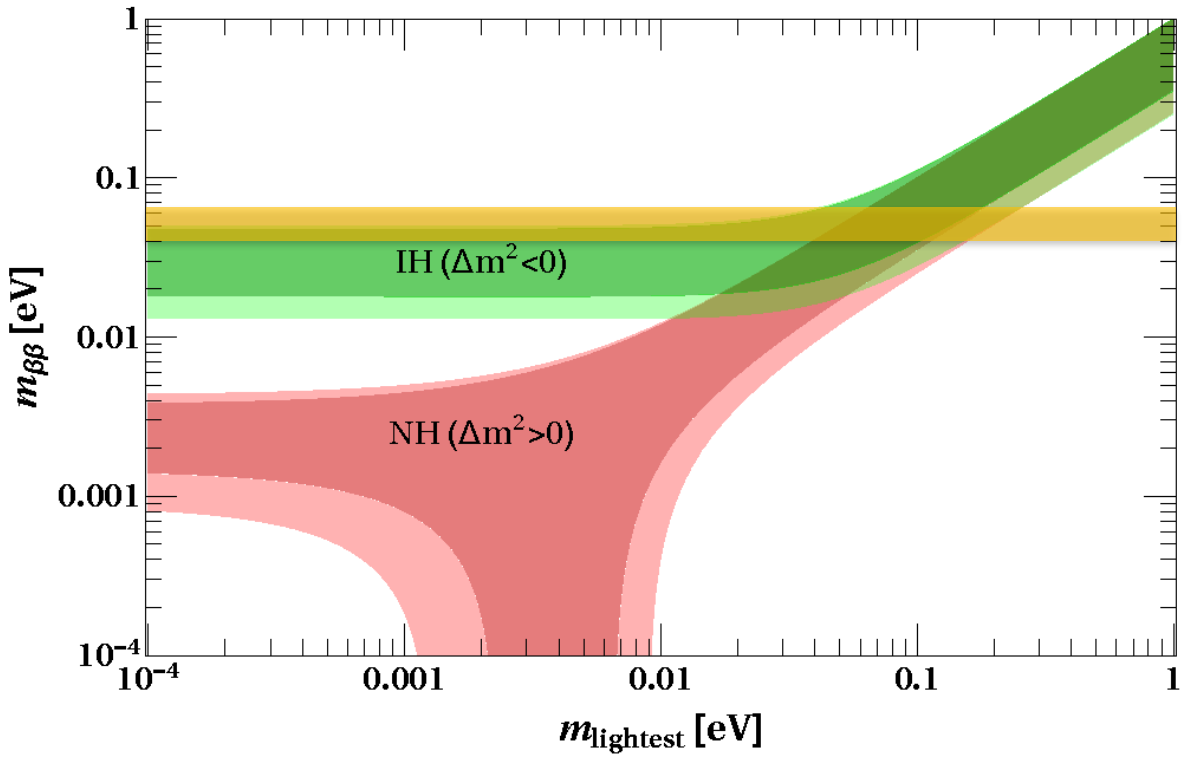


Neutrinoless Double Beta Decay



Future Scale of Tellurium Detectors

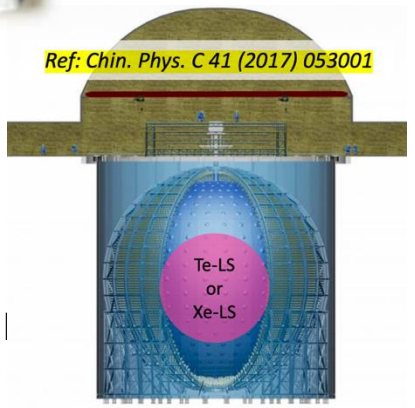
- Towards the bottom of Normal Hierarchy



Ref: Chin. Phys. C 41 (2017) 053001

SNO+

JUNO-II



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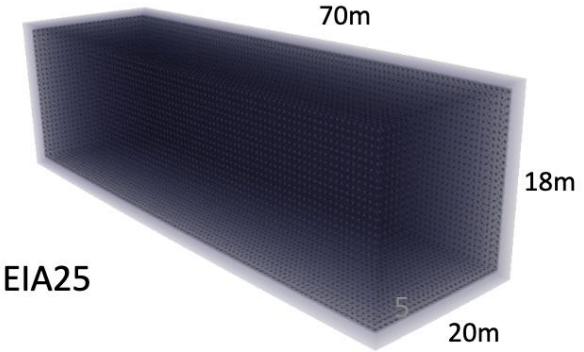

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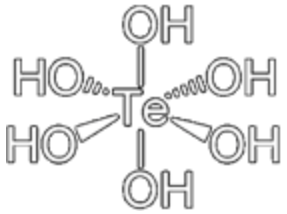
Tellurium

- Telluric Acid crystal



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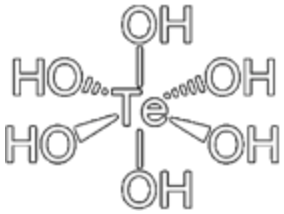
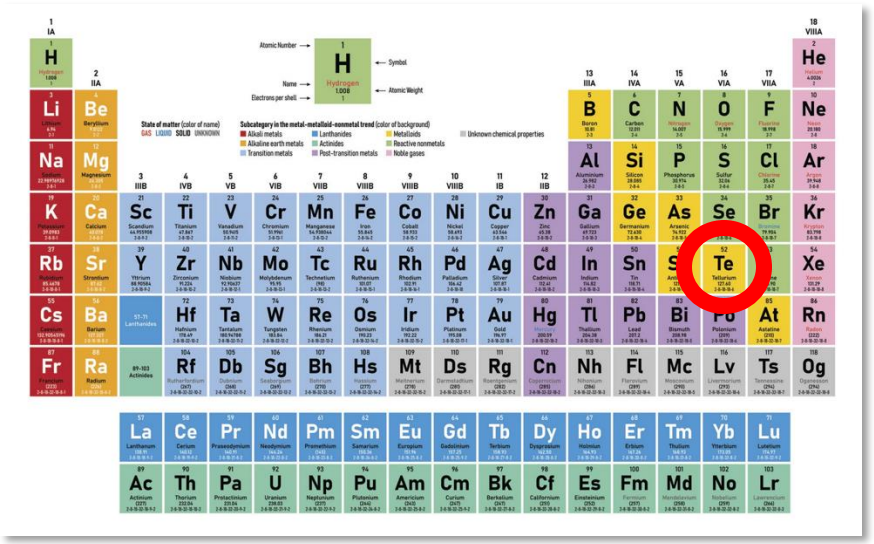
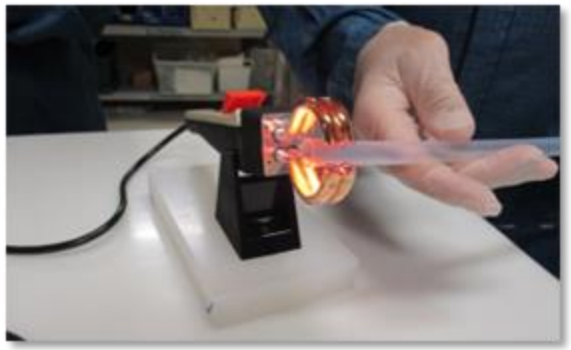




Cosmogenic isotope	Counts in Year 1 (no purification)
^{22}Na	7.04×10^{3}
^{26}Al	9.67×10^{-2}
^{42}K	6.55×10^{2}
^{44}Sc	8.41×10^{1}
^{46}Sc	5.21×10^{-2}
^{56}Co	1.02×10^{-3}
^{58}Co	2.50×10^{-3}
^{60}Co	6.62×10^{3}
^{68}Ga	6.20×10^{2}
^{82}Rb	5.15×10^{-16}
^{84}Rb	8.88×10^{-12}
^{88}Y	2.23×10^{1}
^{90}Y	5.05×10^{2}
^{102}Rh	1.33×10^{3}
^{102m}Rh	9.54×10^{4}
^{106}Rh	8.59×10^{1}
^{110m}Ag	7.96×10^{2}
^{110}Ag	1.07×10^{1}
^{124}Sb	1.77×10^{-2}
^{126m}Sb	3.06
^{126}Sb	2.92×10^{-35}

Process Systems

- Ultra-clean PFA Teflon
  - Every wet process line and vessel constructed with plastic to suppress metals leaching
  - Polypropylene vessels (mostly cost savings)
  - PFA piping
  - Not a good radon barrier



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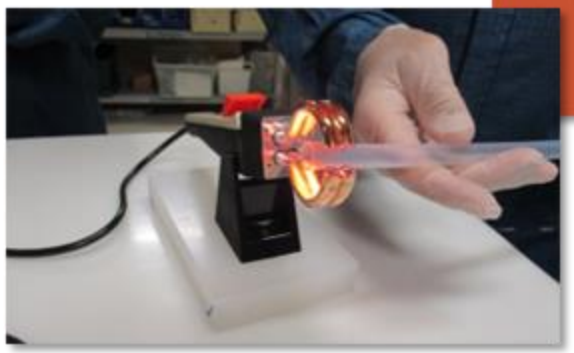

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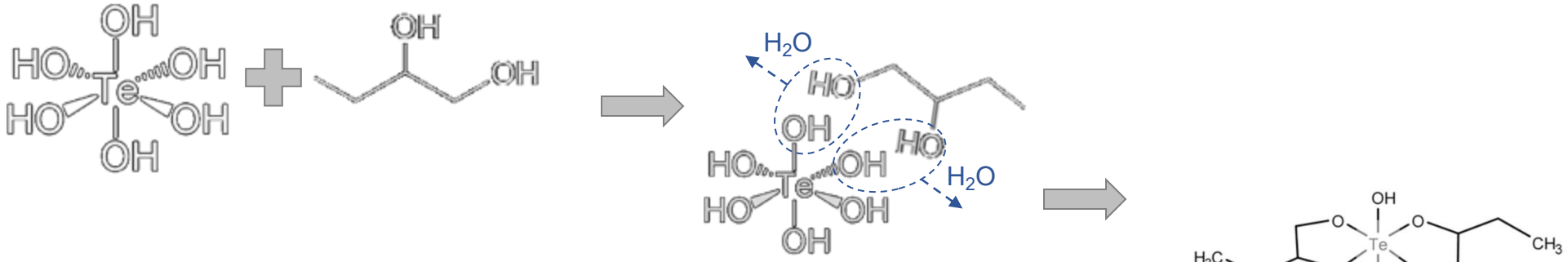
	Soak 1 (2 days)		Soak 2 (4 days)		Soak 3 (4 days)	
	RXT	TRXT	RXT	TRXT	RXT	TRXT
U	1	0.2	<0.05	<0.05	<0.05	<0.05
Th	5	1	1.1	<0.1	<0.1	<0.1
Ca	2700	2000	380	180	<20	<20
Fe	5600	5000	220	170	17	37

Loading method

- (In the case of SNO+) LAB-soluble Tellurium-Diol complexes are formed in condensation and further oligomerization reactions of Telluric Acid with 1,2-Butanediol



- Telluric Acid purification (U/G plant product)
- 1,2-Butanediol *distillation*
- DDA *distillation*

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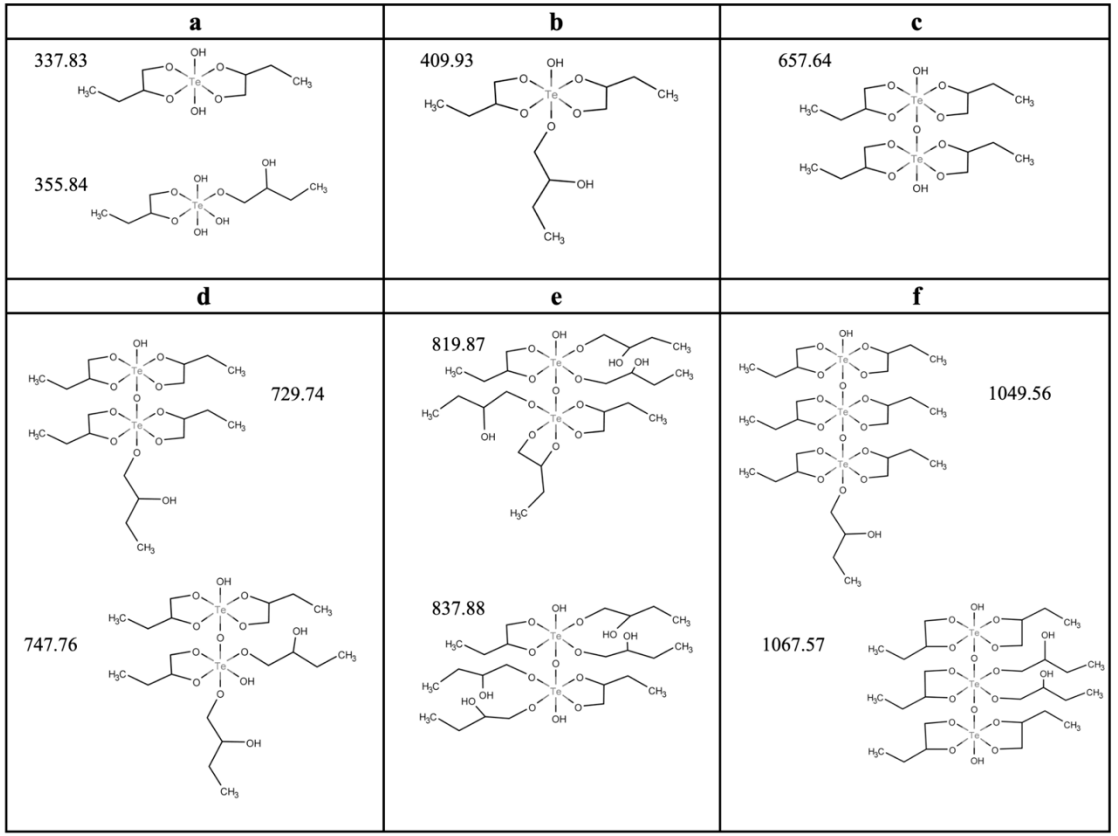
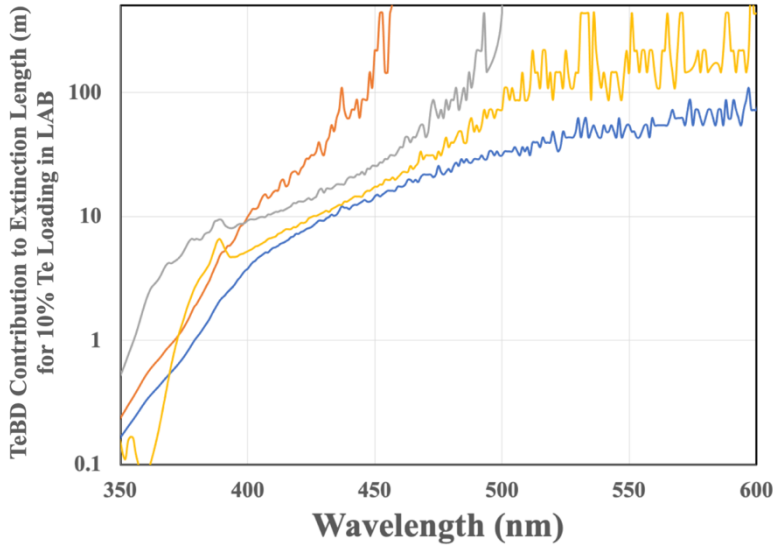


Loading method

- Other, critical considerations
  - Long term chemical stability
  - Long term optical stability
  - Chemical compatibility



- These are critical R&D efforts that must be initiated as early as possible to establish sufficient confidence in the approach down the road
  - Analytical methods, chemical reaction models, material selection, reagents procurement

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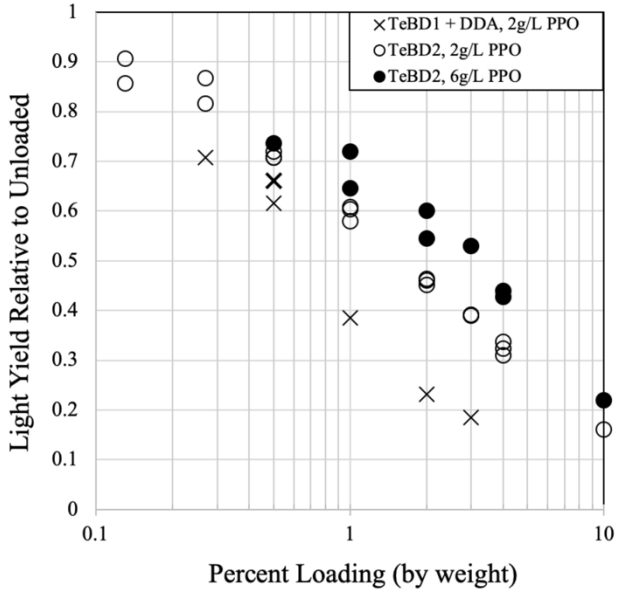

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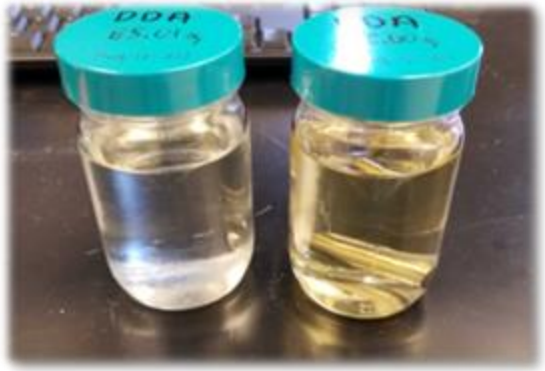
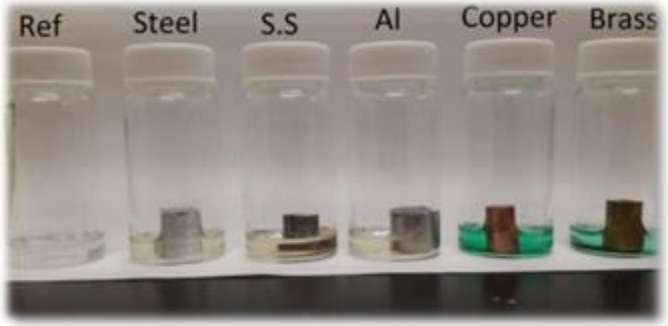
Loading method

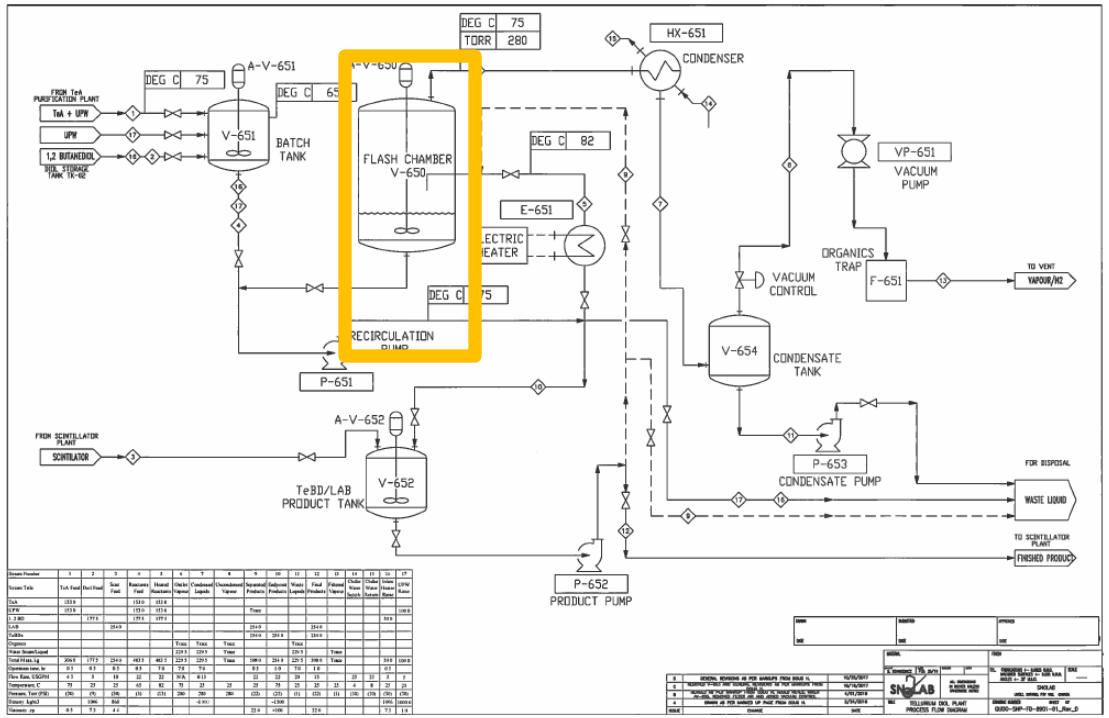
- Long term compatibility testing, e.g.:





Loading method

- Tellurium synthesis to ‘mineral-oil-soluble’ complexes is relatively easily scalable



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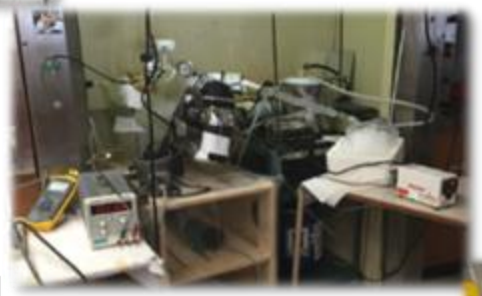
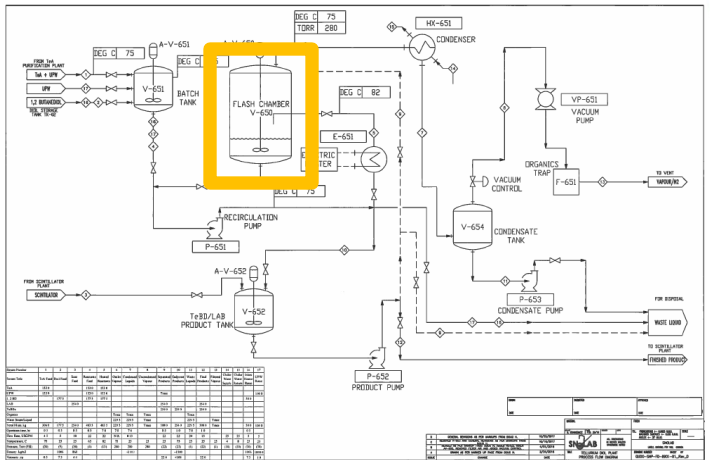
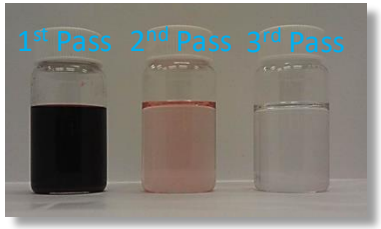


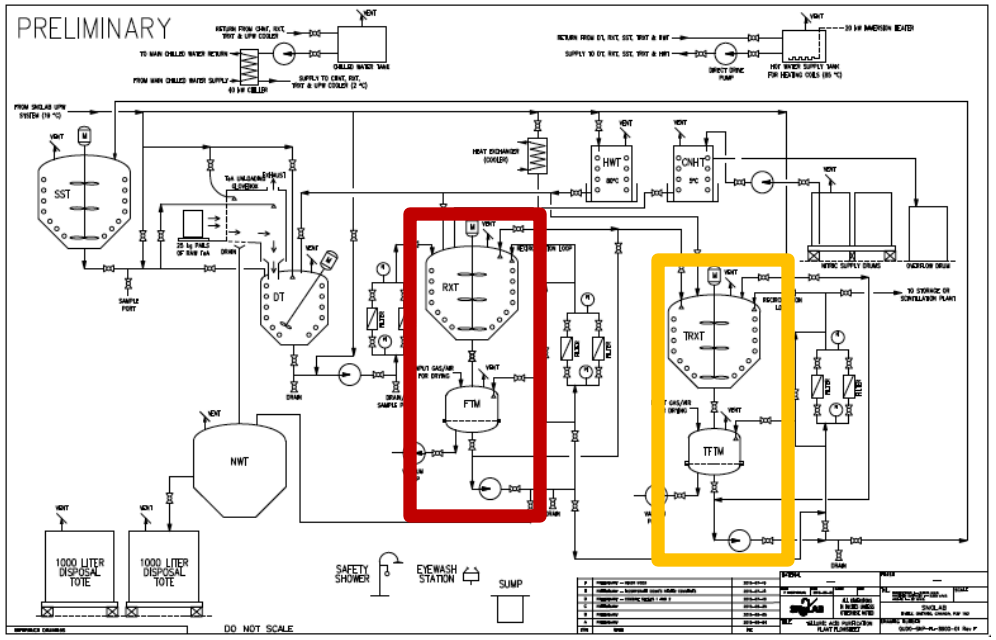


- Scaling of chemical processes is not ‘straight forward’ – a factor of 100 will carry risk.

Tellurium Purification

- Relies on recrystallization and requires the use of nitric acid
  - Filter out insoluble impurities in water
  - Dissolve the rest and drain away after telluric acid is recrystallized





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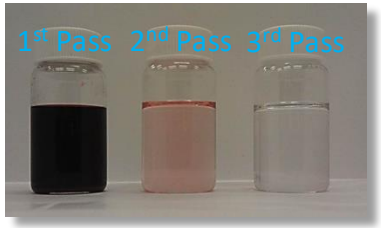
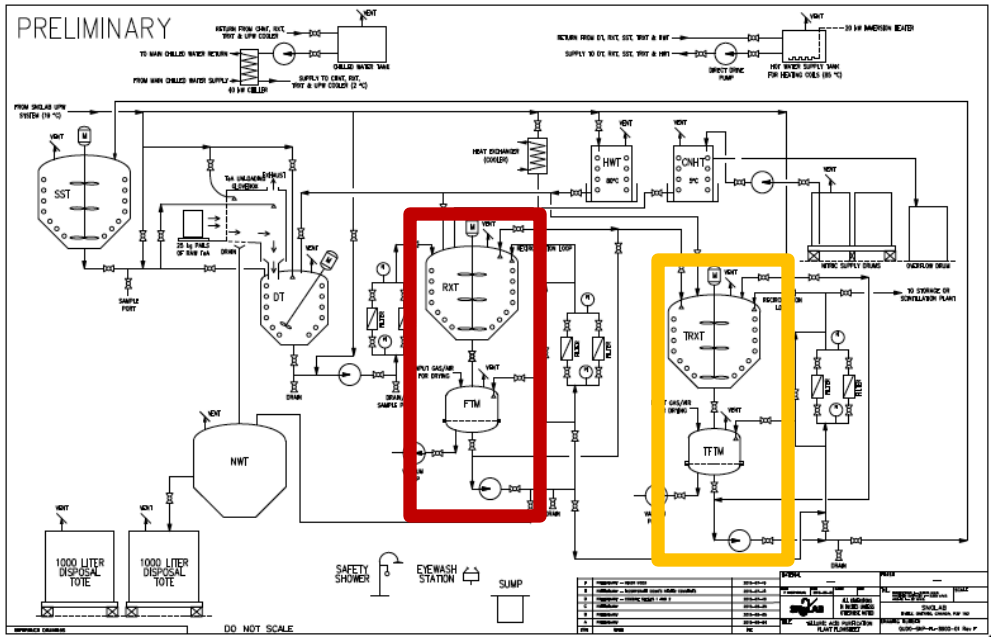
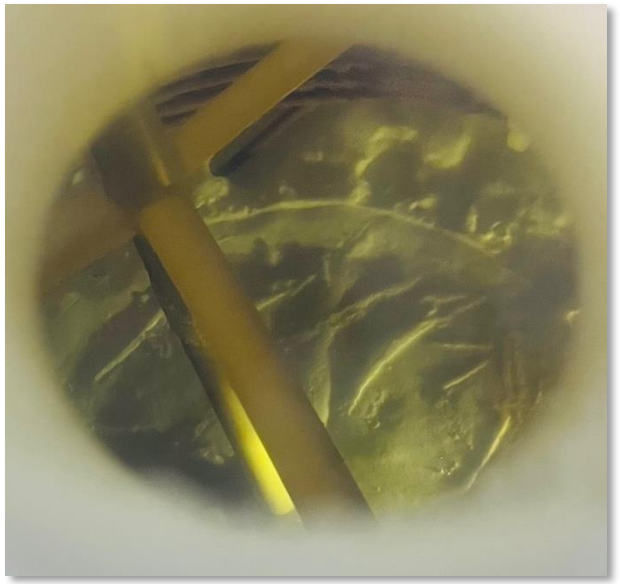




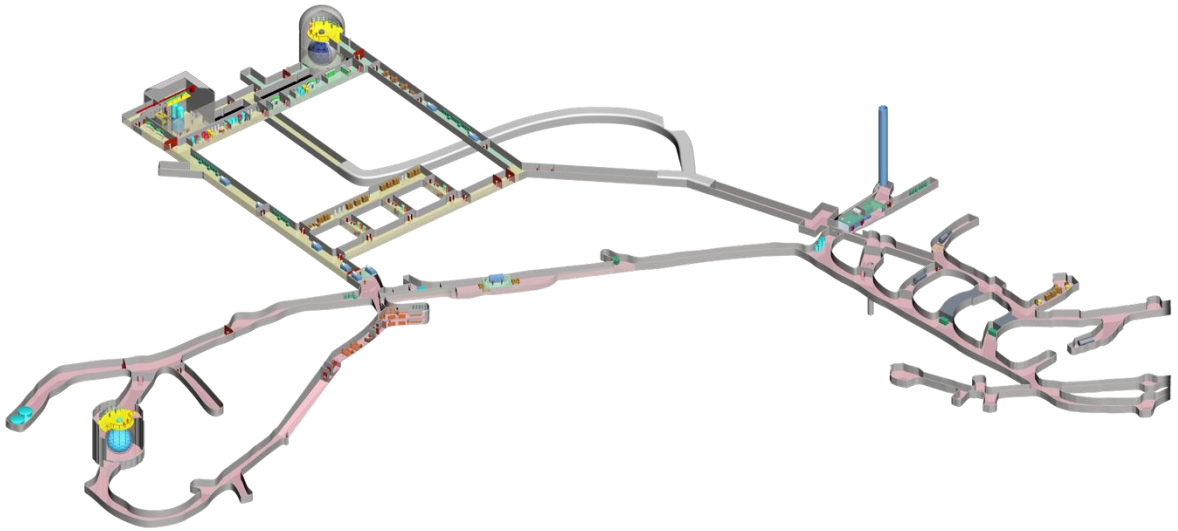


Tellurium Purification

- Relies on recrystallization and requires the use of nitric acid
  - Filter out insoluble impurities in water
  - Dissolve the rest and drain away after telluric acid is recrystallized
- Sufficient optimization and continues operations could give
  - 500 kg of telluric acid per week (~250 kg of tellurium)
- Bottlenecks
  - Logistics: Nitric acid deliveries and waste disposal

Tellurium Purification

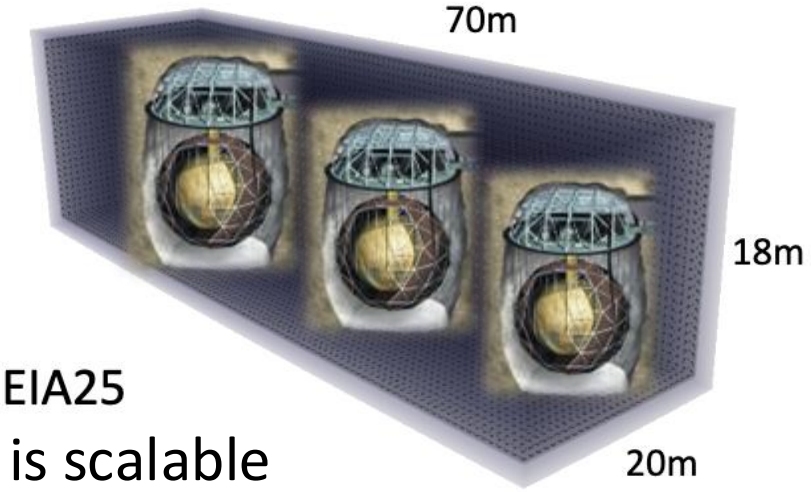
- Underground facilities in the future
  - Tellurium purification
  - Nitric acid purification
    - Filtration
    - Scavengers
    - Distillation



- In the process of tellurium purification, 70% nitric acid transitions to ~40% nitric, contaminated with ’percentage levels of tellurium’ and trace metal impurities

Conclusions

- Achieving normal hierarchy sensitivity requires a 100-tonne scale tellurium loading in LS
- Te in LS is a feasible method
  - Cost of isotope (high isotopic abundance)
  - Synthesis from water-soluble to scintillator-soluble is scalable
  - Purification of tellurium is now being demonstrated with SNO+
  - Scaling of the purification method has room for improvement
    - Optimization of the process and improved logistics for reagents and waste
- Future detector technology needs more refined simulations and engineering work – e.g., acrylic vessel vs nylon balloon(s)



Backup